DETERMINING LONG TERM EROSION RATES IN PANAMA: AN APPLICATION OF ^{10}Be

A Graduate Research Proposal

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Abstract

My research will determine erosion rates in selected watersheds in Panama using cosmogenic nuclide analysis; specifically, ^{10}Be concentration measured in quartz extracted from river sediments. Sampled watersheds stretch from east to west across the country, and most include at least some of the mountainous spine of the isthmus. Landscape variables (both natural and anthropogenic) will be quantified, using GIS, in order to explore their relationship with erosion rates. Bi-variate and multi-variate linear regressions will be used to test the significance of any relationships. Landslide influence on ^{10}Be concentration in river sediments will be explored using samples obtained up and downstream of where a landslide entered the stream. Grain size influence on ^{10}Be concentrations will also be considered. This research is the first attempt to quantify erosion rates in Panama at such a broad scale. Knowledge of background erosion rates, and the controls on them, is important for evaluating land management practices in Panama, where the proper function of the Canal is linked to water storage reservoir sedimentation and thus erosion rates.

Introduction

Knowing drainage basin erosion rates is of significant interest because they influence both water quality and the quantity of water available for human use (Sthiannopkao et. al., 2007). Sedimentation of waterways, an effect of erosion, is associated with deterioration of water quality including increased turbidity and temperature and changes in dissolved oxygen (Bilotta and Brazier, 2008). The yield of water reservoirs can be affected by erosion, since their capacity decreases as they fill with sediment. Although erosion rates may be related to natural factors, such as geology and climate, accelerated erosion is often triggered by human activities (Douglas, 1969; Ouyang et. al, 2010). Deforestation and impervious surfaces can significantly increase erosion (Foley et al., 2005; Marshall and Shortle, 2005).

Erosion has been quantified using a variety of methods. In the 1960s, the volume of sediment deposited in standing water (artificial reservoirs or lakes) was measured and normalized by the area of the basin draining to the sampling point in order to obtain erosion rates under the assumption of steady state (Judson, 1968). Another method used to estimate erosion rates was the measurement of suspended solids carried by streams (Judson and Ritter, 1968). These methods assumed that sediment production and transport are equal over the time interval of sampling.

During the 1990s, cosmogenic isotopes emerged as a method to estimate erosion rates (Bierman, 1994). Cosmogenic isotopes are formed when rocks are exposed to cosmic rays (Lal and Peters, 1967). As a result of this interaction, isotopes, such as ^{10}Be, accumulate in rock and soil. Production of these isotopes decreases exponentially with depth and is in general inconsequential below 2 meters depth in rocks (Lal and Peters, 1967). Because of this, ^{10}Be is a good indicator of the near-surface residence time of materials - hence, the rate at which earth surface is eroding. Cosmogenic nuclides provide a robust method to quantify erosion rates, because they integrate enough time to average out extreme events on centennial time scales. These isotopes have the potential to provide long-term data that can help place human influences on the landscape and its processes (Bierman and Nichols, 2004; von Blackenburg, 2005) in context.

Objectives

This research aims to determine long-term, background erosion rates in Panama using ^{10}Be measured in river sediments. It is important to know background erosion rates in order to make land management decisions in the context of natural process rates. Even though a considerable number of studies use ^{10}Be as a proxy for erosion rates, just a few of them are in tropical environments (total number of tropical samples is 98 out of 1599 total samples; Portenga and Bierman, 2011). Obtaining erosion rates for many watersheds in Panama along with land use data and present-day sediment yield, will allow us to place human impact in the context of background erosion and gain knowledge on background erosion rates in a tropical climate. This research will expand the breadth of environments where cosmogenic isotopes have been measured.

The effect of physiographic controls on erosion and sediment movement had been long debated. Watershed elevation appears to exert control on erosion at a global (Portenga and Bierman, 2011) and at a site-specific (Palumbo et al., 2009) scale. Portenga and Bierman (2011) found that mean basin slope significantly relates to drainage basin erosion at both local and global scale, and that relief is important in controlling erosion rate in the tropical climate zones. However, von Blackenburg (2004) concluded that relief alone does not accelerate erosion. This research aims to shed some light on these physiographic controls on erosion in tropical climates.

