Quantifying the rate of rock weathering in hyper-arid southern Africa

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Isolated, bare rock surfaces are a common, even dominant feature of deserts throughout the world. Over a century of research has provided a plethora of hypotheses regarding the ages of and means by which these rock outcrops, termed inselbergs, form (Twidale, 1982). However, until recently there were no means by which to test these hypotheses nor to measure the rate at which inselbergs are eroding. Over the past several years, we have been collecting samples of granitic rock and, in collaboration with physicists, have used accelerator mass spectrometry to measure the abundance of very rare isotopes formed by the bombardment of cosmic rays (Bierman and Turner, 1995; Bierman, 1994). These measurements, from seven sites in Australia and North America, have allowed us to define an empirical relationship between mean annual rainfall and the denudation rate of exposed rock (Bierman, 1995). This relationship suggests that rock denudation in the absence of measurable precipitation should be 0.4 m/million years and should increase at a rate of 2.6 m/My for each additional meter of precipitation. However, we have yet to sample extremely arid sites. This proposal will fund the collection of samples from the hyperarid Namibian desert in order to test the relationship we have established and to determine the rate of rock weathering and landscape formation in what is thought to be one of the World’s driest and most tectonically stable areas.

Erosion, desert, granite, Namibia, cosmogenic isotope

This will be the first work to estimate the rate at which rock erodes in one of the most arid and tectonically stable settings on Earth. Measuring such rates is fundamental to understanding the evolution of Earth’s surface through time and space and is prerequisite to quantifying the rate at which topography develops and sediment is generated.
Paul R. Bierman

Assistant Professor, University of Vermont, Department of Geology

Baltimore, MD 10/24/61

Ph.D., 1993, Geology, University of Washington, Seattle, WA with A. Gillespie
"Cosmogenic Isotopes and the Evolution of Granitic Landforms"

MS, 1990, Geology, University of Washington, Seattle, WA with A. Gillespie
"Accuracy and Precision of Rock Varnish Cation Ratio Dating"

BA, 1985, Geology and Environmental Studies, Williams College, Williamstown, MA
"Deglaciation of Northwestern Massachusetts," (cum laude and senior thesis)

Bierman has extensive experience collecting, processing, analyzing, and interpreting samples for cosmogenic nuclide abundance. He developed and directs the extraction laboratory at the University of Vermont which has prepared over 500 samples in the past three years. Bierman and his students are the authors of 11 papers incorporating these nuclide measurements. In recognition of his research accomplishments, Bierman will be awarded the Donath Young Scientist Medal from the Geologic Society of America during the 1996 annual meeting.

Bierman will oversee sampling and sample preparation. Isotopic analyses will be made in collaboration with Dr. Marc Caffee of Lawrence Livermore National Laboratory. In southern Africa we will assisted by Dr. Tim Partridge and at the Namibian field station by Mary Seely.
ARTICLES

ABSTRACTS
Bierman, P. (1996) Cosmogenic clues to the tempo of environmental change, AMSIE '96, American Association or the Advancement of Science, p. A-146

Research results will be submitted to major journals most likely, Earth Surface Processes and Landforms and the journal Science, an editor of which has requested Bierman prepare a manuscript on world-wide rates of rock weathering.
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<td>AMS analyses at Livermore Laboratory for 10-Be and 26-Al</td>
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50% on 3/1/97, 50% on 8/1/97
The University of Vermont will provide laboratory facilities for the preparation of samples and computer facilities for data reduction. Total University cost-share is $9596 and consists of three weeks of Dr. Bierman’s academic year effort to process samples plus associated fringe benefits and indirect costs.

No other grants have been submitted for this work.

No other grants have been received by Bierman from the Society

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3/1/98

12/30/98
Paul R. Bierman

**Background** -- Understanding rates of rock weathering over space and through time is a fundamental geologic and geographic question. It is the breakdown of rock that creates sediment as spatial differences in weathering rates generate spectacular landscapes and create topography.

Rates of rock weathering have been notoriously difficult to measure although a variety of techniques have been employed (Saunders and Young, 1983). Until recently, there was no way to determine erosion rates of rock directly over 1,000 to 1,000,000 year time scales; the meaning of measurements made over shorter (human) time scales remains uncertain. The advancement of accelerator mass spectrometry for measuring isotopes produced near Earth’s surface by cosmic rays (Elmore and Phillips, 1987) and the development of models for interpreting these data (Lal, 1991) have revolutionized the study of bedrock landforms and at last provide some constraint on the rate at which bare bedrock surfaces erode (Bierman, 1994). To the first approximation, the abundance of cosmogenic nuclides such as $^{10}$Be and $^{26}$Al is related to the residence time of a sample within a meter of Earth’s surface. Using models, isotope abundances can be interpreted as erosion rates expressed in meters of lowering per million years (m/My; Lal, 1991; Bierman, 1994).

