REFRACTORY INCLUSIONS IN MURCHISON: RECOVERY AND MINERALOGICAL DESCRIPTION. G.J. MacPherson[1], M. Bar Matthews[1,2], T. Tanaka[1,3], E.Olsen[1,4], and L. Grossman[1,5]. [1]Dept. of the Geophysical Sciences, University of Chicago, Chicago, IL 60637.[2]On leave from Geological Survey of Israel. [3]On leave from Geological Survey of Japan. [4]Field Museum of Natural History, Chicago, IL 60605. [5]Enrico Fermi Institute, University of Chicago.

Refractory inclusions in Allende and other C3 chondrites are known for the wealth of information they contain about chemical processes in the early solar system, heterogeneity of the pre-solar cloud and the short elapsed time between explosive nucleosynthesis and condensation, as well as for their diversity [1]. Similar inclusions are known from C2 chondrites [2] but, because of their small size and low abundance relative to those in Allende, these have yielded less information. Fuchs *et al.* [2] described 100-150 μm inclusions in Murchison that contain blue hibonite cores, mantles of white spinel with perovskite and diopside, and outer diopside rims. Unlike Allende coarse-grained inclusions, melilite is absent. Macdougall [3] described irregularly-shaped, spinel-, hibonite-rich (SH) inclusions, up to a mm in size, from Murchison that contain abundant void space. These appear to be the same as those seen in [2], since blue hibonite occupies their cores, melilite is absent and minor perovskite and an outer diopside rim are present. He also reported irregular inclusions composed almost entirely of hibonite, in grains 20-50 μm in size. Later, Macdougall [4] described refractory spherules from Murchison, ~200 μm in diameter, which are more compact than the irregular SH inclusions and have cores of spinel and hibonite, spinel and perovskite or spinel alone with a surrounding 5-10 μm thick band containing an Fe-Al-silicate and an outer 3-5 μm thick diopside rim. The purpose of the present work was to obtain a large number of refractory inclusions from Murchison, to study their mineralogical diversity and the similarities and differences between these inclusions and those in Allende and to see if any of the refractory materials in C2 chondrites formed under different physico-chemical conditions than any of those in C3 chondrites.

All the above inclusions were discovered by optical microscopic inspection of rough surfaces of Murchison. After employing that technique for several years with relatively little success, we began a new method to try to improve the yield of refractory inclusions: freeze-thaw disaggregation experiments followed by heavy liquid separation. A sample consisting of five to ten lumps, each 10-20 g in size, was immersed in water which was driven into the pore spaces under vacuum. The water was then frozen using liquid nitrogen and the ice thawed by warming to room temperature during ultrasonic agitation. The <500 μm fraction was decanted and the <30 μm fraction of this was separated from it by suspension. The entire procedure was repeated 25 times by evacuating and re-freezing the >500 μm fraction. The >30 μm, <500μm fraction was then separated into two density fractions using methylene iodide. The $\rho>3.18$ fraction was washed thoroughly in acetone, split into two further density fractions using Clerici solution, $\rho=3.50$, and washed thoroughly in distilled water.

The $\rho>3.18$ fraction contained black, fine-grained lumps of matrix, olivine crystals embedded in matrix and rare, white, oval to spherical olivine-bearing objects. The $3.18<\rho<3.50$ fraction was composed mostly of individual, colorless, euhedral crystals and crystal fragments of olivine, with minor crystals and crystal fragments of green olivine, olivine-bearing spherules and irregular, greyish, polycrystalline aggregates of olivine and pyroxene. The $\rho>3.50$ fraction contained abundant green olivine crystals and crystal fragments, fewer colorless olivines, minor polycrystalline sulfide spherules and rare fragments of reddish, Cr-spinel crystals or of aggregates of pink spinel and pyroxene. Also present are rare fragments of blue and white hibonite-bearing inclusions up to 500 μm in diameter, blue hibonite-bearing spherules from 50-170 μm in diameter, 50-100 μm fragments of individual blue hibonite crystals and crystal aggregates, euhedral pale blue to colorless spinels and oval to spherical, white or cream-colored, opaque or translucent pyroxene- and olivine-bearing chondrules.

