TRACE ELEMENT ABUNDANCES IN EXTRATERRESTRIAL APATITE AND MERRILLITE.

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Introduction: The Ca-phosphates apatite [$Ca_5(PO_4)_3(F,Cl,OH)$] and merrillite [$Ca_9NaMg(PO_4)_7$] are common accessory phases in many meteorite groups. They are predominantly secondary phases formed by thermal/metamorphic processing (e.g., in chondrites and acapulcoites), but in eucrites, shergottites, and in the ALM-A ureilitic trachyandesite they were formed by igneous processes [1-4]. Both species are important carrier phases for rare earth elements (REE) and other refractory elements and therefore have a major impact on the trace element budget of their host rocks. Hence, studying their distribution, formation mechanisms and inventory of trace elements are fundamental for understanding the genesis and evolution of their host rocks.

Material and Methods: Despite of their accessory occurrence, intensive search by EPMA and SEM has established a chemically and petrographically well-documented pool of over 600 phosphates covering nine different meteorite classes and 24 samples. The trace element concentrations (REE, as well as Sc, Ti, V, Cr, Mn, Co, As, Rb, Sr, Y, Zr, Nb, Ba, Hf, Ta, Pb, Th, and U) of 133 apatite and 163 merrillite grains were analyzed by LA-ICP-MS at the University of Münster and/or by SIMS at the NORDSIM Laboratory in Stockholm.

Results: In all investigated samples Ti, V, Cr, Mn, and Co always show subchondritic concentrations, while Sr, Y and Th are always enriched relative to CI in both Ca-phosphate species (CI abundances from [5]). Arsenic, Rb, Zr, Nb, Ba, Hf, Ta, and Pb concentrations vary from sub- to superchondritic. Chondrites exhibit no resolvable trends between the trace element inventory of their Ca-phosphates and their grade of metamorphism (petrologic type). In contrast to the REE [c.f. 6,7], the abundances of the remaining trace elements in merrillite does not universally exceed those of apatite, except for Y which is aligned with the REE. Thorium and U are typically enriched in both phosphate species, although some grains in ordinary chondrites have low U- and/or Th-abundances (e.g. apatite in Ybbsitz and Devgaon: <0.5 ppm U and <0.3 ppm Th, respectively). Apatite from Bruderheim (L6) shows exceptionally high concentrations for V, Rb, Sr, Zr, Nb, Ba, Hf, and Ta exceeding those of other chondrites by at least an order of magnitude, as well as merrillite from Devgaon (H3.8), which shows significantly higher enrichments in Ti, V, Cr, and Mn. Ybbsitz (H4) stands out due to high Pb concentrations in both species (apatite ≤1800 ppm; merrillite ≤2200 ppm). Adzhi-Bogdo (stone) (LL3-6) phosphates contain high abundances of Ba and/or Sr. Ca-phosphates in the differentiated (granite-like) clasts of this polymict breccia [8] show higher abundances of Zr, Nb, Hf, Ta, Pb and Th compared to their counterparts in the chondritic portion. The trace element inventory of phosphates from differentiated meteorites does not show striking differences to that of chondrites. Yttrium concentrations are up to ~1.8 wt%, as observed in the Millbillillie eucrite accompanied by high concentrations of Zr (~1800 ppm) and Hf (≤~2000 ppm). High Y- (4700 ppm) and Zr- (550 ppm) abundances were also recorded in apatite from the NWA 5073 eucrite. Merrillite in depleted shergottites shows lower Pb (~0.21 vs. ~1.6 × CI) and Th (~37vs. ~525 × CI), but higher Cr (~0.01 vs. ~0.0006 × CI) abundances than in the enriched subgroup. Merrillite from both mesosiderites shows high concentration of Co (≤1400 ppm) and Cr (≤190 ppm), as well as moderately high Mn (≤1900 ppm) content.

Discussion: Despite of their metamorphic origin in chondrites, neither species shows systematics in their trace element inventory which consistently deviates from those of igneous origin. The high Ba- and Sr- content observed in Adzhi-Bogdo (stone) phosphates may indicate terrestrial alteration [9], yet regarding all samples, neither Ba nor Sr abundances correlate with their weathering degree. The high trace element content in the granite-like clasts may have been imposed by partitioning during the formation of the fragments. Most phosphates in eucrites are primary, but late-stage crystallizing phases which gained their high abundances of Y and REE from a highly evolved residual melt (e.g., [10]). Phosphates in enriched and depleted shergottites are primary, late crystallizing phases as well; although phosphates from both subgroups are easily distinguishable from each other in terms of their REE abundances [3,5], this is not the case for most of the remaining trace elements including Y. In contrast to other meteorite groups, merrillite from both mesosiderites (Bondoc and Dalgaranga) has higher abundances of Cr and Mn, which appears to be limited to the Ca-phosphate, as it is not reflected on the bulk scale of the meteorites (c.f., [11]).

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