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Intra-grain common Pb correction in apatite by LA-ICP-MS depth profiling and implications for detrital apatite U-Pb dating

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Apatite is a common accessory phase in igneous and clastic sedimentary rocks and has been widely employed as a low-temperature thermochronometric tool. While apatite U-Pb dating, characterized by a nominal grain-size sensitive closure temperature range between 375-550°C, is a potential powerful tool to reconstruct the thermal evolution of lower to middle crustal rocks, but the fact that apatite, unlike zircon, incorporates significant amounts of non-radiogenic common Pb and only modest amounts of U and Th (1-10s of ppm) has traditionally presented analytical hurdles that have limited its application. In bedrock samples, non-radiogenic Pb in apatite can be corrected for though the analysis of a U-free cogenetic mineral phase (e.g., feldspar. While these traditional methods work well for igneous samples, this approach is not feasible for detrital apatite samples, hindering the application of detrital apatite U-Pb dating in tectonic or provenance studies, despite the fact that the obvious power of apatite U-Pb dating in detrital provenance studies has been widely recognized. This study presents an intriguing and robust new analytical method for in-situ correction of common Pb in apatite by employing LA-ICP-MS depth profiling. Depth-profiling analysis allows for the incremental recovery of U-Pb ratios at high spatial resolution (<1 micron depth intervals) during progressive (continuous) laser ablation of tape-mounted unfractured apatite grains. As U concentrations in apatite commonly show significant spatial variability related to growth zonation, depth-profile analysis recovers spatially variable U-Pb ratios that define a an intra-grain discordia or radiogenic-common Pb mixing line in Tera-Wasserburg space, allowing for the determination of both the radiogenic lower-intercept and hence the U-Pb age as well as the common Pb composition of individual detrital apatite. This novel method, allows for effective correction for common Pb in detrital apatite U-Pb despite the lack a cogenetic phase, making it feasible to conduct detrital apatite U-Pb dating in provenance and source-to-sink studies. For this methodological case study, this methodology was initially tested on Variscan granite bedrock samples from the Eastern Alps in Switzerland – with results showing that single-grain depth-profile intra-grain determinations of common Pb compositions are identical to cogenetic feldspar. Furthermore, individual apatite U-Pb ages (lower intercept) and common Pb compositions are also identical to bulk multi-aliquot apatite discordia intercepts, corroborating the robustness of the method. In a second case study, detrital apatite U-Pb data were analyzed for samples from the Lower Marine and Upper Freshwater Molasse of the Swiss Northern Alpine Foreland Basin. Those data show that the large majority of the apatites exhibit sufficient internal U variability to allow for robust single apatite intra-grain common Pb corrections and derivations of robust corrected U-Pb ages and common Pb composition by LA-ICP-MS depth profiling. These bedrock and detrital apatite case studies illustrate the power of this new methodology and the intriguing feasibility and applicability of detrital U-Pb dating and U-Pb-He double dating to provenance studies.