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Advancing $^{4}He/^{3}He$ thermochronology with new proton irradiation protocols, geological calibrations, and novel applications

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The ability to extract exceptionally high-resolution thermal histories from a single crystal using $^{4}He/^{3}He$ thermochronology has vastly appealing geological implications; however, methodological and analytical challenges have, in part, limited the accessibility in obtaining $^{4}He/^{3}He$ datasets. These challenges include the requirement to induce uniform and high concentrations of spallation ^{3}He within crystals via proton irradiation, and to (quasi-)simultaneously measure particularly low quantities of ^{3}He and ^{4}He during step-heating analysis of individual crystals. Here, we discuss recent efforts to advance the accessibility and utility of $^{4}He/^{3}He$ thermochronology by (1) establishing a new proton irradiation protocol with improved efficiency, (2) assessing apatite $^{4}He/^{3}He$ systematics via a calibration exercise that exploits the late Oligocene Fish Canyon Tuff (FCT) thermochronology age standard, and (3) developing new tools to assist in the application and interpretation of $^{4}He/^{3}He$ datasets. First, in collaboration with the Helmholtz Zentrum Berlin (HZB), we have implemented a newly developed in-vacuum and high-flux proton irradiation protocol that reduces the time-delay between sample irradiation to $^{4}He/^{3}He$ analysis down to ~2 weeks, and can be conducted routinely on a month-to-month basis. We reveal how computer simulations emulating the HZB irradiations can be utilized to optimize the geometry and composition of the target assembly to improve the uniformity of ^{3}He induced across all samples. Second, we present new $^{4}He/^{3}He$ degassing spectra from two distinct FCT sampling localities—the 'classic' locality with comparatively younger reset apatite (U-Th)/He ages, and the distal quarry locality with no apparent post-emplacement reheating. The measured $^{4}He/^{3}He$ spectra show that 'classic' FCT apatite crystals yield notably more diffusive ^{4}He distributions compared to the purely quenched distal FCT apatite, which preserve an apparent alpha-ejection-only $^{4}He/^{3}He$ spectrum. We furthermore observed near-identical $^{4}He/^{3}He$ spectra from FCT apatite crystals irradiated at HZB and those irradiated using the well-established conventional protocol, which corroborates the robustness of the HZB procedure. Lastly, we present the progress of ongoing projects implementing apatite $^{4}He/^{3}He$ thermochronology, and discuss new tools developed to both facilitate data interpretation and inform sampling strategies for $^{4}He/^{3}He$-based studies. In sum, these developments provide important new insights intended to progress the application of both $^{4}He/^{3}He$ thermochronology and ^{3}He-based diffusion studies.