Background

Sediments can have a negative effect on water quality. An increase in suspended solids decreases light penetration, dissolved oxygen, and water temperature (Bilotta and Brazier, 2008). All these factors can significantly compromise the conditions for aquatic life. Erosion at the watershed scale has been related to an increase in suspended sediment and turbidity in waterways (Gao, 2008). Erosion has also been linked to sedimentation of reservoirs, decreasing their yields (Christiansson, 1979). In Panama, where the Canal is fed by reservoirs, it is crucial to avoid an increase in sediment yields that will in turn decrease the amount of water that can be stored and used for its operation (Ibañez et al., 2002). This will not only have an effect on Panama's economy, but on the global economy as well (Graham et al., 2006).

Erosion rates vary at a global scale depending on natural and anthropogenic factors. Natural controls that have an effect on erosion rates include latitude, elevation, relief, slope, seismicity, and vegetation cover (Portenga and Bierman, 2011). Several topographic controls have been positively related to erosion rates: relief (von Blackenburg, 2005), hillslope angle, local relief and slope (Palumbo, et al., 2009), and tectonic forcing (von Blackenburg, 2004). Climatic factors (precipitation and temperature) have long been thought to have a relationship with erosion rates (Douglas, 1969; Thomas, 1994; Woodward and Foster, 1997; Boardman, 2001).

At least two studies on the factors altering erosion rates, using cosmogenic nuclides, have shown that climate control is not important. Von Blackenburg (2004) found that weathering and erosion is not accelerated by increasing temperature and precipitation. Erosion rates appeared to bear little relationship to climate (Riebe et al., 2001). In contrast, Portenga and Bierman (2011) show that different climate zones are governed by different factors when it comes to erosion (i.e.: slope, relief, etc.), and climatic factors are weakly related to erosion.

Landslides can act as a significant source of sediment to rivers. Brown et. al (1995) suggested that landslides deliver large-sized material to streams based on research conducted in Puerto Rico. Using numerical simulations, Niemi et al. (2005) concluded that landslide effect on sediment delivery is dependent on catchment scale, with landslides having a bigger impact on smaller catchments. However, this effect is difficult to quantify, since cosmogenically-derived erosion rates will average out sporadic landslides (Niemi et al., 2005).

Various researchers have shown that land use and land cover change have an effect on water quality. One of the direct effects of land use and cover change is increasing erosion rates (Judson, 1968), as vegetation cover is replaced by agriculture and urban areas. Erosion decreases as vegetation cover increases (Vanacker, et al., 2007).

Cosmogenic nuclides, as a proxy for erosion rates estimates, have not been widely used in tropical climates. Studies carried out in Sri Lanka (von Blackenburg, 2004), Madagascar (Cox et. al, 2009) and Puerto Rico (Brown et. al, 1994, 1998) are among the few that exist. In a study in Puerto Rico, long-term average denudation rate was found to be ≈ 43m Ma^{-1}, and approximately 55% of the sediment reached the stream via landslides (Brown, 1995). In 1998, Brown concluded that the average denudation rate in two sub-basins in Puerto Rico was 43 ± 15mm ka^{-1}. They determined that human influence increased the present-day watershed denudation rate to ~ 85mm ka^{-1}. Long-term denudation rates in Sri Lanka ranged between 2-11 mm kyr^{-1}, and not affected by high temperatures and precipitation, but are rather sensitive to tectonic forcing (von Blackenburg, 2004).

Only one cosmogenic study has been carried out so far in Panama. Nichols (2005) determined the long term sediment generation rate in the Upper Rio Chagres Basin. Denudation was found to be similar to the present-day sediment yield, which is lower when compared to adjacent watersheds where human activities were correlated to higher present day sediment yields.

Study area

Panama is located in Central America, extending between 7-10° N and 77-83° W, sharing borders with Costa Rica in the west and Colombia on the east, occupying 77,400 km^2. Its climate is tropical with high temperatures year round, averaging 26°C (World Water and Climate Atlas, 2011) and high precipitation rates varying between the Pacific and Atlantic Coast. The Pacific coast receives an average of less than 2000mm of annual precipitation, whereas the Atlantic coast receives more than 3000mm (Harmon et al., 2009). Panama is located between (and influenced by) five tectonic plates: North American, South American, Caribbeann, Nazca and Cocos. This tectonic setting has played a major role in shaping the country's topography: a belt of discontinuous mountains on the northern side of the country (Palka, 2005). Darien Mountains are the highest of Panama, reaching 1,876m. Most of the rivers in Panama (60%), flow into the Pacific are longer with low gradients. Remaining rivers flow into the Atlantic (Palka, 2005).

