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A New Component of the Mezö-Madaras Breccia: A Microchondrule- and Carbon-Bearing L-Related Chondrite

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Abstract—Microchondrules with apparent diameters of 2 to 150 μm are found in a black carbon–bearing inclusion in Mezö-Madaras. Some are homogeneous (glassy or micro-crystalline) others show two phases: mainly silica and a pyroxene-rich glass. The bulk chemical composition of the inclusion is related to the host-chondrite in which silica-pyroxene chondrules are ubiquitous. Small black lumps of the same kind are dispersed in bulk Mezö-Madaras. This L-related carbon-bearing material may represent a new specimen of C-rich ordinary chondrite.

INTRODUCTION

THE MEZÖ-MADARAS L3 CHONDRITE breccia is well-known for its numerous inclusions (xenoliths, clasts, lumps . . .) described by Meunier (1871), Wahl (1952), Van Schmus (1967), Binns (1968) as well as for some highly unequilibrated mineral associations which have been discovered in it: merrihueite and "femic" silicates (Dodd *et al.,* 1966), cristobalite or tridymite, olivines and pyroxenes (Brigham *et al.,* 1986, and our unpublished data). These are present in the host also called "normal Mezö-Madaras," in which many glass-rich chondrules are found. Most of the inclusions are of L4–5 types, similar to the host so that Binns calls them "cognate xenoliths." Some are partially melted like the Van Schmus inclusion "C" and one of those found in our section: the chondrules are still easily recognizable but the matrix has melted and metal plus sulfide is grouped in large globules. Owing to the composition of olivine and pyroxenes in the chondrules, they are also "cognate xenoliths."

Some other inclusions are black. The one described by Van Schmus (1967) "consists of small, fine-grained chondrules and fragmental silicates, nickel-iron particles and droplets, troilite, and a very fine-grained unresolvable matrix." With the microprobe analyses available at the time, Van Schmus states that it has "greater chemical similarity to carbonaceous chondrites than to ordinary chondrites, although it cannot be definitely placed with either."

The black inclusion that is studied here contains probably still smaller chondrules as Van Schmus compares his inclusion to the Murray C2 chondrite. Carbon is present, but the bulk analysis does not allow us to classify it with the major carbonaceous chondrite groups.

METHOD

The inclusion was studied optically and by scanning electron microscopy. Analyses were performed by EDS with the Link System AN 10.000 coupled with the SEM and with a CAMEBAX electron microprobe. The presence of carbon has been verified by Raman spectroscopy using the MOLE probe.

DESCRIPTION

The inclusion was discovered while cutting the specimen n°15313 of the meteorite collection of "Ecole des Mines, Paris." Pear-shaped and measuring 8 × 6 mm on the polished section, it has irregular outlines, being compressed between chondrules. A single 0.8 mm wide rock fragment appears included in it (if not protruding from beneath) while all other silicate grains are much finer. Micrometric metallic and troilite blebs are evenly distributed, apart from a few less than 0.3 mm irregular grains.

The size of the observed droplet chondrules varies from 2 to 150 μm. Some are broken though perfectly recognizable and a few are cupulated. The section was scanned under the microscope and all the encountered microspherules were counted and measured. Of the 143 spherules observed, only 5 are 100–150 μm wide; 108 are smaller than 20 μm. Apart from the fact that only the apparent diameter of the spherules are measured, the results are biased by the difficulty of discovering them when their reflectance is similar to the mean reflectance of the matrix. In fact, most of the 29 spherules with less than 5 μm diameter have a low reflectance. Using SEM, more microchondrules are detected. For example, on Fig. 2, the 23 μm silica-rich microchondrule was optically detected but not the two tiny ones. The larger part of the inclusion is made of very finely crystalline rounded rock or chondrule debris, mineral fragments, and matrix (Fig. 1).

The Chondrules

Many of the chondrules, including all of those 50–150 μm in size, are microcrystalline pyroxene chondrules with variable FeO content, the largest ones being the poorest in FeO as observed by Rubin *et al.* (1982). Some tiny 2–10 μm wide spherules are pure or nearly pure silica.

