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Anomalous cosmogenic ^{3}He production and elevation scaling in the high Himalaya

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Abstract

The production rate of cosmogenic ^{3}He in apatite, zircon, kyanite and garnet was obtained by cross-calibration against ^{10}Be in co-existing quartz in glacial moraine boulders from the Nepalese Himalaya. The boulders have ^{10}Be ages between 6 and 16 kyr and span elevations from 3200 to 4800 m. In all of these minerals ^{3}He correlates with ^{10}Be and is dominantly cosmogenic in origin. After modest correction for non-cosmogenic components, ^{3}He/^{10}Be systematics imply apparent sea-level high-latitude (SLHL) apparent production rates for ^{3}He of 226 atoms g^{-1} yr^{-1} in zircon, 254 atoms g^{-1} yr^{-1} in apatite, 177 atoms g^{-1} yr^{-1} in kyanite, and 153 atoms g^{-1} yr^{-1} in garnet. These production rates are unexpectedly high compared with rates measured elsewhere in the world, and also compared with proposed element-specific production rates. For apatite and zircon, the data are sufficient to conclude that the ^{3}He/^{10}Be ratio increases with elevation. If this reflects different altitudinal scaling between production rates for the two isotopes then the SLHL production rates estimated by our approach are overestimates. We consider several hypotheses to explain these observations, including production of ^{3}He via thermal neutron capture on ^{6}Li, altitudinal variations in the energy spectrum of cosmic-ray neutrons, and the effects of snow cover. Because all of these effects are small, we conclude that the altitudinal variations in production rates of cosmogenic ^{3}He and ^{10}Be are distinct from each other at least at this location over the last ~10 kyr. This conclusion calls into question commonly adopted geographic scaling laws for at least some cosmogenic nuclides. If confirmed, this distinction may provide a mechanism by which to obtain paleoelevation estimates.

Keywords: cosmogenic; ^{3}He; ^{6}Li; lithium; helium; apatite; zircon; kyanite; garnet; Nepal; Himalayas; paleoelevation

1. Introduction

Due to its role in determining ages and erosion rates of surfaces in the landscape, cosmogenic nuclide analysis has grown in popularity over the last several decades (Lal and Peters, 1967; Bierman, 1994; Gosse and Phillips, 2001). Although ^{3}He is not as widely applied as ^{10}Be or ^{26}Al, ^{3}He occupies a unique niche in the family of cosmogenic isotopes for several reasons. It has a higher production rate relative to its detection limit than other cosmogenic isotopes, and can thus be used to date very small samples or young surfaces. It is produced by spallation from nearly all target elements,

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so can potentially be applied to many different mineral phases. Because it is stable, ^{3}He is potentially useful for estimating erosion rates on extremely old surfaces, for determining exposure ages of paleo-surfaces, and for estimating catchment-scale erosion rates from ancient sediments. In addition, cosmogenic ^{3}He dating potentially provides a faster and simpler alternative to cosmogenic radionuclide dating because it does not involve intensive preparation chemistry and measurement on an accelerator mass spectrometer.

Most previous studies using ^{3}He have targeted olivine and pyroxene phenocrysts, and numerous production rate determinations for olivine have been made on basalt flows of known age, yielding sea-level high-latitude (SLHL) rates between ~100 and 150 atoms g^{-1} yr^{-1} (Kurz et al., 1990; Cerling and Craig, 1994; Licciardi et al., 1999; Dunai and Wijbrans, 2000; Ackert et al., 2003; Licciardi et al., 2006). Recent efforts have explored extending ^{3}He dating by establishing production rates and the non-cosmogenic background in additional mineral phases found in more diverse lithologies. For example, production rates of ^{3}He in apatite, zircon, titanite and Fe–Ti oxides were determined by cross-calibration against cosmogenic ^{21}Ne in Andean tuffs (Kober et al., 2005; Farley et al., 2006). Similarly, the production rate in garnet was calibrated against ^{10}Be in glacial moraine boulders from the Nepalese Himalaya (Gayer et al., 2004). In addition, Kober et al. (2005) provide estimates of element-specific ^{3}He production rates based on a combination of field calibration and neutron bombardment experiments. These estimates are useful for predicting production rates in minerals that have not been directly calibrated. However, due to complicating variables such as Li content, grain size, elevation, and lithology, further calibration studies are needed before robust and widely applicable production rates are established.

