Carbonaceous Chondritic Microclasts in Meteorites: Samples of the Late Heavy Bombardment? G. Briani[1,2] and M. Gounelle[1], [1]Laboratoire d'Étude de la Matière Extraterrestre, Muséum National d'Histoire Naturelle, 57 rue Cuvier, CP52, 75005 Paris, France, [2]Dipartimento di Astronomia e Scienza dello Spazio, Università di Firenze, largo E. Fermi 2, 50125, Firenze, Italy (briani@mnhn.fr).

Introduction: Xenoliths in meteorites are fragments not genetically related with the host meteorite. They can be of different types and sizes [1-14]. A problem concerning xenoliths is that in most cases the identification of their origin, i.e. of their parent bodies, is very difficult. Carbonaceous chondrite-like inclusions represent the majority of xenoliths [15]. We contend that all or part of these xenoliths sample the Late Heavy Bombardment (LHB) [16].

The Nice model [17-19] suggests that the LHB was triggered when Jupiter and Saturn crossed the 1:2 mean motion resonance, about 700 My after the planets formation. This caused the depletion and migration of icy bodies in the Kuiper Belt (beyond ~15 AU) and of asteroids in the main belt (between ~2 and 3.5 AU). In this context objects composed by more fragile and/or unconsolidated material, such as chondritic asteroids and cometary bodies, are the most affected by collisions [20], i.e. the best candidates for the production of fragments.

The goal of our work is to look for carbonaceous chondritic microclasts (CCMs) in as many meteorites groups as possible. The characteristics we expect from a population of LHB fragments are: (1) their presence in different meteorites; (2) mineralogical and structural properties similar to those of primordial, chemically unprocessed material; (3) difficulties to classify them with respect to meteorites, micrometeorites and IDPs and (4) the presence of some "unusual" xenolith, possibly cometary. The basic idea of this work is to realize a general "survey" of CCMs in meteorites. Instead of characterize some particular inclusion in a meteorite, we want to search for fragments that can reveal, by their common properties, their common origin in a single event.

Experimental procedures: To extend the research of CCMs to meteorites groups other than howardites, we have chosen breccias or gas-rich meteorites, as they clearly show a history of exposure to space and collisions. Analyses of the prepared polished sections by means of an optical microscope are the starting point for the selection of potential xenoliths. Subsequent back-scattered electron images taken by a scanning electron microscope allow a better identification of CCMs, e.g. with respect to the meteorite matrix or impact melt inclusions. We utilize a JEOL JSM 840-A scanning electron microscope, also equipped with an EDAX Genesis X-rays detector to perform energy dispersion spectroscopy of CCMs. Quantitative analyses for the mineralogical composition of CCMs are realized with a CAMECA SX-100 electron microprobe at the University of Paris VI. A 10 nA focalized beam, accelerated by a 15 kV potential difference, is used for punctual analyses of CCMs oxides and metals. For carbonates, a 4 nA defocalized beam, with a 15 kV accelerating voltage, is used.

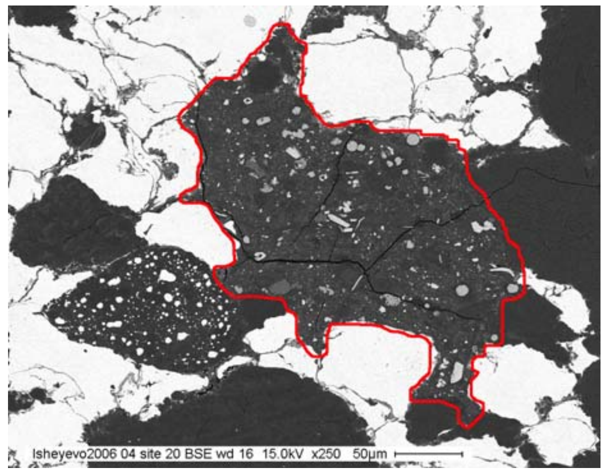

Figure 1. A CCM in the Isheyevo CB chondrite, surrounded by metal grains and silicates. Many magnetite inclusions are present. Lower-left is also visible an impact-melt inclusion.

Results: Up to now, we have identified CCMs in the CB carbonaceous chondrite Isheyevo and in the H5 ordinary chondrite Leighton. Good candidates to be CCMs have been found in the ordinary chondrites Krymka (LL3.2), Mezo-Madaras (L3.7) and Sharps (H3.4). Further analyses and comparisons with precedent works are being performed to establish if they are really xenoliths. No evidence of CCMs has been found in Weston (H4), Bremervorde (H/L3.9), Adzhi-Bogdo (LL3-6) and the aubrite Pesyanoe, despite the fact that they are all breccias.

All new CCMs range in size between 50 and 750 µm (Fig. 1 and 2). In both Isheyevo and Leighton their structure is dominated by a fine-grained matrix composed by sub-µm-sized phases, mainly phyllosilicates with variable amount of sulfides and magnetite. In an Mg-Fe-Si+Al ternary diagram, analyses of matrix plot in the region of CM2 serpentine and CR2 phyllosilicates for Leighton CCMs, while they are more shifted toward the Fe pole for Isheyevo (Fig. 3). A common feature of matrix analyses is the high values of S (between 2 and 15 %wt), due to the presence of either tochilinite or sub-µm-sized sulfides. Anhydrous silicates like olivine and pyroxene are present either as isolated crystals in the matrix or as micro-chondrules. Olivine is mainly Mg-rich, its composition ranging between Fo_{98}-Fa_2 and Fo_{84}-Fa_{16}. In general the same is true for pyroxene, for which enstatite is the principal phase, but in same cases it has been found also Ca-rich pyroxene (En_{13}-Wo_{80}). Magnetite is very abundant in some of the CCMs, and absent in others. When present, it is in the form of either aggregates of a few crystals or of small framboidal clusters. Carbonates are quite rare (of the order of one in some xenoliths) in the Isheyevo CCMs, while they are very abundant in three CCMs in the Leighton ordinary chondrite. In both cases, they are mainly Ca- and Mg-rich carbonates. Sulfides are mostly troilite, with some rare grains of pentlandite. Metals are present as small, µm-sized grains coupled with sulfides.

