Opportunities and challenges for reconstructing past Earth and planetary surface temperatures with cosmogenic noble gases

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Some of the first terrestrial cosmogenic nuclide measurements revealed that cosmogenic noble gases like ^{3}He and ^{21}Ne are diffusively lost at Earth surface temperatures in common silicate minerals like quartz and feldspars. This diffusive loss was originally considered a fatal flaw for applications of cosmogenic noble gases to studying surface processes, but in fact this behaviour can be utilized to understand past surface temperature conditions if the kinetics of noble gas diffusion are understood. We have been working in the last decade to exploit the simultaneous production and diffusion of cosmogenic noble gases to learn about past surface temperatures on Earth and other planetary bodies. In this presentation, I will discuss some of the opportunities and challenges associated with this endeavour using examples from recent and ongoing cosmogenic noble gas applications. First, I will discuss ongoing work to assess what temperatures characterized the McMurdo Dry Valleys in Antarctica during the mid-Pliocene Warm Period. The mid-Pliocene Warm Period is the most recent interval of the geologic past when atmospheric CO_2 concentrations exceeded 400 ppm, and it is widely considered an analogue for how Earth's climate system will respond to current global change. In the McMurdo Dry Valleys, we only have indirect geologic evidence for the magnitude of warming during this time, and climate models suggest that temperatures more than 10 °C warmer than today's temperatures were possible. I will describe our work pairing observations of cosmogenic ^{3}He, ^{10}Be, and ^{26}Al in quartz from bedrock depth profiles in very slowly eroding, continuously exposed surfaces to quantify the amount of ^{3}He lost to diffusion, as well as how we will use these data to inform models of cosmogenic ^{3}He production and diffusion since the mid-Pliocene. I will also discuss the challenges associated with this approach – in particular the limits imposed by the non-uniqueness of thermal history information that cosmogenic ^{3}He records, and the variability of ^{3}He diffusion kinetics in quartz crystals originating from rocks of different lithologies and geologic histories. Second, and relevant to this latter challenge, I will discuss our efforts to understand variable and sometimes complex noble gas diffusion systematics in quartz using a combination of laboratory experiments and computational modelling. Our models suggest that extended defects in quartz play an essential role in modulating helium diffusion. Although this means that helium diffusion kinetics in quartz will be grain or sample specific, it also means that different quartz samples will have different thermal sensitivities, which widens the number of potential paleotemperature applications of cosmogenic noble gases.