

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB NO. 0704-0188

Public Reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comment regarding this burden estimates or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188,) Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE 10/1/03	3. REPORT TYPE AND DATES COVERED Final 01 Oct 02 - 31 Mar 03	
4. TITLE AND SUBTITLE <b>Quantifying sediment generation in humid tropical regions using cosmogenic nuclides – A proof of method</b>			5. FUNDING NUMBERS DAAD19-02-1-0436	
6. AUTHOR(S) Paul R. Bierman				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Vermont, Geology Department, Perkins Hall, Burlington, VT 05405			8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  U. S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSORING / MONITORING AGENCY REPORT NUMBER  44495-1-EV-11	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.				
12 a. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.			12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  We have been funded by the USARO to better understand natural rates of processes in a humid tropical watershed. This report details the progress we have made using grant support over the past year. It describes the research performed by Drs. Kyle Nichols and Paul R. Bierman.				
14. SUBJECT TERMS			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT <b>UNCLASSIFIED</b>	18. SECURITY CLASSIFICATION ON THIS PAGE <b>UNCLASSIFIED</b>	19. SECURITY CLASSIFICATION OF ABSTRACT <b>UNCLASSIFIED</b>	20. LIMITATION OF ABSTRACT <b>UL</b>	

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)  
Prescribed by ANSI Std. Z39-18  
298-102

## **Final Technical Report -- DAAD19-02-1-043**

10/1/03

Performers: Dr. Paul Bierman, Professor, Geology Department, University of Vermont  
Dr. Kyle Nichols, Assistant Professor, Skidmore College

### GOAL

Our overall goal was to constrain better the background or natural rate at which soil and rock surfaces are eroding and sediment is transported. We have collected 37 samples from the tropical, humid Rio Chagres watershed in Panama as a methodological test. Since the headwaters of the Rio Chagres watershed are remote, and relatively undisturbed by humans, it is an ideal tropical location to test the cosmogenic method. This 'proof of method' study in tropical environments has broadened the geographic scope over which cosmogenic nuclides can be used to understand societal and environmentally relevant geologic processes including erosion and sediment transport.

### INTRODUCTION

Quantifying rates of landscape change is fundamental to understanding the natural environment and the persistence of human impacts. Natural rates of landscape change are often slow and imperceptible. Field monitoring techniques, often used to measure landscape change, are labor intensive and time consuming (e.g. Abrahams et al., 1984; Lekach and Schick, 1999). Such methods require personnel and intensive monitoring over several years to decades to understand rates of landscape change. Even after several years of data collection, it is difficult to extrapolate such short-term rates to longer, geologic rates of change because it is difficult to determine if the geomorphic events captured during the study period are representative of the long-term events that shape the landscape (Baker and Twidale, 1991; Kirchner et al., 2001). Furthermore, in order to understand the human impact on landscape processes, it is necessary to compare the present day rates to longer-term average rates, which are often unavailable (Clapp et al., 2000; Trimble, 1999).

Over the past several years many studies have demonstrated the utility of analyzing cosmogenic nuclides in sediment in order to determine long-term average sediment

generation rates (Clapp et al., 2002, 2001, 2000; Nichols et al., 2002; Bierman et al., 2001a, 2001b; Kirchner et al., 2001; Matmon et al., 2001a, 2001b; Schaller et al., 2001; Bierman and Steig, 1996; Granger et al., 1996; Brown et al., 1995). Such long-term cosmogenic-nuclide-based sediment generation rates provide baseline data for comparison to present-day sediment generation rates. Without measuring such long-term average rates of sediment generation, it would be impossible to determine if the present day sediment export rates are greater (e.g. Clapp et al., 2000) or are less (e.g. Kirchner et al., 2001) than the long-term average. Furthermore, wide scale coverage allows one to determine areas of a basin that have high rates of sediment generation. By knowing the sediment generation rates at several locations in a basin, it is possible to develop a mixing model that tracks the sediment from the source areas through the drainage basin to the outlet (e.g. Clapp et al., 2002).

