PETROGRAPHY OF A SUITE OF REFRACTORY INCLUSIONS FROM THE LEOVILLE, EFREMOVKA AND VIGARANO CARBONACEOUS CHONDRITES; S.B. Simon[1] and L. Grossman[1,2], [1]Department of the Geophysical Sciences, [2]The Enrico Fermi Institute, The University of Chicago, Chicago, IL 60637, USA.

As part of an ongoing study of refractory inclusions contained in members of the reduced subgroup of C3V chondrites, we report the initial results of SEM study and electron probe analysis of polished sections of a diverse suite of inclusions from Leoville, Efremovka and Vigarano. Each inclusion was also analyzed for major, minor and trace elements via INAA, and those results are discussed in a companion paper [1].

The most complex Ca-, Al-rich inclusion (CAI) is Vig1, an altered, palisade-rich Type B2, originally oval and 3 $\times$ 2 mm in size. Anhedral fassaite crystals, mostly 100 μm across and containing 4-9% TiO_2, are poikilitically enclosed in melilite. Spinel occurs as 10 μm, anhedral to subhedral grains enclosed in melilite, fassaite and anorthite; in framboids, palisades and palisade bodies; and as rounded crystals up to 50 μm across enclosed in Al-diopside in the Wark-Lovering rim [2]. Numerous, 10-20 μm NiFe grains are enclosed in melilite and fassaite. Quite unlike all other coarse-grained inclusions in this study, Vig1 contains abundant secondary alteration products, including aluminous diopside, sodalite and calcite, the latter two in 100-200 μm-sized patches in melilite throughout the inclusion. As defined by [3], palisade bodies are structures in which melilite $\pm$ fassaite $\pm$ spinel is enclosed in a spherical shell of spinel that is typically one grain thick. In this sample, the bodies range in diameter from ~100 μm (PB2 and PB3) to ~300 μm (PB1 and PB4). It has been suggested [3] that palisade bodies are actually small CAI's that formed independently and were later incorporated into their present host CAI's. To test this idea, we analyzed melilite in four palisade bodies in Vig1. PB1 has the widest range, Ak_{25-64}. PB3 and PB4 are adjacent to each other in the inclusion and have similar compositions (Ak_{52-63}); the melilite compositions in PB2 (Ak_{4-21}), however, do not overlap with those of the other palisade bodies and its range extends to compositions that are slightly more aluminous than are found outside the palisade bodies (Ak_{10-68}). PB2 also has spinel that is richer in V_2O_3 than spinel elsewhere in the inclusion (0.55-0.65 wt % vs. 0.25-0.50). These analyses show that the palisade bodies did not equilibrate with the same liquid, and that PB2 formed from a different source and/or at higher temperature than the other palisade bodies and the host CAI. In addition to textural and mineral-chemical contrasts, isotopic differences between palisade bodies and their hosts have been detected [4, 5], also supporting the theory that palisade bodies formed outside their host CAI's [3]. Palisade bodies compose about 10 vol % of Vig1. Despite this additional component, Vig1 has a normal Type B composition, with unfractionated REE [1]. Therefore, the palisade bodies probably sampled the same chemical reservoir as the host CAI, although we cannot rule out different isotopic reservoirs. Palisade bodies probably formed as whole, small CAI's or by separation of droplets of melt from molten CAI's, nucleation of spinel on the droplet surfaces, and incorporation of the spinel-encrusted droplets into liquid or partially solidified CAI's that became hosts. If the spinel shell were continuous or the melting point of the palisade assemblage higher than the temperature of the host, limited interaction between palisade and host might be expected, making possible the preservation of distinct chemical, petrographic and/or isotopic characteristics of the palisade body.