Besides these homogeneous microchondrules, 35% show more complex features: immiscible liquids have been frozen side by side. A nickel–iron spherule embedded in silicate was found only in 3 microchondrules but the association "femic" silicate glass-silica is common as shown in Figs. 2 and 3 where the silica glass is associated with a pyroxene-rich glass. These 23 and 30 μm diameter microchondrules (n° 49 and 11) are rimmed by a silicate mush or dust aggregate containing tiny nickel–iron blebs. EDS analyses of the different components of microchondrule 49 are shown in Table 1. No explanation is found for the low sum of the glass analyses. We notice the absence of alumina and the presence of phosphorus. The pyroxene glass is dominated by En 88 bronzite and the rim is much more iron-rich and close to olivine Fo 70. Ni was not measured. We have tried to avoid nickel-iron blebs but cannot be sure that we have.

The occurrence of these silica-rich microchondrules can be compared with that of silica-rich rock fragments and chondrules

FIG. 1. General aspect of the black inclusion. Two 13 and 11 μm wide microchondrules (A and B), mineral fragments (C), a finely crystallized rock clast or chondrule debris (D), an olivine-glass object (arrow) are enclosed in a very fine matrix. White blebs are nickel-iron grains.

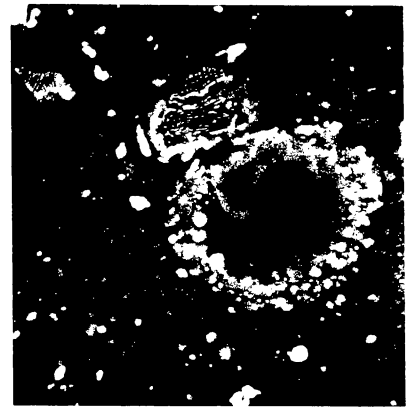

FIG. 2. A 23 μm wide microchondrule (n° 49) analyzed in Table 1. The dark area is almost pure silica; the grey area has a very-low-calcium pyroxene composition. The rim is crowded with tiny white nickel-iron blebs. A 10 μm wide chondrule (C), an olivine-glass triangular object, a sodium alumino-silicate dark crystal against a 5 μm wide half microchondrule (arrow) are also noticeable.

in the host chondrite. These are ubiquitous and particularly abundant in the thin section L3416 from the meteorite collection of the Wien Naturhistorischen Museum. The microchondrules may be interpreted as the product of the remelting of a fragment of this type of rock, or as the cooling of a common parent melt, very low in aluminium and calcium, which was heated to more than 1700 °C. The tiny droplets were quenched and the immiscible liquids may or may not have separated in isolated droplets. It is not clear when and why some 20–40 μm diameter microspherules acquired their rim rich in nickel–iron irregular blebs.

In contrast to the numerous siliceous microspherules that are highly depleted in aluminium and calcium, we found a 40μm diameter chondrule which has a hibonite core with minor anorthite and perovskite and a mainly fassaitic pyroxene rim (Fig. 4). Microprobe analyses were performed with concentric defocused beams of 40 μm, 20 μm, 5 μm diameter (Table 2). They show the progressive enrichment of SiO_2, FeO, MgO, CaO and Na_2O from center to the surface, correlated with a decrease of Al_2O_3 and TiO_2.

Other Constituents

All the rock fragments are rounded and very finely crystallized with panther-like (Fig. 2) or microdendritic appearance. Olivine, which is not observed in the microchondrules, is the dominant mineral of the rock or chondrule fragments. On the contrary, the mineral fragments are angular. Among these olivine and pyroxenes predominate, feldspar and spinel are rare. Fe-Ni-Co analyses were performed on numerous metallic grains. These grains do not differ from "normal Mezö-Madaras." The compactness of the matrix does not allow us to distinguish morphological features.

To account for the black colour of the clast, we looked for the occurrence of carbon, using Raman spectroscopy. Carbon is indeed present, but it is poorly graphitized just as the carbon of the fine-grained rims around normal Mezö-Madaras chondrules.

Chemical Composition of the Inclusion

Bulk analyses have been performed on the polished section; by EDS, two 0.4 × 0.3 mm areas were scanned avoiding large metallic patches; with the microprobe, three defocused 20 μm wide areas at distant spots were analysed, avoiding objects greater than 5 μm and metallic blebs. In fact, these are matrix analyses, if the term is used as including all that is less than 5 μm wide. . . .

