MORPHOLOGY OF HIBONITE-BEARING INCLUSIONS SEPARATED FROM THE MURCHISON METEORITE. L. Kööp[1,2,4], A. M. Davis[1,2,3,4] and P. R. Heck[2,4], [1]Department of the Geophysical Sciences, [2]Chicago Center for Cosmochemistry, [3]Enrico Fermi Institute, The University of Chicago, Chicago, IL, [4]Robert A. Pritzker Center for Meteoritics and Polar Studies, Field Museum of Natural History, Chicago, IL. (koeoep@uchicago.edu)

Introduction: Hibonite (Hib)-rich inclusions preserve the largest known non-mass-dependent isotope anomalies, for example in ^{50}Ti and ^{48}Ca, of all materials with a solar system origin [1]. This and their refractory nature have led many authors to suggest that they formed prior to CAIs from CV chondrites, which are the oldest dated solar system materials [2,3]. However, in contrast to CV CAIs, those Hib-rich inclusions with large isotope anomalies appear to have incorporated only minor or no live ^{26}Al during formation, e.g., [1,4]. These unusual properties suggest that these inclusions might shed light on one of the earliest sampled epochs of solar system history. However, due to their small size (often <200 µm), high-precision isotope data comparable to that available for CV CAIs cannot be obtained. We plan to extend the knowledge about Hib-rich inclusions by studying the isotopic composition of different elements, for example by resonance ionization mass spectrometry (RIMS). As a first step, we have separated and identified 161 new Hib-rich grains from the Murchison meteorite. Here, we present the morphology of these inclusions.

Methods: We have obtained two different population of Hib inclusions. First, we picked candidate grains from an existing Murchison meteorite acid residue (heavy fraction as described in [5]; referred to as Lewis separate herein), which had been picked for hibonites twice prior to this study. Then, we disaggregated a ~91.65 g Murchison rock from the Field Museum meteorite collection (ME 2644) in 40 to 70 freeze-thaw cycles. Hib-bearing grains were concentrated by heavy liquid density separation (Cargille Labs organic heavy liquid, density 3.31 g cm^{-3}). The heavy fraction was then washed in acetone and isopropanol, distributed among 25 dishes and picked in isopropanol.

After identification of Hib candidates by color and luster, the grains were transferred to aluminum mounts covered with conductive tape for scanning electron microscopy (SEM) at the Field Museum (LEO (Carl Zeiss) EVO 60 SEM) and at the University of Chicago (JEOL JSM-5800LV). Since the grains were unpolished, energy dispersive spectroscopy yielded only qualitative results, but these were sufficient to distinguish phases such as Hib and spinel (Sp) from silicate phases.

Results and discussion: In the Lewis separate, we have identified 62 spinel-hibonite inclusions (SHIB) and 45 grains that contained Hib ± perovskite, but no Sp (table 1). Of the latter, 40 are single, platy hibonite crystals (PLAC), the rest are aggregates. In the FM separate, we have identified 39 SHIBs, 11 PLACs and four aggregates consisting of Hib only.

SHIBs. In both separates, angular spinel-hibonite inclusions (ASHI; Figs. 1a, 1b and 1c) are the most abundant type of SHIB (~79%, table 1). The remaining are spherical hibonite-spinel inclusions (SHIS; Fig. 1d) and platy spinel-hibonite inclusions (PSHI). The FM SHIBs are larger on average than those in the Lewis separate (table 1). Roughly 40% of FM SHIBs are partially surrounded by fine-grained silicate rims (Fig. 1d). In contrast, Lewis SHIBs have no rims, which is consistent with them being exposed to hydrofluoric acid.

Table 1: Abundances and sizes of different types of Hib-bearing inclusions in the two different separates.

	SHIBs			Spinel-free	
	ASHI	SHIS	PSHI	PLACs	aggregates
Lewis separate					
Number	43	15	4	40	5
Average maximum diameter (µm)	77	81	91	89	86
Maximum maximum diameter (µm)	200	119	167	208	101
Minimum maximum diameter (µm)	33	48	23	42	70
Field Museum (FM) separate					
Number	31	6	2	11	4
Average maximum diameter (µm)	128	95	95	97	117
Maximum maximum diameter (µm)	222	120	113	136	150
Minimum maximum diameter (µm)	60	77	77	65	68

Most commonly, SHISs and ASHIs contain thin (<5 µm), platy Hib grains with irregular to hexagonal margins (43%). About 25% have thicker Hib plates (Fig. 1a). Sp grains are usually small (<5 µm) and occur interstitially between Hib plates or as aggregates, but in some inclusions, Sp grains are up to 20 µm in diameter. These two types of inclusions probably belong to the bladed class in [1]. We further found a small number of inclusions (n<10) that showed the following features: (1) compact ASHIs and SHISs with very fine-grained Sp and Hib (Fig. 1d), (2) ASHIs with massive or amoeboid (i.e., nonplaty) Hib grains (Fig. 1b), (3) ASHIs that consist of a thick Hib plate that is partially covered by Sp (either fine-grained Sp aggregate or one massive amoeboid Sp grain, Fig. 1c). For a few other inclusions, it was difficult to recognize textural features because the inclusions were almost completely covered by silicate rims or had apparently been fractured in a way that created a smooth, curvy surface.

Hib grains consist of multiple sheets in some SHIBs, and both Sp and Hib grains often have small holes, particularly in SHIBs from the Lewis separate. Perovskite was rarely observed, but appeared as small (<10 µm), mostly rounded grains in some inclusions.