Another unusual inclusion is L5, an irregularly-shaped, 7 $\times$ 3 mm object that has the mineralogy of a Type B2 and an unusual texture and mode. It is melilite-rich (>60%) and fassaite-poor (10-15%) for a Type B, with spinel (~10%) and anorthite (~15%) also present. Melilite occurs as equant grains, most of which are 10-50 μm across with compositions between Ak_{20} and Ak_{35}, averaging Ak_{29}. The melilite is predominantly spinel-free, except at the rim of the inclusion. Most of the spinel in the interior occurs as knots of euhedral, 10 μm crystals enclosed in mutually exclusive, ~100 μm patches of anhedral fassaite (6-13% TiO_2, 16-23% Al_2O_3) or anorthite. Fassaite and melilite are intergrown, but fassaite and anorthite are not. A notable feature of this inclusion is that anorthite invades melilite, entering cracks between grains and isolating small (10 μm), individual crystals in a lacy, "Swiss cheese" texture. The melilite enclosed in anorthite ranges in shape from rounded to euhedral and in composition from Ak_{19} to Ak_{35}. Melilite crystals adjacent to fassaite have similar compositions. Note that these are rather aluminous compositions; if the entire inclusion crystallized by normal fractional crystallization, fassaite should have been a late phase to nucleate and should therefore preferentially occur with late (>~Ak_{50}) melilite. This is not observed. Although the anorthite may have crystallized from a liquid, it is clear that it solidified after melilite but that it did not co-crystallize with fassaite, which is a problem. Mg isotopic analysis may help resolve the relative timing of crystallization of these phases. On the other hand, the relative uniformity of the grain size and composition of the melilite, as well as the equant shapes of the melilite grains, may indicate solid-state recrystallization after solidification from a liquid. Perhaps recrystallization was caused by shock, as shock effects have been suggested for some Leoville inclusions [6]. Several cracks are present, each about one mm long. At least one of these is related to displacement and is probably a microfault.

Vig2 is a 5 $\times$ 3 mm, comma-shaped fragment of a Type B1 inclusion. The mantle is spinel- and fassaite-rich compared to those in typical Allende B1's, containing fassaite crystals that are ~100 μm across and spinel framboids, 50-200 μm across. Compositions of melilite in the mantle vary from about Ak_{20} at the rim to Ak_{45-50} at the core/mantle boundary. Except for one melilite-rich, spinel-poor island, the inclusion core is extremely spinel-rich and melilite-poor, with coarse (200-500 μm) fassaite and anorthite and minor melilite poikilitically enclosing nu-

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merous, uniformly distributed, ~10 μm, euhedral spinel crystals. Enclosed within the core is a framboid, 450×350 μm, consisting of a ring of coarser (~30 μm), euhedral spinel crystals which encloses melilite (Ak_{72-74}), Ti-poor fassaite, spinel and anorthite. Framboids are rare in Allende Type B1 inclusions [3]. The texture and mineral-chemical variations in this inclusion are consistent with growth of the mantle inward from the rim. Melilite grew slowly enough to push many of the co-crystallizing spinels into the core, where they became poikilitically enclosed by phases crystallizing in the core. Toward the end of core formation, the framboid may have formed *in situ* from the last liquid, possibly during a period of slow cooling which allowed larger spinel crystals to develop. Alternatively, the framboid may consist of spinel which started growing early, was pushed into the core, and finished growing together in a spherical arrangement, trapping the late, fractionated liquid.

