Occurrence, Formation and Destruction of Magnetite in Chondritic Meteorites

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Occurrence: Magnetite with low Cr_2O_3 occurs in aqueously altered carbonaceous chondrites (CI1, CM2.0-2.2, CR1, $CV3_{OxA}$, $CV3_{OxB}$, CO3.00-3.1) (Figs. 1,2), type 3.00-3.4 OC and type ≤3.5 R chondrites: CI magnetite has 0.04 wt.% Cr_2O_3; CO3 magnetite has 0.27 wt.% Cr_2O_3; LL3.00 magnetite is nearly pure Fe_3O_4. Magnetite is rare to absent in more-metamorphosed CM, CR, CO, OC and R chondrites.

In equilibrated chondrites that contain magnetite, the magnetite grains are rich in Cr_2O_3: e.g., R-chondrite magnetite ~9-20 wt.% Cr_2O_3; CK magnetite ~4 wt.% Cr_2O_3.

In CO3 chondrites, chromite occurs commonly as 2-30-µm grains within Type-II chondrules (Fig. 3) or in association with ferroan olivine grains in the matrix. In CO3.1 chondrites, chromite is present as <4-µm grains associated with magnetite within chondrules and in the matrix. Chromite constitutes 0.37±0.11 wt.% (n=35) of type-6 OC; magnetite is essentially absent.

In type-3.00-3.4 OC, magnetite occurs in association with cohenite, haxonite, kamacite, troilite, pentlandite and Ni-rich metal. In CO3.00-3.1 samples, Type-I chondrules typically contain 10-25-µm spheroidal or irregular masses of metal+troilite and/or magnetite+pentlandite. Many opaque masses In CO3.00-3.1 chondrites have cores of metal (kamacite, taenite, tetrataenite) mantled by magnetite.

Formation: There is an inverse correlation in CO3 chondrites between the abundances of metal and magnetite: magnetite-rich CO chondrites contain ≤1.2 vol.% metal, whereas metal-rich CO chondrites contain ≤0.6 vol.% magnetite (Fig. 4). Magnetite generally formed from metallic Fe during aqueous alteration on chondritic asteroids.

Destruction: The essential absence of magnetite in type-6 OC and CO3.2-3.8 chondrites and the decreased abundance of magnetite in more-metamorphosed $CV3_{Ox}$ chondrites suggest that magnetite is destroyed during thermal metamorphism.

Reduction of magnetite during parent-body heating produces secondary metal: the kamacite/Ni-rich-metal ratio in CO3.1 DOM 08351 (~2-3) is far lower than that in CO3.2 Kainsaz (~10).

Thermochemical equilibrium calculations show that, during metamorphism, the H_2/H_2O ratio in the gas within asteroids increased, leading to reduction of magnetite and the formation of fayalite and secondary kamacite. Chromite is more stable than magnetite under reducing conditions; the magnetite/chromite ratio decreases as the $f(H_2/H_2O)$ ratio increases. This is consistent with the ubiquitous occurrence of chromite and essential absence of magnetite in equilibrated OC.

Magnetite with appreciable Cr_2O_3 is also more stable than Cr_2O_3-free magnetite under reducing conditions; i.e., Cr_2O_3-rich magnetite behaves similarly to chromite. This is consistent with the presence of magnetite with high Cr_2O_3 in equilibrated R and CK chondrites.

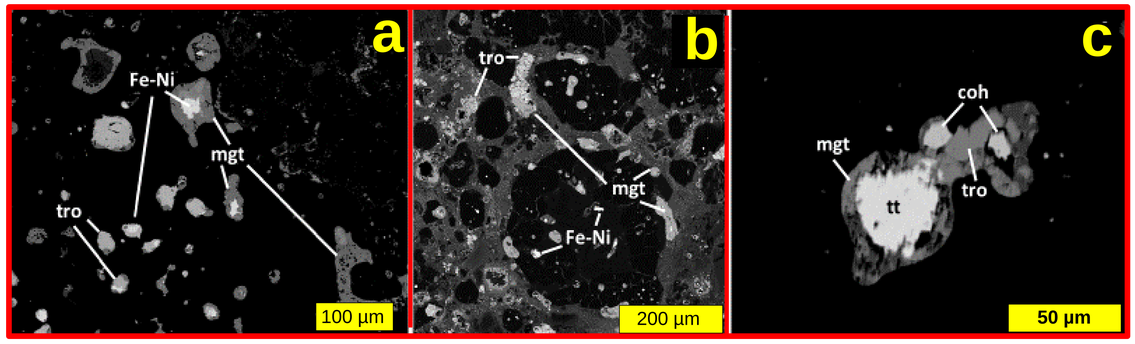

Fig. 1. Magnetite-rich opaque assemblages in Cargo Muchacho Mountains. (a) Magnetite mantles around metal grains within a type-I chondrule. (b) Magnetite aggregates within and at the margin of a type-I chondrule. (c) Opaque nodule in a type-I chondrule consisting of cores of cohenite (coh) and tetrataenite (tt) surrounded by troilite (tro) and magnetite (mgt).