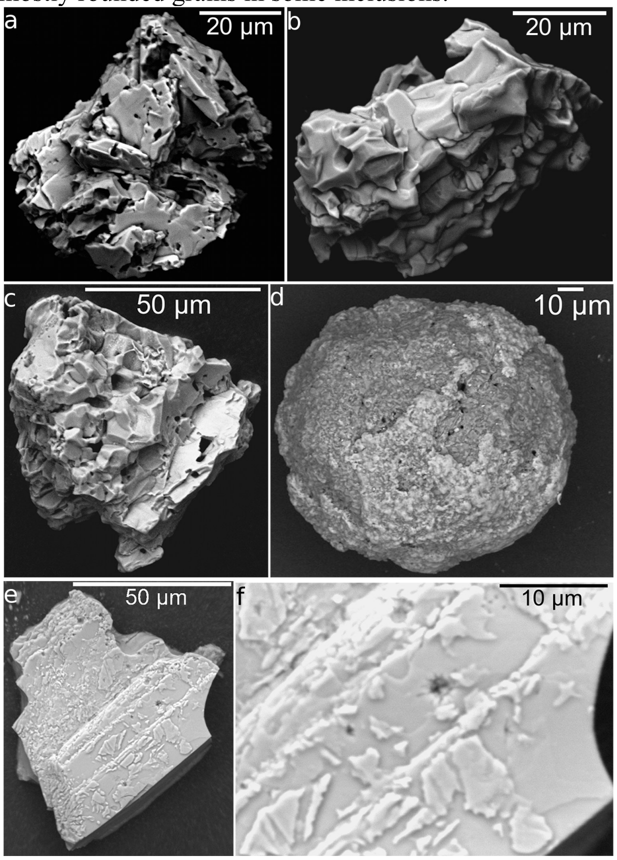

Figure 1: Back-scattered electron images of five different inclusions. a) ASHI with thick Hib plates and interstitial Sp. b) ASHI with amoeboid Hib and Sp grains. c) Single Hib plate (right) with Sp aggregate on top. d) Compact, fine-grained SHIS with partial silicate rim (bright). e) PLAC with discontinuous sheets and decorated surface. f) Enlargement of PLAC in e). Decorations are on all Hib sheets.

PLACs. The majority of PLACs are angular crystal fragments, others have rounded margins. In addition, both separates contain 3 PLACs each with recognizable hexagonal crystal faces. The PLAC thickness ranges from 30 µm to 67 µm at least (based on two measurements). A few of the single Hib crystals are blocky rather than platy, which may be due to fragmentation.

About 20% of PLACs exhibit smooth surfaces and margins, but most have irregular surfaces that are composed of multiple discontinuous Hib sheets and/or are 'decorated' with small, flat Hib grains (Figs. 1e and 1f). In addition, roughly 80% of PLACs in the Lewis separate show irregular or hexagonal dents (<5 µm; Fig. 1f), but only one PLAC in the FM separate has dents, which are rather small (<1 µm).

Differences between inclusions from the FM and the Lewis separate:

Textural. The grains from both separates show many textural similarities. However, a few distinct differences exist between the two separates. (1) In the Lewis separate, we found 8 inclusions that had very large holes between minerals. Since comparable inclusions were absent in the FM separate, it is possible that these holes represent dissolved silicates. (2) Perovskite-bearing inclusions are more abundant in the FM separate (12 in the FM, 1 in the Lewis separate). (3) Hib crystals in Lewis inclusions show holes and dents (both irregular and hexagonal) more often than FM grains. Similar to the absence of silicates in Lewis inclusions, dents may be dissolution features.

Abundances. So far, we have found significantly more Hib-bearing inclusions in the Lewis than in the FM separate. In the latter, PLACs and small inclusions are particularly underrepresented. Assuming that the two original Murchison rocks had the same abundance of inclusions, the difference can be due to multiple reasons. (1) The initial mass of the rock used by [5] was slightly larger (113.58 g compared to 91.65 g). (2) Both separates have not been entirely picked. For the Lewis separate, particularly smaller grains remain in the dish, and 6 FM dishes have not yet been picked. (3) Not all silicate rims surrounding FM inclusions were completely removed by the freeze-thaw procedure, which makes recognition of Hib-bearing grains more difficult than in the Lewis separate. (4) Many PLACs are colorless in planar view, which makes them particularly easy to miss in a dish that is rich in silicates. (5) Inclusions remaining in clumps of matrix may have been separated from the heavy fraction during heavy liquid density separation due to a lower average density. (6) If the acids attacked grain boundaries, some Hib plates may have been liberated from SHIBs in the Lewis separate and were thus falsely grouped with the PLACs.

Outlook: We plan to continue our search for Hib grains by picking the remaining dishes and by treating both the heavy and the light FM fractions with acids to remove the bulk of the silicates. Nevertheless, we have already found a large number of Hib-bearing grains. Particularly the 38 SHIBS and 15 PLACs with diameters >100 µm make us hopeful that we will be able to obtain novel isotope data by RIMS and secondary ion mass spectrometry.

References: [1] Ireland T. (1990) *GCA, 54*, 3219-3237. [2] Amelin Y. et al. (2002) *Science, 297*, 1678-1683. [3] Connelly J. N. et al. (2012) *Science, 338,* 651-655. [4] Liu M.-C. et al (2012) *EPSL, 327-328*, 75-83. [5] Amari S. et al (1994) *GCA, 58*, 459-470.