Inclusion L4, 10×3 mm before sampling, can be described as a fluffy Type A [7], or FTA, that is more compact and less altered than those in Allende. It has a nodular texture, with irregular, rounded bodies ~200-500 μm across consisting of melilite (Ak_{7-16}) which poikilitically encloses subhedral, 10 μm spinel crystals and minor amounts of anhedral fassaite, perovskite, and Os-, Ir-, Pt-bearing NiFe grains. The nodules have rims of aluminous diopside which are generally 10-20 μm thick. Small, isolated grains of calcite are present in the interior of the CAI, but no Na-bearing phases have been observed. The melilite compositions in this inclusion are similar to those in Allende FTA's [7] and, based on the inclusion's bulk composition, are more åkermanitic than would be expected for crystallization from a melt, as was found for Allende FTA's [8]. The uniform rims on convoluted surfaces indicate deposition after deformation [7], and the structure of the inclusion itself is probably more easily explained by a condensation origin, as has been suggested for Allende FTA's [7]. Additional arguments of [7] for a condensation origin for Allende FTA's include the wide range of spinel V_2O_3 contents (0.6-5 wt %), indicating a lack of equilibration between grains, and a crystallization sequence with hibonite before melilite, which should not result from crystallization from a melt. The latter arguments do not apply to L4, however, because its spinel has a narrow range of V_2O_3 contents (0.3-0.4 wt %) and the inclusion lacks hibonite.

Four inclusions, L1, Ef1, Ef2 and Ef3 are compact Type A's (CTA's), consisting of melilite and spinel with minor perovskite and anhedral fassaite. They range in size from 4×2 mm (Ef3) to 7×4 mm (L1). Melilite in Ef1 is the most aluminous (Ak_{7-18}), followed by L1 and Ef2 (mostly Ak_{20-25}) and Ef3 (mostly Ak_{25-35}). Ef3 has the most Fremdlinge, including one that is oxide- and P-rich and ~100 μm across. Although Fremdlinge are abundant in the polished section of Ef3 and relatively rare in those of Ef1 and Ef2, the latter two inclusions are strongly enriched in refractory siderophiles (>100 × C1) but Ef3 is not (~15 × C1) [1]. Ef1 has a rim sequence, from inside to out, of spinel ± perovskite, fassaite and aluminous diopside. Some melilite has been altered to fine-grained anorthite, but no Na-bearing phases are present in this or any of the Efremovka inclusions. Ef2 has no rim structure and has the least spinel and perovskite of all the CTA's in this study. It contains a few, ~15 μm grains of wollastonite that probably formed by alteration of melilite. Ef3 has a two-layer rim of spinel + perovskite and fassaite, and the interior contains numerous, euhedral, 10-50 μm spinel crystals, many of which enclose perovskite. L1 also has a spinel + perovskite rim, with a layer of gehlenitic (Ak_{10-20}) melilite ~ 20 μm thick between it and the matrix of the meteorite.

This suite of CTA's provides us with an opportunity to study rims on unaltered to lightly altered inclusions and to make comparisons with Allende inclusions, which contain large amounts of secondary alteration products. MacPherson *et al.* [9] noted a correlation between the amount of alteration products in Allende inclusion interiors and the thicknesses of rims, leading them to conclude that rims formed as a result of diffusion caused by the release of Ca from the metasomatic breakdown of melilite. The discovery of E2, an Efremovka inclusion with a melilite rim layer like L1 in this study, called this model into question, as it is difficult to envision a melilite rim layer as the product of the alteration of melilite [10]. This may not be an insurmountable problem, as the rim melilite is more gehlenitic than the interior melilite in both inclusions. A much more difficult problem for this model, however, is posed by the fact that the rim layers on both L1 and E2 are of normal thickness, despite the almost complete absence of secondary alteration products in the interiors of both. A different model seems to be required, perhaps condensation of externally derived material (including CaO) around the outsides of the inclusions, although we differ from [10] in favoring solid, as opposed to liquid, late condensates. The different sequences of rim layers on different inclusions would then reflect the different physico-chemical conditions experienced by the inclusions during rim formation.

The remaining two inclusions are L2, a typical Type B2 with melilite laths, blocky fassaite crystals up to 300 μm across, spinel and anorthite, and L3, an unzoned, fine-grained inclusion consisting of 10 μm spinel grains with thin (<1 μm) rims of low-Ti fassaite in a matrix of a Ca-, Al-rich silicate, probably grossular. Some of the spinel grains enclose perovskite.

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