IN-SITU BUILDUP OF COSMOGENIC ISOTOPES AT THE EARTH'S SURFACE: MEASUREMENT OF EROSION RATES AND EXPOSURE TIMES

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Cosmic rays produce a number of nuclides in rocks that can be used to determine the geomorphic history of surfaces. The most useful are the radioactive isotopes ^{10}Be ($t_{1/2}$ = 1.5Ma), ^{26}Al (0.7Ma) and ^{36}Cl (0.3Ma). Within the top 2m of the surface, these are produced principally by fast neutrons. At greater depths, production is dominated by the capture of negative muons. Measurements of a single nuclide produced *in situ* can be used to determine total exposure times or erosion rates. The use of multiple nuclides with different half-lives makes it possible to determine more complex histories such as exposures interrupted by periods of burial. At the ANU, all three of the isotopes above are being used to study a variety of problems in geomorphology and paleoclimatology, although to date, most of the work has concentrated on ^{36}Cl.

The accumulation of cosmogenic ^{36}Cl in calcite ($CaCO_3$) provides a means of measuring erosion rates on limestone surfaces. Sensitivity is achieved over a wide range of erosion rates due to the high production rate of ^{36}Cl in calcite (typically greater than 30 atoms/g/yr) and a detection limit of ca. 5000 atoms/g attainable with the ANU AMS system. The method is simplified by the predominance of Ca reactions (principally spallation) over other sources of ^{36}Cl in calcite, and the ease of sample preparation. The geological abundance of limestone ensures widespread applicability.

To provide a quantitative basis for the method, we have calibrated empirically the production rates of ^{36}Cl by Ca spallation, negative muon capture by ^{40}Ca and capture of muon-produced secondary neutrons. Samples were collected from glacial pavements in the Sierra Nevadas and to a depth of 20m from a marble quarry. Our estimate for the Ca spallation rate is in excellent agreement with the determination of Zreda *et al.* [1] and preliminary results for the $^{40}\mathrm{Ca}(\mu^-,\alpha)^{36}\mathrm{Cl}$ reaction rate suggest a value close to that measured by Dockhorn *et al.* [2]. These results imply that for shallow depths production decreases roughly exponentially, with Ca spallation dominating negative muon and thermal neutron capture production. At depths below 1 - 2m, the relative contributions of muon capture and mu-genic secondary neutron capture are comparable in magnitude (the latter varying with chlorine content) and total ^{36}Cl production follows the negative muon stopping rate.

For surfaces eroding at low rates (< 20 microns/yr), the effects of muon capture are subordinate to spallation and erosion rates can be calculated from measured ^{36}Cl concentrations using an exponential approximation for production with depth. At higher erosion rates, a greater proportion of ^{36}Cl at the surface is muon-produced, and the exact form of the production rate profile must be used to calculate rates accurately. Since near-surface and deep samples respond to erosion on different timescales (due to differing attenuation lengths for nucleon and muon fluxes) measurement of ^{36}Cl profiles can be used to detect changes in erosion rates through time.

We have measured ^{36}Cl in calcite from limestone samples from Australia and Papua New Guinea. Erosion rates derived from these measurements range from 3 microns/yr on the Nullarbor Plain of Western Australia to > 200 microns/yr in the New Guinea highlands. Numerous measurements on samples from south-eastern Australia give values ranging from 10 - 40 microns/yr. These results, which reflect rates over the past 50,000 to 200,000 years, accord surprisingly well with rates of limestone surface ablation measured directly on similar outcrops over the past decade [3]. They are somewhat higher, however, than average rates of landscape denudation and valley incision (generally estimated at < 5 microns/yr) in eastern Australia over the past 20 - 40 million years.

A series of measurements have also been performed on samples from the Vestfold Hills area of East Antarctica. This area is presently unglaciated and the extent of its glaciation during the previous glacial maximum is an important open question bearing on the role of the Antarctic ice sheet in changes in sea level at that time. Both ^{36}Cl and ^{26}Al have been measured at a number of locations. The results are highly variable, with apparent exposure ages varying from 10 to 60 ka. Possible explanations will be discussed.

[1] M.G. Zreda, F.M. Phillips, D. Elmore, P.W. Kubik, P. Sharma and R.I. Dorn, Earth Planet. Sci. Lett. 105, 94-109 (1991).

[2] B. Dockhorn, S. Neumaier, F.J. Hartmann, C. Petitjean, H. Faestermann, G. Korschineck, H. Morinaga and E. Nolte, Hadrons and Nuclei 341, 117-119 (1991).

[3] A. Spate, pers. comm.