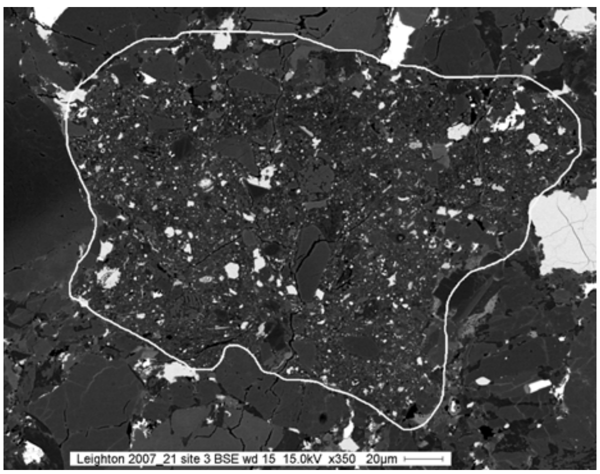

Figure 2. A CCM in the H5 ordinary chondrite Leighton. Several silicates and metal inclusions are visible.

It has to be noticed that one CCM in Isheyevo has an unusual aspect. It is very dark, with a very fine-grained matrix, composed by sub-µm-sized grains of phyllosilicates, magnetite and sulfides. It does not resemble to any previously known CI- or CM-like xenolith, but it might have some of the properties indicates for cometary material [21].

Conclusions: We propose that CCMs, present in meteorites as xenoliths, are fragments produced by collisions during the LHB. Our preliminary results on the mineralogy of new CCMs indicate that they are made by C2-like material. Further analyses are in progress in order to obtain a more precise classification of micro-xenoliths in meteorites. But the fact that CCMs are composed by chemically unprocessed material is one of the characteristic we expect from a population of fragments coming from collisions of primordial bodies. Discovering and analyzing other xenoliths is necessary to establish if they are really widespread in meteorites, as supposed by the hypothesis that they originate from the LHB event. In addition, new "unusual" CCMs, as the one found in Isheyevo, might reveal new insights on possibly cometary samples.

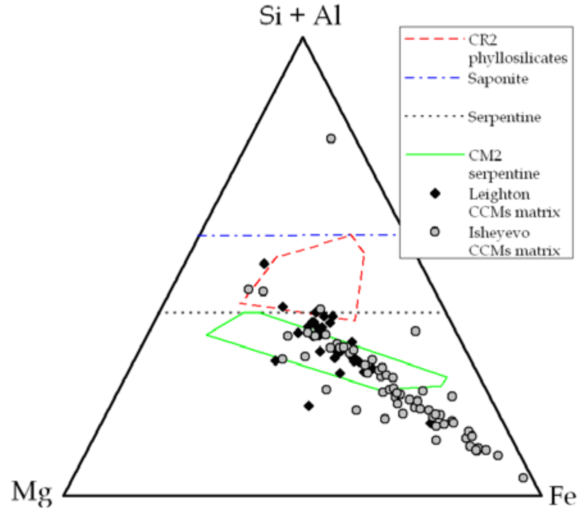

Figure 3. Ternary diagram for matrix of CCMs in the H5 ordinary chondrite Leighton and in the CB chondrite Isheyevo.

References: [1] Whal W. (1952) *GCA, 2*, 91-177. [2] Wilkening L. L. (1976) *LPSC, 7*, 3549. [3] Leitch C. A. & Grossman L. (1977) *Meteoritics, 12*, 125-139. [4] Wilkening L. L. (1977) In *Comets, Asteroids, Meteorites*, 389-395. [5] Neal C. W. & Lipschutz M. E. (1981) *GCA, 45*, 2091-2107. [6] Brearly A. J. & Printz M. (1992) *GCA, 56*, 1371-1386. [7] Noguchi T. et al. (2003) *GCA Supplements, 67*, 341. [8] Nakashima D. et al. (2003) *EPSL, 212*, 321-336. [9] Ikeda Y. et al. (2003) *Antarct. Meteorite Res., 16*, 105-127. [10] Gounelle M. et al. (2003) *GCA, 67*, 507-527. [11] Semenenko V. P. (2005) *GCA, 69*, 2165-2182. [12] Rubin A. E. et al. (2005) *GCA, 69*, 3419-3430. [13] Bischoff A. et al. (2006) In *Meteorites and the Early Solar System II*, U. of A. Press, 679-712. [14] Zolensky M. E. (2006) *MAPS, 31*, 518-537. [15] Meibom A. & Clark B. E. (1999) *MAPS, 34*, 7-24. [16] Gounelle M. et al. (2005) *GCA, 69*, 3431-3443. [17] Tsiganis K. et al. (2005) *Nature, 435*, 459-461. [18] Morbidelli A. et al. (2005) *Nature, 435*, 462-465. [19] Gomes R. et al. (2005) *Nature, 435*, 466-469. [20] Levison H. F. et al. (2008), American Astronomical Society, DDA meeting #39, #12.05. [21] Campins H. & Swindle T. D. (1998) *MAPS, 33*, 1201-1211.