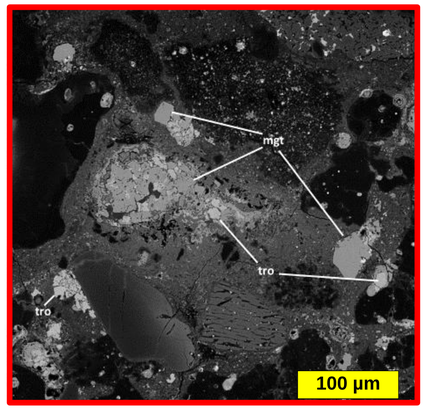

Fig. 2. Irregularly shaped opaque aggregates in the matrix of DOM 10104 consisting mainly of magnetite (mgt) and troilite (tro).

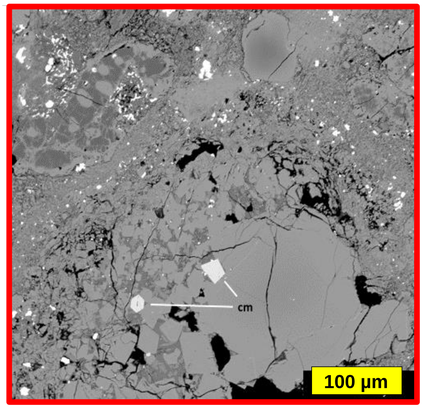

Fig. 3. Euhedral chromite (cm) grains within an equilibrated porphyritic chondrule in ALH 83108. The chromite grains are adjacent to olivine and mesostasis.

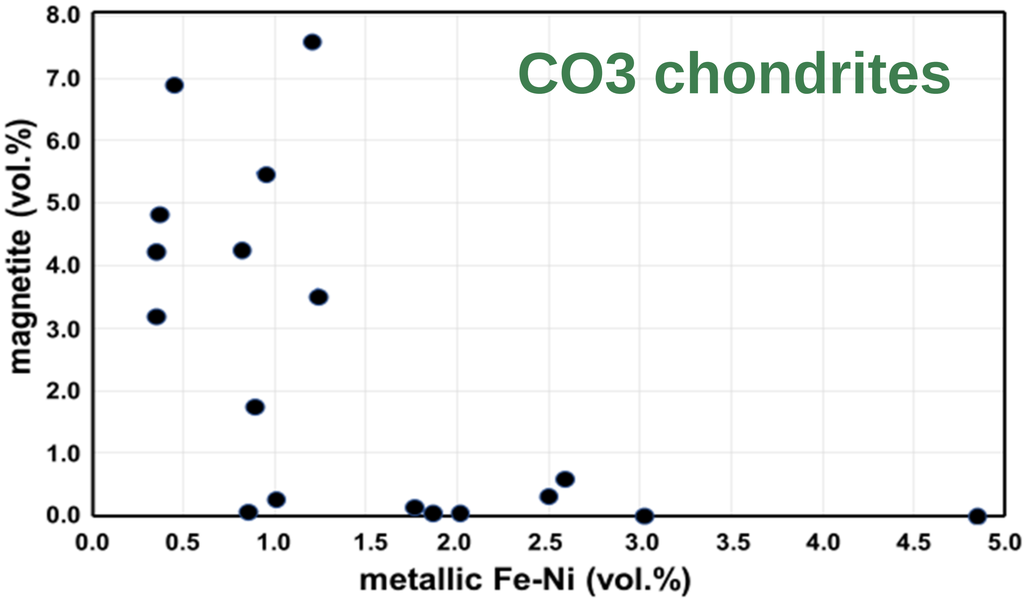

Fig. 4. Modal abundance of magnetite vs. modal abundance of metal for CO3 chondrites. Metal-rich CO chondrites contain <1.0 vol.% magnetite; magnetite-rich CO chondrites have <1.5 vol.% metal.