Crystalline rocks, such as granite and gneiss, underlie much of the continents and are the lithologies upon which extensive geomorphic surfaces, described by some as peneplains, develop. Isolated rock outcappings or inselbergs project from relatively flat landscapes. Field observation and geologic reasoning have been used to generate many hypotheses regarding the origin and age of inselbergs but little data exist to test these hypotheses. For example, since weathering reactions are mediated by water, one might expect that inselberg surfaces in humid regions would be shed sediment more rapidly than those in arid regions.

In order to determine the effect of water on the rate of rock weathering, we have sampled and made cosmogenic isotopic analyses of granitic and gneissic rocks in seven different locations in Australia and North America (Bierman, 1995). Mean annual precipitation (MAP) at these sample sites ranges from 150 mm/yr to >1500 mm/yr. Comparing the lowest model erosion rate at each sample site, we find that rates of mass loss from the inselberg surfaces are linearly relate to MAP (Figure 1). The lowest rates we have measured so far (0.5 m/My; Bierman and Turner, 1995) are from the tectonically stable, semi-arid (340 mm/yr) Eyre Peninsula of southern Australia. These rates are very low but are still an order of magnitude higher than rates measured on sandstones in the Dry Valleys of Antarctica where liquid water is absent (Nishiizumi et al., 1991).

In order to compliment our existing data set, we propose to collect samples from one of the driest places on Earth, the inselbergs of the Namibian desert in southern Africa. Inselbergs are common Namibian landscape elements and their location has been mapped by several workers (Ollier, 1978; Selby, 1977; Selby, 1982c). The Namibian inselbergs have been well studied (Selby, 1977; Selby, 1982c) and provide the opportunity for us to examine the weathering rates of different lithologies including both Precambrian schist and younger granites, which in some cases are exposed on the same inselberg (Selby, 1982a). The Namib Desert receives extremely little precipitation (15-23 mm/yr, MAP). Prior research suggests that the area has been arid for much, if not all, of the Quaternary (Ollier, 1978; Selby et al., 1979). Fog may add up to 30 mm/yr of moisture in some regions of the Namib Desert (Goudie, 1972).

Samples we collect from the Namib Desert will allow us to estimate isotopically the rate at which crystalline rock erodes in the near absence of precipitation.

Furthermore, our data will be analyzed in the framework of the Namib rock strength data gathered by Selby (Selby, 1982a; Selby, 1982b; Selby, 1982c) and will be compared to the extensive isotopic data sets we have gathered from the inselbergs of southern Australia, central Texas, southern California, and the southeastern United States (Bierman, 1993; Bierman et al., 1995; Bierman and Turner, 1995).

**Work Plan** -- Bierman and a field companion, most likely Caffee, will travel to Namibia in order to collect samples. In the interest of safety, our field party will be a minimum of two people. We will stay at the Gobabeb research station (Desert Research Foundation of Namibia) and we have already been advised as to permit, sampling and entry requirements by Mary Seely who is associated with the station. The station and its staff provide local expertise in natural history and in
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Namibian logistics; furthermore, the station is located near many of the well-studied Namibian inselbergs. Working out of the research station will allow us to collate sample information in the evening and provide a secure repository for our field equipment, supplies, and samples. We have also been in contact with Dr. Timothy Partridge, Professor of Physical Geography, University of Witwatersrand, who has studied extensively southern African geomorphic surfaces (Partridge and Maud, 1987). If possible, we plan to spend time in the field with Dr. Partridge.

In the field, we plan to collect 3 to 5 samples from each of 8 to 10 inselbergs. These samples will be collected from the tops of the inselbergs which have been shown to have the highest isotope abundances and correspondingly lowest erosion rates (Bierman, 1993; Bierman and Turner, 1995) and from the side slopes which typically have lower isotope abundances by a factor of >2 even after geometrical corrections for cosmic ray dosing have been made. Sampling the tops of numerous inselbergs will indicate whether the erosion rates we measure are spatially uniform such as those for the Eyre Peninsula Australian inselbergs (Bierman and Turner, 1995) or whether there are significant differences between inselbergs in terms of erosion rate and cover history.

Samples will be returned to the UVM where they will be processed using our standard protocols. Rocks will be cleaned of lichen, jaw crushed, plate ground, and sieved before acid etching and mineral separation to isolate a quartz-rich fraction. This fraction will be ultrasonically etched to provide 10-20 g of nearly pure quartz which will be dissolved in the presence of Al and Be carrier. Be and Al will be separated using ion exchange and AMS targets will be prepared at UVM and transported to Livermore National Laboratory for isotopic analysis. Samples will be handled in batches of eight; each batch includes a process blank. Although we are only requesting funding for processing and analysis of 15 samples, we plan to oversample while in Namibia given the cost of travel and the difficulty of access. On the basis of the initial 15 samples, we will choose additional samples to run in the future as laboratory time and funds become available.

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Rates of rock weathering are poorly known but of great importance to understanding how Earth’s surface and environment have changed over time. New techniques now allow direct measurement of rock erosion rates and allow estimation of how quickly topography is generated and landscapes change. This study will measure rates of rock weathering in one of the driest regions of the world, the Namibian Desert. Data collected in Namibia will complement data gathered from other regions of the world and will address the fundamental scientific question, “How quickly do the landscapes in which we live, change?”