COMPARISON OF SPHERULES OF HEATED PHYLLOSILICATE-EVAPORITE MIXTURES TO SPHERULES IN CI AND CR CHONDRITES.

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Introduction: Carbonaceous chondrites are the most primitive class of meteorites. The CI chondrites are the class that is most solar-like in composition though they do show signs of being aqueous altered by containing minerals like phyllosilicates, sulfates, and hydroxides [1]. There is however a large amount of amorphous phases in the matrix. Rubin (1997) has summarized the different alteration products that are found in the carbonaceous chondrites. It has been argued that the sulfate veins are a result of remobilization and reprecipitation of the sulfate as a consequence of the meteorites' interaction with the water in the atmosphere after time spent on Earth [3].

Understanding pre-alteration composition and mineralogy of the CI chondrites is important to better understand the early solar system. In the course of the studying the CI chondrites Orgueil and Alais, rounded yellowish-brown objects were discovered [4]. On average these objects are between 10 to 60 µm in diameter, but can be as large as 100 µm. These rounded objects also look similar to the "organized elements that have been observed in the carbonaceous chondrites in the past [5]. These rounded objects consist of fine-grained, flaky phyllosilicates of serpentine and saponite, or they are poorly crystalline ferromagnesian material with similar composition as phyllosilicates [4]. These are the materials that dominate the known minerals in the CI chondrites [6,7]. It has been suggested that the rounded phyllosilicates aggregates were originally glassy spherules that went through various stages of aqueous alteration [4]. The yellow and brown spherules in the CR chondrites, particularly Al Rais, are generally less than 1 mm in diameter and are most likely glassy, preaccretionary-aged objects that are from different stages of aqueous alteration [4]. While heating phyllosilicates to investigate their spectral properties, we have produced spherules that might be relevant to the rounded objectes described above.

Method: Laboratory mixtures of 40wt% serpentine-60wt% epsomite and 40wt% chlorite-60wt% epsomite were produced as analogs of C asteroid surfaces. Independent two-gram samples of the phyllosilicate-evaporite mixtures were heated from 100 to ~1150 ± 1%°C in 200°C intervals. The heating duration for the 200 to 800°C treatments were 24 hours and for the highest temperature samples the heating duration was six hours.

Digital photos of the heated phyllosilicate-evaporite mixtures generated spherules were taken. Some were broken to expose their interiors. Images are compared to thin sections of CI (Ivuna and Orgueil) and CR (Al Rais and Acfer 187) chondrites using an electron microscope. Two thin sections of Orgueil were examined using a scanning electron microscope to study spherules and rounded voids in the meteorite.

Observations and Comparisons: In the process of being heated, our mixtures released their water and formed a slurry that when dried during subsequent heating expanded to produce bubbles and then solidified (Fig. 1). As the temperature increased, the formation of one large bubble gave way to the formation of numerous smaller spherules. At even higher temperatures the individual spherules formed conglomerates of spherules. Small conglomerate spherules in 40wt% chlorite-60wt% epsomite happen at lower temperatures than for the mixture of 40wt% serpentine-60wt% epsomite. Spherule formation is clearly the result of slowly escaping water vapor and significant surface tension in the slurry. In both the 40wt% serpentine-60wt% epsomite and 40wt% chlorite-60wt% epsomite by 600°C all the minerals in the mixtures are decomposed. When the temperature exceeds 800°C the albedo is reduced, first by darkening the free fine-grained material and then the conglomerate spherules.

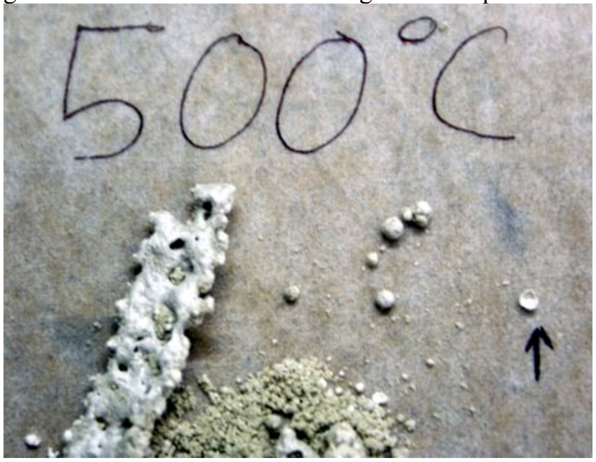

Figure 1: Heated mixture of 40wt% serpentine-60wt% epsomite to 500°C. Bulk of material becomes a long bubbly solid body with hollow pockets. Arrow points to a spherule that was cracked open to show that they are hollow.

The CI and CR chondrites contain both rounded objects and rounded voids. In the matrix of the CI

Alais only rounded voids, having a maximum diameter of about 0.1 mm, are observed near empty veins. The matrix in the region of the voids is composed of serpentine and amorphous material [8], where it has once been suggested to be composed of gypsum [9]. One set of the laboratory experiments created spherules from serpentine, but by time the individual hallow spherules had formed the evaporite was in an amorphous state. Similar objects were observed in Ivuna, although the rounded hollow objects in the meteorite are only about 0.02 mm in diameter.

