Hibonite-bearing microspherules: A new type of refractory inclusions with large isotopic anomalies

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(Received February 8, 1990; accepted in revised form November 1, 1990)

Abstract—Reported are petrographic descriptions, major and trace element chemistry, and Mg, Ca, and Ti isotopic compositions of a new class of refractory inclusions that consist of spherules composed of hibonite and a silicate glass. The distinctive features of these inclusions are excesses in $^{48}\text{Ca}$ and $^{50}\text{Ti}$ in both glass and hibonite, and $^{26}\text{Mg}$ depletions relative to terrestrial isotopic compositions. Three spherules have been examined and analyzed, one from the Lancé CO3 meteorite and two from the Murchison CM2 meteorite. Lancé 3413-1/31 (LA3413-1/31) and Murchison 7-228 (MUR7-228) have euhedral to subhedral hibonite crystals enclosed within glass. Murchison 7-753 (MUR7-753) has a rounded hibonite core with several small inclusions of perovskite. A small fragment of glass is attached to the hibonite and an Fe-silicate rim is imperfectly preserved around the grain. LA3413-1/31 has a Group II REE pattern; MUR7-228 a refractory pattern with depletions in the relatively volatile elements Sr, Ba, Nb, V, and Eu; and MUR7-753 a pattern characterized by the prior removal of an ultrareflectory component and overall fractionation of all REEs. The partitioning of the LREEs between hibonite and glass in MUR7-228 is consistent with equilibrium hibonite-liquid partition coefficients previously determined; LA3413-1/31 shows much less partitioning, while MUR7-753 shows no evidence for partitioning and preserves an unequilibrated refractory component highly enriched in Gd. All spherules have initial magnetism depleted in $^{26}\text{Mg}$ by around 3% relative to terrestrial Mg, but only MUR7-228 shows evidence for $^{26}\text{Al}$ enrichment. Both hibonite and glass in all three spherules show excesses of $^{48}\text{Ca}$ and $^{50}\text{Ti}$, ranging up to $+40$ and $+20\%$, respectively, relative to terrestrial Ca and Ti.

The hibonite in the spherules shows similarities to isotopically anomalous hibonite crystal fragments (PLACs), but it is unlikely that the spherules formed by remelting of PLACs. The precursors include isotopically anomalous Ca-Ti carriers but also isotopically normal refractory components that probably formed as condensates. The spherules formed by melting of these precursors under disequilibrium conditions and rapid cooling after hibonite crystallization. These inclusions must have formed early, prior to the dilution of isotopic anomalies by mixing processes and in an area characterized by excesses of $^{48}\text{Ca}$ and $^{50}\text{Ti}$, depletions of $^{26}\text{Mg}$, and lack of $^{26}\text{Al}$.

1. INTRODUCTION

Calcium-, aluminum-rich inclusions (CAIs) from CM and CV meteorites are believed to be among the first solids to have formed in the early solar system and thus to carry information about the physical and chemical conditions that prevailed in the solar nebula (for reviews see, e.g., L. Grossman, 1980; MacPherson et al., 1988). Of special interest among them are hibonite-bearing inclusions. Hibonite is one of the most refractory minerals found in primitive meteorites. Because it is only second in sequence, after corundum, of the minerals predicted to condense from a cooling gas of solar composition (L. Grossman, 1972, 1980; Kornacki and Fegley, 1984; Geiger et al., 1988), its origin is thought to be associated with high temperature processes.

In CV meteorites hibonite appears mostly as a minor primary phase in CAIs consisting largely of melilite. Hibonite in these inclusions normally shows $^{26}\text{Mg}$ excesses (Lorin and Christophe Michel-Levy, 1978; Hutcheon et al., 1984, 1986; Brigham et al., 1986), but no large anomalies in Ca and Ti have been found to date (Fahey et al., 1987d; Fahey, 1988).

In contrast to CAIs in CV chondrites, the mineralogy of CM refractory inclusions is dominated by the oxide minerals spinel, hibonite, and perovskite, while melilite and pyroxene are generally only minor constituents when present. Hibonite in many of these inclusions shows large anomalies in Ca and Ti (Zinner et al., 1986; Fahey et al., 1987b; Hinton et al., 1987; Ireland, 1988, 1990), exceeding those seen in FLN inclusions (Lee et al., 1978, 1979; Niederer et al., 1981; Papanastassiou and Brigham, 1989) by an order of magnitude. There exist general correlations between the morphology, Ca-Ti anomalies, $^{26}\text{Mg}$ excesses, and refractory trace element abundances of the hibonite-bearing, silicate-free CAIs (mostly from CM chondrites). Based on these systematics, we have previously divided these inclusions into four different classes: PLACs, SHIBs, BAGs, and HAL-type hibonites (Ireland, 1988, 1990; Ireland et al., 1988a, 1989; see Table 1).

In addition to its occurrence in inclusions of the first five classes listed in Table 1, hibonite has been found in association with silicate in igneous spherules containing a pyroxene-like glass rather than melilite. The first example of such an object...