The material is relatively homogeneous and the mean results agree fairly well as shown in Table 3. Compared with bulk Mezö-Madaras and to the L4 xenolith (Binns, 1968) after subtraction of the opaques, our inclusion shows a lower SiO_2 and a slightly higher MgO content. Owing to the different analytical techniques employed, the comparison should not be too close, but the similarity between EDS analysis (bulk inclusion) and microprobe analysis (matrix) is remarkable. The FeO content is similar to that of bulk Mezö-Madaras and much lower than that of the matrix according to Huss *et al.* (1981) and Matsunami (1984). It is also much lower than that of Piancaldoli (Rubin *et al.* 1982) and Rio Negro (Fodor *et al.* 1977) microchondrule-bearing clasts, and of that of the carbonaceous chondrites. In Table 4, we see that the Al/Si and Ca/Si ratios are those of

TABLE 1. Composition of silica-rich microchondrule n° 49 (wt.%).

	SiO_2	Al_2O_3	Cr_2O_3	FeO	MgO	CaO	MnO	Na_2O	P_2O_5	Σ
Silica	90.6	0	0	0.7	0	0	0	0	0.4	91.7
Pyroxene	55.4	0	0.8	7.4	29.3	0.2	0	0.5	0.2	93.8
Rim	39.3	0	0.7	24.3	32.3	0.8	0.5	0.5	1.0	99.4

EDS analyses.
0: the apparent concentration is less than the error inherent to the method.

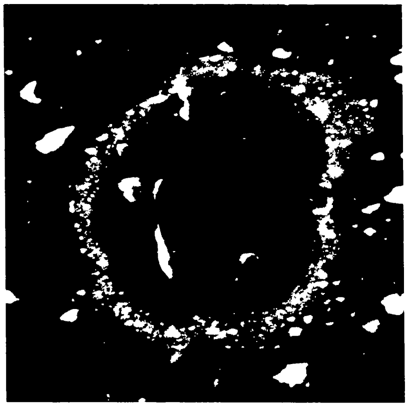

FIG. 3. A 30 μm wide microchondrule (n° 11) similar to n° 49. Here, the pyroxene-rich glass occupies the core of the chondrule.

FIG. 4. The high-alumina microchondrule (n° 1) analyzed in Table 2 lies between the two bars. Hibonite laths and interstitial anorthite occupy the central 30 μm core surrounded by tiny perovskites and by a rim of fassaitic pyroxene. White spots inside the chondrule are holes; outside, they are mostly nickel-iron blebs. Another microchondrule lies near n° 1.

ordinary chondrites, while the Mg/Si ratio agrees with that of carbonaceous chondrites. This leaves some ambiguity.

Occurrence of Similar Material Elsewhere in Mezö-Madaras

Small black inclusions of the same kind are dispersed everywhere in "normal Mezö-Madaras" as observed on a large polished slice and on the thin section L3416. Part of a nice inclusion 200 μm wide is shown in Fig. 5. It contains a glassy 20μm–wide microchondrule and a rounded micro–emulsion clast (Fig. 6) with silica droplets a few tenths of a micrometer in size enclosed in "femic" matrix.

We must however be aware that all black inclusions in Mezö-Madaras are not of the microchondrule-rich type, and that all microchondrules are not enclosed in black lumps. For example,

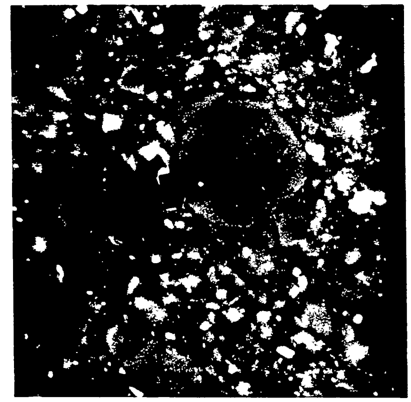

FIG. 5. A 20 μm wide glassy microchondrule in a 200 μm wide black lump of Mezö-Madaras section L3416. It bears a tiny white α Ni-Fe bleb (arrow). Besides, a 2 μm wide silica microchondrule (black). Notice the angular mineral fragments in the fine-grained matrix.

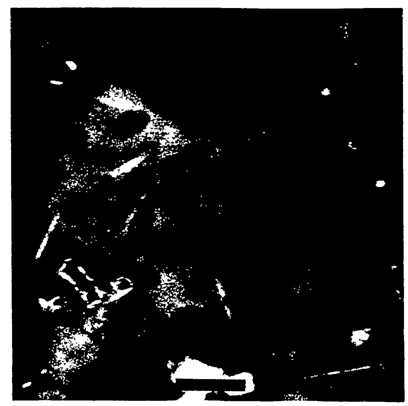

FIG. 6. In the same lump, a micro-emulsion of silica in an iron-rich silicate fragment. Scale bar: 2 μm. The light spindles are an artifact.

