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Studies of Geomorphic Rates and Processes with Cosmogenic Isotopes – Examples from Australia

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Cosmogenic isotopes are formed by high energy cosmic ray reactions in the uppermost 10-20 meters of the crust. ^{10}Be ($t_{1/2}$ = 1.5 Myr) and ^{26}A1 ($t_{1/2}$ = 0.7 Ma) are produced *in situ* from O and Si in quartz, ^{36}Cl (0.3 Ma) from Ca, K and ^{35}Cl in calcite, K-feldspar and whole rock samples, and the stable noble gas isotopes ^{3}He and ^{21}Ne from O, Na, Mg, Al and Si in olivine and feldspar. Isotope production rates depend strongly on depth, hence isotope accumulation reflects a sample's shielding history in the uppermost crust. Where a sample's exposure geometry was altered instantaneously by a geomorphic event (a landslide, fault rupture, etc), cosmogenic isotopes provide age information. Where a geomorphic process continuously alters a sample's shielding geometry, the process rate can be determined from cosmogenic isotope data *via* a model of the shielding history. Cosmogenic isotopes have been used in studies of erosion, sediment transport, neotectonics and landscape evolution in stable and active terrains.

Rock advected to the surface by erosion is exposed to a progressively increasing cosmic ray flux. The exposure duration is controlled by the erosion rate - the higher the erosion rate, the shorter the exposure time and the lower the ultimate isotopic concentration. A steady-state isotopic concentration is reached at the surface after erosion of 3-5x the characteristic attenuation depth for isotope production (i.e. total erosion > 2-5 m). Erosion rates can be determined on individual outcrops or on sediment created by erosion over larger areas. Measurements on sediment leaving a drainage basin give the mean lowering rate over the catchment, but are subject to constraints and assumptions regarding bedrock lithology and sediment storage (cf. Lal, 1985; Brown et al., 1988).

Erosion rates measured with cosmogenic isotopes around Australia vary with climate and lithology, in addition to local geomorphic controls. Chlorine-36 measurements on calcite from limestone outcrops around the continent indicate erosion rates from 1 m/Myr in the arid interior to 150 m/Myr in the Papua New-Guinean highlands. Limestone erosion rates are well correlated with mean annual rainfall at values close to those predicted by the equilibrium solubility of calcite. Under given climatic conditions, erosion rates for silicate rock surfaces are 2-5 x lower than karst erosion rates. Silicate erosion rates of 2-10 m/Myr in the eastern highlands fall in the range of estimates for long-term (10-100 Myr) denudation based on geomorphic constraints, thermochronology, sediment volumes and geomorphic modelling. This is either profound or perplexing, given the different depth- and time-scales addressed by the techniques. Erosion rate estimates based on cosmogenic isotopes pertain to removal of the last few meters of rock, typically corresponding to the past 0.01-1 Myr (depending on the erosion rate). Thermochronological erosion rate estimates address a longer timescale, averaging over the last 2-3 km of denudation. In general, the depth-sensitivity of cosmogenic-isotope-based erosion estimates is far shorter than the characteristic relief of landscapes, hence landscape evolution studies based on cosmogenic isotope data involve significant extrapolation and assumptions.

In the Mt Isa area of northern Australia, short- and long-term erosion rates can be compared in the framework of a well-defined weathering chronology. Landscape evolution in this region has been controlled by sequential episodes of deep weathering and planation throughout the Tertiary (Vasconcelos and Stone, *in prep.*). ^{40}Ar/^{39}Ar ages on K-bearing Mn oxides from deep-weathering profiles beneath planation surfaces show a consistent distribution with altitude - old ages extending back to the late Mesozoic and early Tertiary occur at the highest elevations in the landscape; late Pliocene to Pleistocene ages at the lowest. The erosion history required to produce and preserve this distribution is reflected in the distribution of erosion rates measured with cosmogenic isotopes. The oldest and highest planation surface remnants have the lowest erosion rates, of 1-2 m/Myr. Inset surfaces at lower elevation have higher erosion rates of 2-5 m/Myr. The short-term (0.1-1 Myr) erosion rates measured with cosmogenic isotopes are consistent with preservation of ancient weathering profiles, though they are 2-3x higher than the long-term erosion rates indicated by regional relief. Induration and armoring by deep weathering appears to play a fundamental role in the geomorphic evolution of this and other cratonic landscapes.

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