Here we calibrate the production rate of cosmogenic ^{3}He in zircon, apatite, kyanite, and garnet against ^{10}Be in quartz in a suite of glacial moraine boulders in the Nepalese Himalaya. Our approach and sampling locality are similar to the study of cosmogenic ^{3}He in garnet performed by Gayer et al. (2004). Our sample suite also allows us to assess Gayer et al.'s observations of anomalous production rates and altitude scaling of cosmogenic ^{3}He in Himalayan garnets, and a recently proposed explanation that these anomalies arise from nuclear reactions on lithium (Dunai et al., 2007).

Natural samples have multiple sources of ^{3}He in addition to the sought-after cosmogenic spallation component. With the knowledge of the Li concentration of the analyzed phases, the composition of the whole

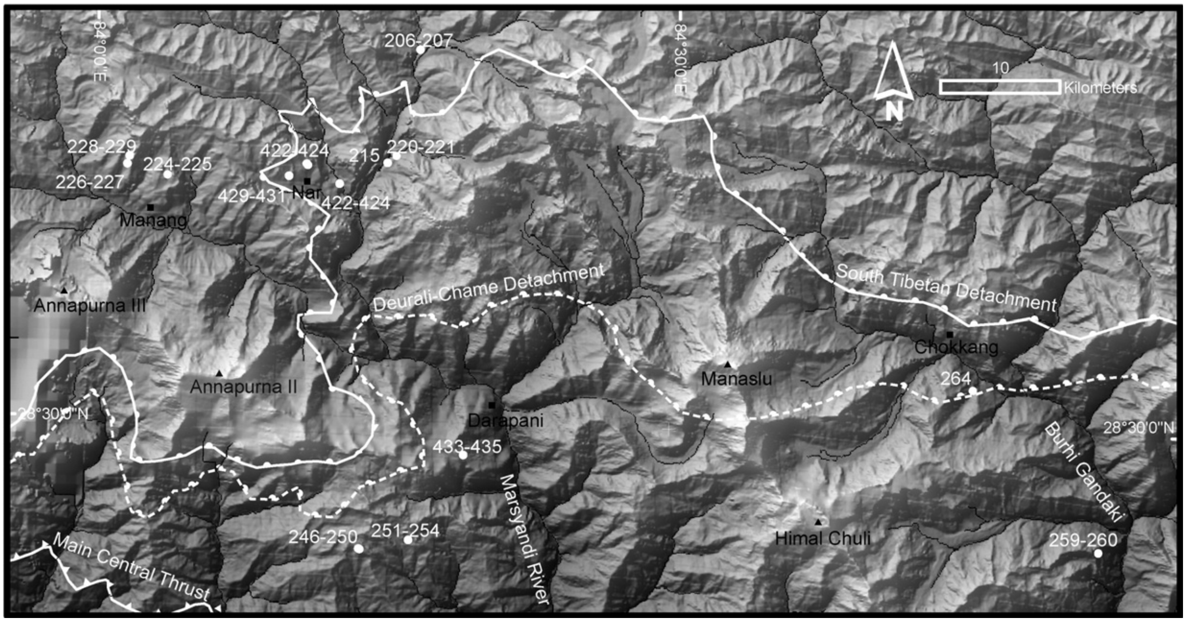

Fig. 1. Map of field area showing sample sites (white circles), towns (black squares), and major summits (black triangles). Major structural features are shown following Searle and Godin (2003), and delineate the Tethyan Sedimentary Series (north of the South Tibetan Detachment), from the Greater Himalayan Series (south of the Deurali-Chame detachment). The shaded relief map is derived from SRTM 90 m data.