## WORK ACCOMPLISHED

Our findings are detailed in a pair of abstracts as well as a paper that is *in review*. We measured in situ-produced cosmogenic  $^{10}\text{Be}$  in 17 sand-sized sediment samples (0.25 to 0.85 mm) to estimate the rate and distribution of sediment generation in the upper Chagres watershed over the last 20,000 years. Results suggest that the Chagres watershed is generating sediment uniformly. Nuclide activities of small tributary basins suggest basin-wide sediment generation rates between 143 to 354 tonnes  $\text{km}^{-1} \text{y}^{-1}$  (average =  $234 \pm 74$  tonnes  $\text{km}^{-1} \text{y}^{-1}$ ;  $n = 7$ ). The basin-wide sediment generation rates of large tributary basins are 248 to 281 tonnes  $\text{km}^{-1} \text{y}^{-1}$  (average =  $267 \pm 97$  tonnes  $\text{km}^{-1} \text{y}^{-1}$ ;  $n = 3$ ). The sample collected near Lake Alhajuella suggests that the entire basin is exporting sediment to Lake Alhajuella at a rate of  $275 \pm 62$  tons  $\text{km}^{-2} \text{y}^{-1}$ . These three sets of cosmogenic nuclide measurements all suggest that the Chagres basin (when considered on scales  $<5.2 \text{ km}^2$  to  $>350 \text{ km}^2$ ) is generating sediment at  $\sim 270$  tonnes  $\text{km}^{-1} \text{y}^{-1}$ . This long-term (background) sediment generation rate is the same as the estimate made from suspended sediment yield measured below the Chagres-Chico confluence from 1981 to 1996 (289 tonnes  $\text{km}^{-2} \text{y}^{-1}$ ). Such similarity implies contemporary and long-term sediment yields are similar. Thus, this basin is in long-term, erosional steady state.

Such a background sediment yield suggest it would take  $\sim 3,600$  years to completely fill Lake Alhajuella, the reservoir for the Panama Canal. Taking into account the 2 to 3 fold increase in sediment yields for adjacent disturbed basins, the filling time is reduced to  $\sim 2,000$  years. However, it would only take between 250 to 600 years to reduce the

reservoir capacity (69% of maximum) enough to drain the entire reservoir during climatic conditions similar to the 25% decrease in precipitation during the 1982 El Niño event. Such models highlight the importance of proper watershed management in order to reduce the sedimentation of Lake Alhajuela.

#### PROFESSIONAL RECOGNITION

Bierman has been promoted to full professor based in part on the success of the work that he and his students have done as a result of this and other US ARO funding.

Nichols, a doctoral candidate supported by ARO when this grant was submitted and the initial work was done, is now in his second year as a tenure-track professor at Skidmore College.

#### REFEREED PUBLICATIONS SUPPORTED BY THIS FUNDING

Nichols, K.K., Bierman, P.R., Finkel, R., and Larsen, J., (in review) Long-term sediment generation rates for the Río Chagres Basin based on cosmogenic  $^{10}\text{Be}$ . In: **The Rio Chagres: A Multidisciplinary Profile of a Tropical Watershed.**

Nichols, K.K., Bierman, P.R., Finkel, R., Larsen, J. (2003) Long-Term Erosion and Sedimentation Rates of the Río Chagres Basin Based on Cosmogenic  $^{10}\text{Be}$ . □ **International Scientific Symposium The Rio Chagres: A Multidisciplinary Profile of a Tropical Watershed Abstract Volume.**

Nichols, K.K., Bierman, P.R., Larsen, J., and Finkel, R. (2002), Sedimentation of the Panama Canal reservoir: cosmogenic nuclide estimates of background sediment yield, **Geological Society of America Abstracts with Programs** 34(6)