NEW MINERALOGICAL STUDIES OF REFRACTORY INCLUSIONS IN MURCHISON.

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As part of our continuing study of refractory inclusions in the Murchison meteorite (1-5), we report mineralogical and petrographic data for a new collection of inclusions recovered from Murchison by the freeze-thaw disaggregation technique described in (1). Some of these objects are completely different from any described previously in Murchison (1,3,4,7), while others differ only slightly from the latter.

The most remarkable new inclusion,GR-1, contains corundum, the second known occurrence of this phase in Murchison. The center of this compact spherule, $d \sim 160 \mu m$, contains several hexagonal hibonite plates ($30 \mu m$) that are lower in Ti and Mg ($TiO_2 \sim 0.6$ wt %, $MgO \sim 0.2$ wt %, $Sc \sim 800-1100 ppm$) than any other meteoritic hibonite reported so far, except for that in the unique FUN Allende inclusion HAL. The outer surfaces of these hibonite crystals in GR-1 are rounded and embayed in places, and are decorated by tiny ($<3 \mu m$) grains of Ca-Ti-Sc-Zr-Y oxide. The hibonite plates are completely enclosed in massive corundum (Mg <100ppm, $Sc \sim 400-500 ppm$) of uncertain grain size. Numerous rounded to polygonal voids in the corundum appear to be primary, and are concentrated in the inner part of the inclusion. Around the outer margins of the inclusion are hibonite plates that are larger (up to $53 \mu m$), poorer in Sc (350-500ppm) and richer in Ti and Mg ($TiO_2 \sim 1.4-1.5$ wt %, $MgO \sim 0.4-0.6$ wt %) than hibonite at the center. Also, no rare-element oxide grains decorate the surfaces of these peripheral hibonite grains. A few small ($\sim 3 \mu m$) perovskite grains are present within the outer hibonite. These hibonite grains clearly mantle corundum crystals and replace the latter on grain boundaries and cleavage traces. The corundum, in turn, encloses and partially replaces the central hibonite crystals. Chemical and textural differences thus indicate that the two types of hibonite represent two generations. A vapor-solid condensation model for the origin of such a refractory phase assemblage would necessarily involve two distinct stages of hibonite formation, possibly in different locales. Alternatively, GR-1 may have formed by partial incongruent melting of Mg-, Ti-poor hibonite to form corundum + CaO-rich liquid and, upon cooling, by incomplete reaction of crystallizing corundum with the melt to form a second generation of hibonite. Mass balance would require loss of Ca from or gain of Al by the melt. Although this seems to be a more straightforward model than condensation, solar nebular production of the extreme temperature, 1830°C, required for melting is a major drawback.

Two inclusions, SH-5 and SH-6, are unlike any described previously from Murchison. Both are porous aggregates of blue-pleochroic, hexagonal hibonite plates ($<10 \mu m$) and, in both cases, the aggregates are mantled by a $10-12 \mu m$ thick rind of spinel. At the contact between hibonite and spinel, individual crystals with hibonite morphology are composed of spinel at their ends which are contiguous with the spinel rind and of hibonite at their opposite ends, indicating pseudomorphous replacement of hibonite by spinel. The hibonite plates show no intergrowths or growth interference textures with one another, suggesting that the crystals formed separately from one another and later aggregated together. No secondary phases fill the very abundant void spaces between hibonite grains. Hibonite and spinel in these two inclusions are similar in composition to the same phases in other Murchison inclusions: hibonite --4.3-4.6 wt % TiO_2, 2.1-2.2 wt % MgO, Sc below detection limit of 240ppm; spinel--.8-.9% TiO_2,.08-.09% V_2O_3, .2-.3%FeO. The absence of intergrowths between the tiny euhedral hibonite plates and the lack of additional primary

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phases interstitial to them pose serious difficulties for any genetic model
involving crystallization from a melt. On the other hand, the perfectly
euhedral character of the hibonite and the aggregate structure of the hib-
onite portions of the inclusions suggest that these objects formed by accre-
tion of vapor-condensed hibonite crystals. Spinel clearly condensed after
the aggregate had formed. Pseudomorphing of hibonite crystals by spinel in
these inclusions and the absence of melilite show that, in at least some
regions of the solar nebula, spinel condensed before melilite and not after-
wards as predicted by equilibrium condensation calculations (8). The reason
for this discrepancy is unclear, but we propose premature condensation of
spinel, possibly due to failure of higher-temperature, Al-bearing phases to
remove the full amount of Al from the gas that is required at equilibrium (5).
Recovery of such fragile-looking objects during freeze-thaw disaggregation
implies that this procedure can preserve such delicate-appearing inclusions.

Four inclusions can be classified as spinel-hibonite spherules (3) whose
properties add greatly to the diversity of objects within that class. One,
BB-7 (d$\sim$73μm), consists of a dense intergrowth of hibonite and spinel crys-
tals of uncertain size, rare melilite (<10μm) and a thick (5-10μm) rim of Fe-
rich phyllosilicate. BB-7 has a striking asymmetry in its structure: one
half of the spherule consists mostly of hibonite while the other is mostly
spinel. Many small cavities in BB-7 are partially filled with Fe-rich phyl-
losilicate. BB-9 is a fragment of a second spherule (d$\sim$112μm) containing
mostly spinel crystals of uncertain size, lesser hibonite plates ($\leq$52μm) and
rare melilite (<4μm) and perovskite (<3μm) grains. Many of the numerous
cavities in BB-9 are mantled by melilite, a feature noted previously in other
such spherules (3). Two other spherules, BLUB-1 (133μm) and BLUB-2 (113μm),
differ markedly in texture from those described previously in having unusu-
ally abundant cavities and internal alteration. Primary phases in these
inclusions are hibonite, spinel and perovskite. Both hibonite and spinel
enclose many rounded cavities and, in many cases, the cavities are partially
to completely filled with Fe-rich phyllosilicate and/or calcite. Why these
two inclusions are so full of cavities and secondary phases while other
spherules are not is unclear. This observation, however, reinforces the
interpretation in (3) that the population of refractory inclusions in Murch-
ison represents a wide variety of evolutionary histories and that alteration
of all of the inclusions could not have occurred in the same place under the
same conditions.

Our new set of inclusions contains three olivine-pyroxene-spinel aggre-
gates, two of which are like the nodular and banded ones described in (3).
One, OC-12 (170μm), has a remarkable structure unlike any other object in
this class. A highly spheroidal central zone (d$\sim$64μm) is an intergrowth of
aluminous diopside, spinel and forsterite. Surrounding this core and par-
tially separated from it by forsterite is a discontinuous halo consisting of
irregular strands of aluminous diopside. Enclosing this concentric structure
is a thick ($\leq$50μm) mantle consisting almost entirely of pure forsterite.
Whereas the irregular structures of other olivine-spinel-pyroxene aggregates
are difficult to explain by crystallization of a melt, the spherical sym-
metry of OC-12 suggests that a melt phase may have been present in this case.
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