American Mineralogist, Volume 102, pages 1856–1880, 2017

Trace element inventory of meteoritic Ca-phosphates

Dustin Ward[1,*], Addi Bischoff[1], Julia Roszjar[2], Jasper Berndt[3], and Martin J. Whitehouse[4]

[1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany
[2]Department of Mineralogy and Petrography, Natural History Museum Vienna, Burgring 7, 1010 Vienna, Austria
[3]Institut für Mineralogie, Westfälische Wilhelms-Universität Münster, Corrensstrasse 24, 48149 Münster, Germany
[4]Department of Geosciences, Swedish Museum of Natural History, Box 50007, 10405 Stockholm, Sweden

Abstract

Most extraterrestrial samples feature the two accessory Ca-phosphates (apatite-group minerals and merrillite), which are important carrier phases of the rare earth elements (REE). The trace-element concentrations (REE, Sc, Ti, V, Cr, Mn, Co, As, Rb, Sr, Y, Zr, Nb, Ba, Hf, Ta, Pb, Th, and U) of selected grains were analyzed by LA-ICP-MS and/or SIMS (REE only). This systematic investigation includes 99 apatite and 149 merrillite analyses from meteorites deriving from various asteroidal bodies including 1 carbonaceous chondrite, 8 ordinary chondrites, 3 acapulcoites, 1 winonaite, 2 eucrites, 5 shergottites, 1 ureilitic trachyandesite, 2 mesosiderites, and 1 silicate-bearing IAB iron meteorite.

Although Ca-phosphates predominantly form in metamorphic and/or metasomatic reactions, some are of igneous origin. As late-stage phases that often incorporate the vast majority of their host's bulk REE budget, the investigated Ca-phosphates have REE enrichments of up to two orders of magnitude compared to the host rock's bulk concentrations. Within a single sample, each phosphate species displays a uniform REE-pattern, and variations are mainly restricted to their enrichment, therefore indicating similar formation conditions. Exceptions are brecciated samples, i.e., the Adzhi-Bogdo (LL3-6) ordinary chondrite. Despite this uniformity within single samples, distinct meteorite groups do not necessarily have unique REE-patterns. Four basic shapes dominate the REE patterns of meteoritic Ca-phosphates: (1) flat patterns, smoothly decreasing from La-Lu with prominent negative Eu anomalies (acapulcoites, eucrites, apatite from the winonaite and the ureilitic trachyandesite, merrillite from ordinary chondrites); (2) unfractionated patterns, with only minor or no anomalies (mesosiderites, enriched shergottites, IAB-iron meteorite); (3) LREE-enriched patterns, with either positive or slightly negative Eu anomalies (chondritic apatite); and (4) strongly LREE-depleted patterns, with negative Eu anomalies (depleted shergottites). The patterns do not correlate with the grade of metamorphism (petrologic type), specific adjacent mineral assemblages or with Ca-phosphate grain size. Neither the proportions of different REE, nor particular REE patterns themselves are universally correlated to a specific formation mechanism yet Eu (i.e., magnitude of the Eu anomaly) is a sensitive indicator to evaluate the timing of plagioclase and phosphate crystallization. Based on our data, U and Th abundances in apatite increase (almost linearly) with the grade of metamorphism, as well as with the differentiation of their host rock.

Keywords: Meteorites, apatite, merrillite, Ca-phosphates, trace elements, REE, LA-ICP MS, SIMS