SPINEL-RICH SPHERULES FROM MURCHISON: A REVIEW AND SOME QUESTIONS. S. B Simon[1] and L. Grossman[1,2]. [1]Dept. of the Geophysical Sci., 5734 S. Ellis Ave; [2]Enrico Fermi Inst., 5640 S. Ellis Ave., Univ. of Chicago, Chicago, IL 60637. (sbs8@midway.uchicago.edu)

Introduction. One way in which we investigate the origin of refractory inclusions is by performing equilibrium condensation calculations for a gas of solar composition and comparing the results to observed assemblages. Although many refractory inclusions have undergone melting, by definition they consist of phases predicted to condense at high temperatures from a gas of solar composition. Bulk compositions of the silicate-rich inclusions from CV3 chondrites, for example, generally follow trajectories of bulk condensate compositions, with an offset probably due to partial evaporative loss of Mg and Si [1]. Spinel-, hibonite-bearing spherules, a major type of inclusion common in CM2 chondrites, however, consist of assemblages of phases that are not predicted by thermodynamic calculations to coexist. Despite updates and additions to the data base over the years condensation calculations [e.g. 2-4] consistently show that melilite should condense after hibonite and before spinel. Spinel-hibonite-melilite inclusions can be found but they are rare. Hibonite-, spinel-bearing inclusions that are melilite-free or melilite-poor are much more abundant, and their origin has puzzled researchers for years. One way to reconcile the observed assemblages with the condensation calculations is if melilite originally present was lost due to evaporation of Ca, Si and Mg during heating of the precursors [5]. If evaporation occurred from partially molten inclusions, then they should be measurably enriched in the heavier isotopes of these elements. Previous studies of Ca [6] and Mg [7] isotopes in Murchison inclusions showed some positive mass-fractionations greater than analytical uncertainty and no large, negative fractionations, providing a hint that Ca and Mg evaporation did take place. We have undertaken a petrologic and ion probe study of a variety of spinel-bearing inclusions from Murchison to see if they are isotopically fractionated and if there are any correlations of isotopic composition with mineral assemblage.

Petrography. The first step in this study is a detailed, systematic petrographic classification of spinel-rich spherules. Also known as “blue spherules” [5] or SHIBs [6,7], spinel-rich refractory spherules from CM chondrites actually exhibit a variety of mineral assemblages and textures and should not all be grouped together. The 40 spherules or fragments thereof selected for this study are from Murchison and range from 50 to 200 µm across. They comprise 12 spinel (sp)-hibonite (hib)-perovskite (pv) inclusions; 6 sp-hib-pv-melilite (mel); 8 sp-pv-mel; 2 sp-hib; 2 sp-pyroxene (pyx); 9 sp-pv-pyx; and one sp-mel-anorthite. We found no sp-pv inclusions, although such inclusions have been reported [8]. Some have rims of Fe-bearing phyllosilicate enclosed in an outer rim of aluminous diopside. Most inclusions have many rounded cavities, like those shown in [5, 8] that are commonly lined with mel or pyx, but some have few cavities and may be considered compact. Some spherules have uniform distributions of phases while others have phases that are concentrated in their cores relative to their edges. **Sp-hib-pv inclusions:** Of the nine complete or nearly-complete spherules, four have uniform distributions of phases and four have hibonite-rich cores and spinel-rich edges. The remaining inclusion has a massive outer rim of spinel and a porous core of sp + pv separated by a band of hib + pv. In this group of inclusions, widths of hibonite laths range from just a few µm up to ~25 µm, and their lengths are 10-50 µm. **Sp-hib-pv-mel:** Four of these are spherule fragments. Two appear to have sp-rich rims and hib-rich cores with mel lining cavities in sp. Another fragment is a pie-slice-shaped piece with a hib+sp+pv mantle and a monomineralic melilite core ($Åk_{4-14}$). Another unusual inclusion has a uniform texture of hibonite laths 50 µm long enclosed in melilite and spinel, with grains of perovskite mostly occurring at hib-sp contacts. The remaining two have been described previously [5]. BB-1 has a typical texture, with a hib-rich core and fine mel occurring between spinel grains. MUM-1, also shown in [5], in contrast is a very melilite-rich fragment that resembles a compact Type A inclusion. Melilite encloses a chain of sp and hib grains. **Sp-hib:** These are SH-5 and SH-6 of [9]. They have fluffy cores of loosely aggregated hibonite laths with no interstitial material, and sp-rich rims. Some of the sp is also lath-shaped. **Sp-pv-mel:** With two exceptions, these inclusions consist almost entirely of cavity-riddled spinel, with small (<~5 µm) blebs of pv and mel. Another inclusion has an elongated mel-rich core enclosed in sp + pv. The remaining inclusion consists of massive melilite enclosing euhedral to rounded sp and fine blebs of pv. **Sp-pyx:** Two inclusions consist of porous spinel with pyroxene inclusions. The pyx in the interiors of these objects is Ti-bearing, so these are not analogous to previously described sp-pyx inclusions [5, 10]. **Sp-pyx-pv:** These spherules are typically dominated by porous to massive spinel with fine, sparse to abundant pyx and pv inclusions. One spectacular inclusion, however, consists of lath-shaped spinel with interstitial pyx and pv throughout. Pore space and pv decrease and pyx increases from core to rim. If SH-6 [9] represents partial pseudomorphic replacement of hibonite by spinel, this object could be the product of that reaction proceeding to completion. **Sp-mel-an:** This unique spherule consists almost entirely of spinel with small inclusions of mel and anorthite.

Discussion: Some of the inclusions contain very small amounts of one or more of the phases used to classify them, so some of the categories may reflect non-representative sampling instead of genetic differences. A test of this will be to see if phases in the different groups have characteristic minor element abundances. A lack of mineral-chemical differences among the different inclusion types would imply that they had similar sources. There are trace element and isotopic differences between the major inclusion types used by [11] and within their broadly defined SHIB group, but it is not known if trace element variations correlate with our mineral assemblage types or with texture.

Many of the inclusions upon which this study is based have features, such as interlocking spinel and hibonite grains and hibonite laths that interfered with each other during growth, that suggest that they crystallized from molten droplets. At the temperatures required to keep these objects even partially molten, ~2000ºC, Mg, Si and even Ca should volatilize in a reducing gas. The isotopic compositions of these elements should be strongly fractionated in any spherule that underwent this process. Some questions we will address in the context of our petrographic classification scheme with new mineral-chemical and isotopic data are: Which, if any, of the types of spherules described above underwent evaporative loss of MgO, SiO_2 and CaO? Do melilite-free spherules show more evidence for mass-dependent isotopic fractionation than melilite-bearing ones? If inclusions lost Si, Ca and Mg, what were their original bulk compositions, and could they represent equilibrium condensate assemblages?

A lack of isotopic mass-fractionation in the spherules would eliminate evaporation from partially molten assemblages as an explanation for the “missing melilite”, but would not rule out evaporation from the solid state [12]. It might support an alternative explanation, also suggested by [5], that when hibonite reacted with the solar nebular gas it formed melilite more slowly than spinel. Complete suppression of melilite condensation does not work, as calculations in which this is done yield absurd phase assemblages [13].

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