DETECTION OF INCIPIENT AQUEOUS ALTERATION IN CARBONACEOUS CHONDRITES

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Introduction: All carbonaceous meteorites show evidence of secondary processes (e.g., [1-3]). The quest for the least processed chondritic material has been a long-standing one, as it allows accessing the physico-chemical conditions in the solar nebula. To this end, it is necessary to constrain secondary processes based on qualitative and quantitative parameters. The current classification in chondrites uses 6 petrographic types from 1 to 6 [4], divided in subtypes with [5], with the most primitive chondrites between type 2.9 and 3.00, which escaped intense aqueous alteration and thermal metamorphism. In this work, we studied four ungrouped carbonaceous chondrites showing minimal aqueous alteration and thermal metamorphism by several techniques. We discuss the performances of those techniques to detect incipient aqueous alteration, and try to constrain the definition of the subtypes 2.8 to 3.00.

Methods: We studied four ungrouped carbonaceous chondrites, Chwichiya 002, El Medano 200, North West Africa (NWA) 11750 and NWA 12957, classified C3 or C3.00-ung using scanning electron microscopy (SEM), (scanning) transmission electron microscopy (S)TEM, energy-dispersive X-ray spectroscopy (EDS), infrared spectroscopy, Raman spectroscopy, electron microprobe (total in the matrix), X-ray diffraction (XRD), position-sensitive-detector (PSD) XRD, thermogravimetric analysis (TGA) and secondary-ion mass spectrometry (SIMS).

Results: The four meteorites appear to be less heated than the least heated type 3.00 ordinary chondrite, Semarkona, based on the structural order of the polyaromatic matter estimated by Raman spectroscopy, and the Cr_2O_3 content of ferroan olivine [6]. In each object, we documented the different phases considered as keys in the detection of alteration in their matrix: GEMS-like phases, metal, sulfides, magnetite, tochilinite-cronstedtite intergrowths (TCIs), carbonates and phyllosilicates. The four studied meteorites display different alteration phases and alteration intensity. Chwichiya 002 and NWA 12957 show similar alteration with abundant unaltered GEMS-like assemblages and µm-sized TCIs, with low abundance of carbonates, magnetite, sulfides and phyllosilicates. The main alteration phase in NWA 11750 consists of carbonate veins surrounding chondrules (their extraterrestrial origin verified by determining their O-isotopic compositions by SIMS), as well as nanometric fine-grained carbonates intermixed with small olivine in the matrix, with unaltered metal grains and low abundance of sulfides and phyllosilicates. El Medano 200 shows extremely high abundance of magnetite (~19 wt.% by magnetic measurements), and fine-grained matrix showing some silicate aggregates, sulfides, phyllosilicates and metal.

Electron microscopy allows the identification of primordial unaltered materials, and to estimate the composition and spatial distribution of secondary phases. SEM is limited to ~100 nm crystals, therefore the nano-scale crystals and fine-grained matrix is only accessible through (S)TEM studies. IR transmission spectroscopy can detect phyllosilicates at abundance of ~2 vol%, but has a higher detection limit for carbonates (>10 vol%), and is inefficient for the detection of metal or sulfides. EPMA of the matrix allows the detection of hydrated minerals that lower the analytical totals but does not reflect the overall alteration. XRD and PSD-XRD detect the same alteration phases, with PSD-XRD showing a lower detection limit of ~1 vol%. It can also estimate Fe-bearing amorphous phases abundance. XRD techniques, however, have difficulties to measure very small phyllosilicates, due to their small coherence domains. TGA allows detection of hydrated phases but the results are also affected by presence of organic matter and sulfides in the matrix, so that the modal abundances of secondary alteration phases are only upper limits.

Conclusion: The very low amount of aqueous alteration puts these four meteorites among the most primitive chondrites in the collection, similar to Asuka 12085 [7]. Still, they all show faint incipient aqueous alteration. We observed different secondary phases in these meteorites, evidence for the occurrence of a variety of alteration fluids and conditions. Their type 3.00 classification thus represent a summary of their alteration state, not their detailed post-accretion history. Also, we observed that the detection of the aqueous alteration of meteorites is technique dependent.

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