Methods

Sampling

Sampling for this project builds up on a previous project by Nichols in the Rio Chagres (2002). Northern watersheds were sampled in 2004 to compare with erosion rates obtained previously. Watersheds in southern Panama were sampled in 2007 to determine spatial variance of erosion in the country and to explore the relationship between erosion and tectonic activity.

Sample locations

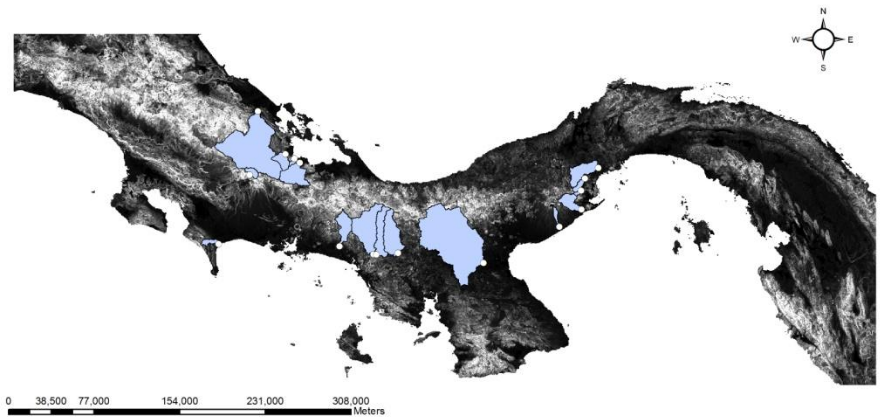

Figure 1: Country of Panama, shaded relief map. Sampling locations are indicated with white dots, and the watersheds draining to them have been delineated and showed in blue. Map data from CGIAR-CSI.

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^{10}Be extraction and measuring

Samples were provided when I started my work at UVM. Quartz from the sand fraction had already been isolated and purified. I extracted beryllium from the purified quartz in the UVM Cosmogenic Laboratory. Each batch (10 samples and two blanks) took about a week to process. About 40 grams of quartz was weighed in and digested in hydrofluoric acid. A small amount (250µg) of Be carrier was added to each sample. Subsequent treatments with hydrochloric, nitric, sulfuric and perchloric acid prepared the samples for column chemistry. Both anion and cation chromatography columns stripped the sample from metals that would interfere with ^{10}Be isotopic analysis (i.e. titanium and iron). An aliquot of each sample was analyzed in the ICP to confirm that the Be fraction of the sample was isolated and purified. Samples were precipitated and packed into targets to measure their $^{10}Be/^{9}Be$ isotopic ratio.

Be ratios were obtained using the accelerator mass spectrometer at Lawrence Livermore National Laboratory. ^{10}Be concentrations, physiographic characteristics of the sampling location (i.e. latitude, longitude, and elevation), and information on calibration for ^{10}Be production rates were used to calculate erosion rates, using the on-line CRONUS Earth calculator (http://hess.ess.washington.edu/).

Data analysis

ArcGIS 9.3 was used to obtain average basin slope, mean basin elevation and watershed area. Land use and land cover change data will be used to relate anthropogenic factors to erosion rates. As of today, land use data for Panama have not yet been found, and satellite imagery lacks quality because of the constant cloud cover over Panama. Precipitation and temperature information will be displayed and averaged in ArcGIS and used for statistical analyses. The relationship between erosion rates and the parameters obtained using GIS will be explored with linear regressions and multivariate analysis using SPSS v.20.

Work Completed

In the fall of 2010, I processed my samples to extract ^{10}Be at the UVM Cosmogenic Laboratory. Samples were packed in targets for AMS analysis. In June 2011, I traveled to Livermore, CA with Paul Bierman and Kyle Nichols to obtain ^{10}Be measurements on Lawrence Livermore National Laboratory's accelerator mass spectrometer. In July 2011, I submitted an abstract to the Geological Society of America for their Annual Meeting. The abstract was accepted, so I will be presenting my research at the meeting in October 2011.

