Improving the accuracy and precision of scaling factors for *in-situ* cosmogenic geochronometers: New measurements of cosmic-ray neutrons in India and Hawaii

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Production rates of *in-situ* cosmogenic nuclides are determined by the intensity of energetic cosmic-ray nucleon fluxes, which is highly dependent on elevation. An incomplete knowledge of how nucleon fluxes vary with elevation remains a major obstacle to utilizing cosmogenic nuclides as geochronometers in applications requiring small time resolution. One problem is that attenuation characteristics of nucleon fluxes depend on nucleon energy. Measurements of high-energy (>50 MeV) fluxes tend to give shorter attenuation lengths than low-energy (<1 MeV) fluxes, but these differences are not well characterized due to a lack of data at lower energies. Another problem is that the elevation dependence varies with geomagnetic cutoff rigidity (a parameter related to geomagnetic latitude), R_C, and that there has been an incomplete mapping of neutron fluxes at high R_C (low latitude). We report new measurements of neutron fluxes from altitude transects in Hawaii (R_C=12.8 GV) and Bangalore, India (R_C=17.2 GV). Our measurements in Hawaii of low-energy neutrons (median energy 1 eV) and energetic nucleons (median energy 140 MeV) confirm that nucleon scaling functions are energy dependent in the range of energies at which cosmogenic nuclides are produced. Our measurements in India extend our previously reported scaling model for spallation reactions (Desilets and Zreda, 2003, Earth and Planetary Science Letters 206, 21-42) from R_C=13.3 GV to R_C=17.2 GV, nearly the highest modern cutoff rigidity on earth. The anomalously high cutoff rigidity over India provides a geomagnetic shielding condition that is effectively the same as would be observed at the geomagnetic equator in a dipole field with an intensity 1.2 times the modern value. This makes it possible to scale low-latitude production rates to paleomagnetic fields that are stronger than the present dipole field.

Calibrating the production rate of cosmogenic ^{36}Cl from postglacial lava flows in Iceland

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One large uncertainty in surface exposure dating commonly arises from incomplete knowledge of production rates of cosmogenic isotopes and their variation with latitude, altitude and time. In Iceland, the production rates of *in situ* cosmogenic isotopes are predicted to be higher than globally averaged rates due to persistent low atmospheric pressure (Stone, 2000). Licciardi and Kurz (2002) determined that ^{3}He production rates in Iceland are significantly higher than normalized values measured in the western United States (Licciardi et al., 1999), supporting Stone's prediction.

We measured cosmogenic ^{36}Cl concentrations in whole rock basalts from radiocarbon-dated lava flows in Iceland. The ^{36}Cl data were obtained from splits of rock material from the same calibration sites used by Licciardi and Kurz (2002) to calculate their ^{3}He production rates. These ^{36}Cl measurements thus allow for the first direct co-calibration between these two widely used cosmogenic isotopes.

An immediate application of our ^{36}Cl production rates is to enable accurate ^{36}Cl dating in Iceland (e.g., Principato et al., 2003). Moreover, the ^{3}He-^{36}Cl co-calibration will further elucidate the influence of atmospheric pressure on the production rate of *in situ* cosmogenic isotopes.

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