Solar modulation and scaling *in situ* cosmogenic nuclide production rates

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Solar modulation affects *in situ* cosmogenic nuclide (CN) production rates the most at the high geomagnetic latitudes to which those production rates are traditionally referenced. This variability leads to significant scaling model uncertainties that have not been addressed rigorously to date. We have developed new CN production rate scaling models for spallogenic nucleons, slow muon capture and fast muon interactions that specifically address these uncertainties. Our spallogenic nucleon scaling model, which includes data from portions of 5 solar cycles, explicitly incorporates a measure of solar modulation, and our fast- and slow-muon scaling models (based on more limited data) account for solar modulation effects through increased uncertainties. These models improve on previously published models by better sampling the observed variability in measured cosmic ray intensities as a function of geomagnetic latitude, altitude, and solar activity.

Our results show that we can accurately account for the effects of solar modulation on measured cosmic ray intensities with our models, within the uncertainties of each of our source datasets. Published spallogenic nucleon scaling models predict scaling factors ranging from ~15% below to ~30% above those of our spallogenic model, while published muogenic scaling models predict scaling factors up to ~90% above ours. We also estimate solar modulation variations over the last 11.4 ka from a recent sunspot number reconstruction based on tree-ring ^{14}C data. These data suggest that spallogenic scaling factors in our model for sea level and high geomagnetic latitudes can vary by up to ~10%, depending on the time period over which the modulation conditions are averaged. The potential magnitude of this variation supports our contention that incorporating long-term solar modulation into CN production rate scaling is important.

Dating alluvial sediments with cosmogenic nuclides

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The dating of alluvial deposits is an important but difficult application of terrestrial cosmogenic nuclides. Initial work showed that exposure ages of surface clasts may be inaccurate because of nuclide inheritance and/or surface instability. Single nuclide depth profiles permitted inheritance to be estimated, and generated useful new ages for youthful deposits with stable surfaces. However, many alluvial deposits cannot be dated with single nuclide profiles because of surface disturbance or erosion. In the general case, three unknowns must be estimated: erosion rate of the contributing catchment; time since deposition; and erosion rate of the alluvial surface. Recently, measurements of long ^{10}Be and ^{26}Al profiles, studies of muonic production at depth, and measurement of nuclide concentrations in modern alluvium have invigorated the quest for a more robust means of dating ancient alluvium. These studies demonstrated that all three unknowns can be estimated from ^{10}Be and ^{26}Al profiles in favorable settings.

In this study, the utility of ^{10}Be and ^{26}Al depth profiles for dating alluvial deposits was investigated in an archaeological setting. The Luangwa Valley of Zambia is an extension of the African Great Rift Valley but lacks the interbedded volcanic deposits that have enabled a detailed chronostratigraphic record elsewhere in the Great Rift system. Six samples of amalgamated gravel and sand were analyzed for ^{10}Be and ^{26}Al from a 4.5 m terrace section containing Oldowan artifacts at the base. A sample consisting of surface clasts was also analyzed, as was a sample of modern alluvium. The terrace is dissected and original depositional surfaces are absent. Preliminary results suggest that gravels associated with Oldowan stone tools were deposited at about 0.9-1.0 Ma. This is younger than the dated range of Oldowan artefacts in Africa and suggests that the age is a minimum. The apparent exposure age of the surface of the section is only about 85 ka. A model terrace erosion rate of 10 m/Ma suggests that at least 9 m of section has been lost. Denudation rates from the contributing catchment vary from about 10 to 70 m/Ma, and are similar to the modern alluvium estimate of 45 m/Ma.