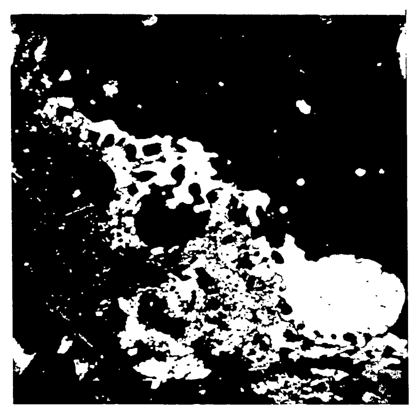

FIG. 7. Microchondrules (arrows) sticking out of the nickel-iron plus troilite rim of a large olivine-glass chondrule in normal Mezö-Madaras section L3416. Scale bar: 100 μm.

TABLE 2. Microprobe analyses of Hibonite microchondrule n° 1 (wt.%).

	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	Σ
Whole chondrule	20.67	3.07	45.75	6.26	8.37	15.39	0.53	100.04
Core	8.16	4.41	66.83	4.80	2.61	12.66	0.20	99.67
Central point	6.31	5.68	73.26	3.29	1.25	11.63	0	101.42

TABLE 3. Composition of the black inclusion (wt.%) avoiding opaque grains compared to bulk Mezö-Madaras, L4 xenolith (Binns, 1984) and matrix (Huss *et al.*, 1981).

	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	Ni	Σ
EDS	41.6	0.15	2.1	0.8	17.9	0.3	30.1	1.9	1.2	0.2	0.25	0.3	0.3	97.15
Microprobe	43.3	0.10	2.8	0.6	17.46	0.29	31.4	1.57	0.66	0.12	nm	nm	nm	98.46
Bulk	45.7	0.15	3.05	0.52	17.1	0.40	28.9	2.23	1.59	0.02	0.28	—	—	99.95
Xenolith	45.8	0.11	2.92	0.36	16.8	0.37	29.5	1.98	1.34	0.03	0.29	—	—	99.50
Matrix	39.6	0.09	1.9	0.53	25.9	0.45	29.3	0.94	0.80	0.22	0.28	—	—	100.01

nm: not measured.

a perfect 30 μm diameter microchondrule and a less perfect larger one are protruding from the nickel iron and troilite rim of a millimeter-sized olivine and glass chondrule (Fig. 7).

CONCLUSION

Among the various components of the Mezö-Madaras chondrite, a carbon-bearing material, different from the known classes of carbonaceous chondrites, is dispersed through the whole stone and has been found in a large lump.

The total amount being 0.45% C in Mezö-Madaras (Otting and Zähringer, 1967), it is reasonable to think that a few percent C is concentrated in inclusions, chondrule rims and matrix. According to previous experiments, it is not likely that we are able to detect less than 1% C by Raman spectroscopy. This content may be considered as a lower limit in our inclusion. It is mixed with very fine-grained silicate material and with microchondrules the composition of which are clearly related to the host chondrite, as are also the metallic minerals.

This new type of chondrite may be compared with the microchondrule-rich clasts such as those found in Piancaldoli (Rubin *et al.,* 1982) and Rio Negro (Fodor *et al.,* 1977), and with the C-rich ordinary chondrites and chondritic clasts studied by Scott *et al.,* (1987).

The occurrence of silica-rich microchondrules in the black inclusions of a chondrite bearing silica-rich chondrules is an indication if not a proof that the host chondrite and the black inclusions are cogenetic. As Scott observed (personal communication), liquid immiscibility may offer an explanation for the origin of SiO_2-rich chondrules. The variety of composition of the microchondrules seems better explained by the remelting of already differentiated material than by the melting of dust aggregates.

TABLE 4. Element/Si ratio (atom%) of Mezö-Madaras components compared to ordinary and carbonaceous chondrites.

	Al/Si	Ca/Si	Mg/Si
Mezö-Madaras			
Inclusion EDS	5.9	4.8	107
microprobe	7.6	3.9	108
Bulk	5.3	5.2	95
Matrix	5.6	2.5	87
Ord. chondrites	5.9–7.7	4.6–5.4	88–98
C-chondrites	8.3–14.3	6.2–10.2	102–113

Ord. and C-chondrites: Wasson, 1974.

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