The CI chondrite Orgueil contains both clustering of rounded voids and spherules of serpentine [4] (Fig. 2). Orgueil contains the largest rounded voids of all the investigated meteorites at a diameters just under 0.2 mm, though most of the voids are less than this size. The serpentine spherules are small compared to the rounded voids, with diameters in the range of 0.02 mm. Serpentine is the most common phyllosilicate in Orgueil [8] and the most common evaporite is espomite [9]. This mineral combination is consistent with one of the phyllosilicate-evaporite mixtures that produce hollow spherules in the laboratory. The amorphous nature of the rims of the rounded voids in Orgueil could be similar to the high temperature amorphous spherules generated from 40wt% serpentine-60wt% epsomite.

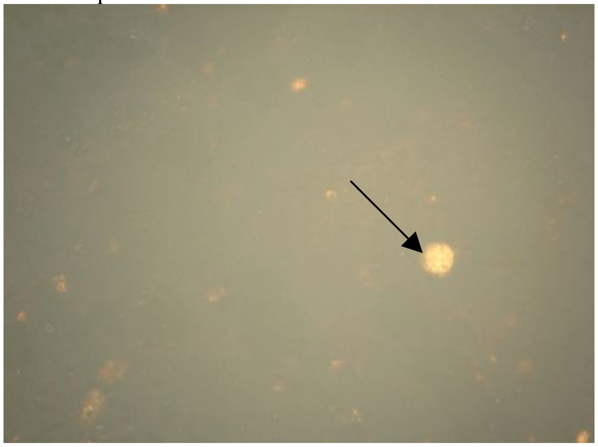

Figure 2: Electron microscope image of the CI chondrite Orgueil, section MZ2. Arrow points to large well defined phyllosilicate spherule of a diameter of about 0.03 mm. This spherule is composed of fine-grained serpentine [4].

The CR chondrites have few of the rounded voids that are observed in the CI chondrites. More of the voids are irregular in shape and represent different mineral grains that are in the meteorites. Both CR chondrites have yellowish-orange spherules in the matrix (Fig. 3). These spherules are about the same size as the ones in Orgueil, of a average size less than 0.04 mm. The CR spherules are mostly glassy material, but have an origin of serpentine material [4].

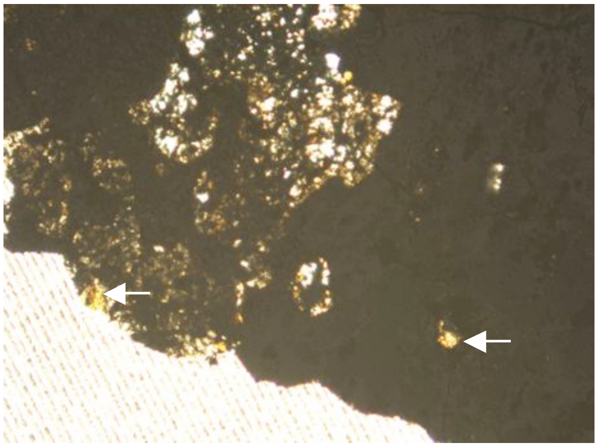

Figure 2: Electron microscope image of the CR chondrite Al Rais, from the thin section USNM 1794-1. Arrows point to yellow spherules of glassy (non-crystalline) material near the outside edge of the meteorite.

Conclusion: The heating of mixtures of epsomite with either serpentine or chlorite produces hollow spherules. At temperatures ~500°C the epsomite is decomposed and at higher temperatures both minerals are decomposed and the spherules are made of an amorphous material.

Spherules have been observed in the CI and CR chondrites. In the CI Orgueil the spherules are composed of serpentine, while in the CR chondrites the spherules are of a non-crystalline nature that have a precursor material of serpentine. Additionally, both types of chondrites contain rounded voids. The spherules made in the laboratory are larger than the spherules in the meteorites, but otherwise very similar, while the rounded voids in the meteorites have amorphous rims and resemble the hollow laboratory spherules. It seems likely that some or many of the spehules in C chondrites were produced by a mechanism similar to that we have observed in the laboratory.

References: [1] Zolensky M. E. and McSween H. Y. Jr. (1988) *Meteorites and the Early Solar System,* The University of Arizona Press 114–143. [2] Rubin A. E. (1997) *Meteoritics & Planet. Sci., 32,* 231-247. [3] Gounelle M. and Zolensky M. E. (2001) *Meteoritics & Planet. Sci., 35*, 1321-1329. [4] Zolensky M. E. et. al. (1996) *LPSC XXVII*, ABSTRACT #1348. [5] Nagy B. (1975) *Carbonaceous Meteorites*, Elsevier 624-634. [6] Bass M. N. (1971) *Geochimica et Cosmochimica Acta.* 35, 139-147. [7] Tomeoka K. and Buseck P. R. (1988) *Geochimica et Cosmochimica Acta. 52*, 1627-1640. [8] Brearley A. (2006) *Meteorites and the Early Solar System II*, The University of Arizona Press 584-624. [9] Richardson S. M. (1978) *Meteoritics. 13*, 141-159.