Nanoscale horizons in apatite geochemistry

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The fields of Earth and planetary science are undergoing something of an analytical renaissance, with nanoscale techniques such as electron backscatter diffraction (EBSD), atom probe tomography (APT) and transmission electron microscopy (TEM) providing exciting new insights into fundamental mineralogical and geochemical questions. Of particular interest in this regard are C, F and OH-bearing apatites ($Ca_5(PO_4)_3$), a particularly robust group of minerals that provide a vital archive of the volatile content, U-Th-Pb age and REE composition of many planetary materials. Here we apply this new suite of nanoscale techniques (EBSD, APT, TEM) to apatite grains in a range of planetary materials, including Apollo samples, eucrites (asteroidal meteorites from 4 Vesta), and shergottites (Martian basalts), greatly aiding interpretation of the shock state, volatile composition and age of these rare samples of planetary crusts.

In two newly typed eucrites, EBSD targeting of shocked apatite grains, which have been crystal-plastically deformed (CPD; < 15°) or altered to a nanocrystalline state (appearing amorphous in EBSD), yield a precise U-Pb age of 4206 ± 72 Ma. Unshocked grains, with a maximum of ~3° CPD, yield U-Pb ages of 4512 ± 4.4 Ma, congruent with the formation age of the asteroid 4 Vesta. Without microstructural context, these grains appear similar in SEM imaging, greatly hindering interpretation of these discrete geological events. APT analyses of these same grains further support this approach, revealing the nature of U, Th and Pb distribution on the sub-nanometer scale and hinting at the nature and severity of isotopic resetting within deformed grains.

In Apollo samples, APT analysis of 'amorphous' apatite (at the length-scales of EBSD) reveals the presence of recrystallized nanocrystallites of apatite composition. Subgrain boundaries, highly enriched in and decorated by Mg cations, form discrete triple point junctions throughout the ~300 nm microtip specimen. These pathways may act as important diffusion pathways for volatile species, though cannot be observed at the ~micrometer length scale of existing techniques.