Initial Results

No significant (p<0.084) linear relationship was found between any of the parameters (elevation, slope and area) and erosion. However, this may change once land use and other criterion (as needed) are added to the analysis. Also, the dataset will increase in size to between 30 and 35 samples because some samples that were not included in my initial analysis will be added.

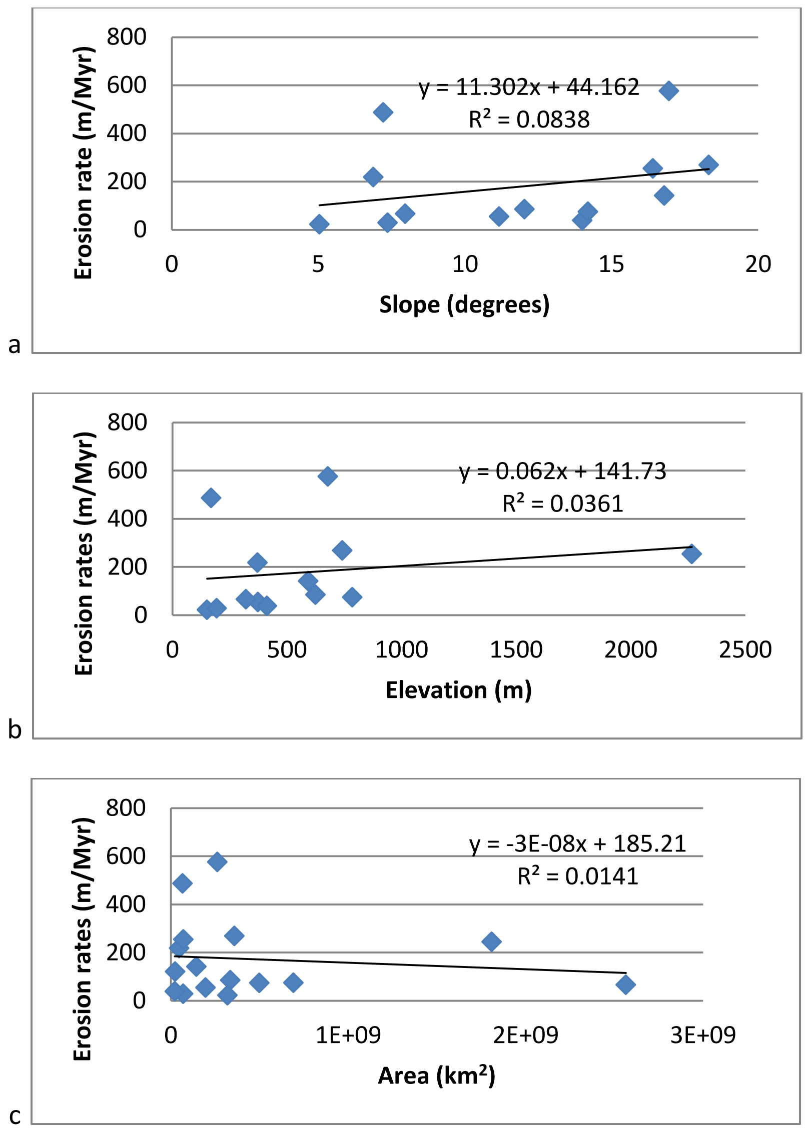

Figure 2: The relationship between erosion rates and slope (2a) was the strongest among the ones tested, even if it does not explain much variability in erosion rates. Elevation (2b) and Area (2c) do not show relationship with erosion rates.

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Timeline

Fall 2011	• Obtain land use information • Spatial and statistical analysis • Present at GSA Annual Meeting • Begin writing thesis
Spring 2012	• Finish writing thesis • Thesis defense

Facilities and Equipment

Quartz was isolated and purified in the Mineral Separation Laboratory. Samples were processed in the Cosmogenic Laboratory of the University of Vermont (www.uvm.edu/cosmolab)

^{10}Be concentrations were obtained using AMS at LLNL (https://st.llnl.gov/?q=research-unique_facilities-center_for_accelerator_mass_spectroscopy).

Budget and Budget Justification

Samples used for this research were paid by a grant to my Advisor. Funding for my stipend while at UVM was provided by a Graduate College Opportunity Fellowship.