Approximately 30 bluish hibonite-bearing objects were recovered from the densest fraction. Four of these were studied here. Two blue spherules, BB-1 and BB-2, and a blue chip, DJ-1, were subjected to SEM/EDA studies of their exterior surfaces prior to preparation of polished thin sections, SEM/EDA studies of their resulting polished surfaces and electron microprobe analysis (EPMA) of their constituent phases. A blue and white fragment, MUM-1, of a once-larger inclusion was also made into a polished thin section and studied by SEM/EDA and EPMA.

DJ-1 is a fragment of a single blue hibonite crystal, 90 μm in longest dimension, in which no inclusions were found. It is of interest because of the possibility that hibonite may be the highest-temperature condensate of any major element from a gas of solar composition [1]. From its size, DJ-1 probably did not come from an SH inclusion or a pure hibonite inclusion. Also, since hibonite spherules survived our separation procedure relatively intact, we doubt that DJ-1 was broken out of a spherule during our experiment. It may have been an isolated fragment in the matrix, like MH88 [5]. It is also possible that it originated in another inclusion type not yet observed. It contains 1% MgO and 1.5% TiO_2.

MUM-1 is 400 μm in longest dimension and has a white interior of tightly intergrown melilite laths (≤200 μm; Åk 0-26). Fe-, Cr-free rounded spinels (up to 200 μm), euhedral hibonite crystals (up to 50 μm; 3-4% MgO) and irregular perovskite (<10 μm) are poikilitically enclosed by melilite as individual crystals and intergrown in a long chain. In a cavity-riddled region rich in hibonite and spinel are wormy intergrowths of calcite, hibonite, spinel, perovskite and Fe-sulfide. The sulfide and carbonate are interpreted as secondary alteration products. MUM-1 is bounded by a continuous rim sequence, the innermost of which is perovskite + Fe-free spinel. Exterior to this is a 5-10 μm thick rim of melilite (Åk 6-19), then a 3-10 μm thick anorthite rim and an outermost 5-10 μm thick rim of pyroxene which grades outward from Ti-, Al-fassaite to Fe-bearing aluminous diopside. The outer two rim layers are porous, the voids sometimes containing Fe-sulfide. Where the rim is present, it is not breached by the alteration products. This is the first reported occurrence of melilite in a refractory inclusion in Murchison. In fact, MUM-1 is very similar in texture and mineralogy to compact Type A coarse-grained Allende inclusions [6], with two important differences which indicate that it has a significantly different low-temperature history from them: Na-bearing phases are absent both from alteration products and rim layers and Fe oxide-bearing phases like hedenbergite and andradite are absent from the rims.

BB-1, a 120 μm diameter spherule, has a spongy exterior surface that contains Fe-free spinel, melilite and minor Fe-sulfide. BB-1 is concentrically zoned, with euhedral hibonite (MgO 3-4%) and perovskite concentrated in its center relative to spinel and minor irregular melilite (Åk 7-12). Numerous small cavities are present, often shaped by faces of surrounding euhedral crystals. In contrast to Macdougall's spherules [4], neither BB-1 nor BB-2 have diopside rims. Although MUM-1 has an intact rim, we cannot be sure that our extraction procedure does not remove rims from spherules. BB-2, a 90 μm spherule, differs from BB-1 in having hibonite on its exterior surface, in having no melilite and in not being concentrically zoned. Hibonite crystals

(MgO 1.6-4.5%) project inward from the inclusion margin, suggesting that BB-2 and perhaps also BB-1 (because of its other similarities to BB-2) crystallized from liquid droplets [6]. Abundant Fe-free spinel and minor perovskite and Fe-sulfide are present, as are cavities shaped by euhedral crystals, but the latter are rarer than in BB-1. The absence (BB-2) or very low abundance (BB-1) of melilite implies that the spherules are ultra-high-temperature objects which formed before condensation of significant SiO_2, suggesting that they represent a smaller fraction of the total condensable matter than most Allende inclusions.

We have demonstrated that large numbers of refractory inclusions can be extracted from Murchison by this procedure in a relatively short time. One disadvantage of the technique is occasional ambiguity about the pre-extraction petrographic context of the recovered samples. Because of the ease of recovery, the diversity of the objects obtained and their large content of information, much of which is not retrievable from Allende inclusions, we believe that it is a valuable technique, particularly since the petrographic ambiguity can be minimized by parallel studies of *in situ* samples. Chemical and isotopic data for some of these inclusions are given in a companion paper [7].

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