COSMOGENIC ^{10}BE EROSION HISTORY OF THE BLUE RIDGE ESCARPMENT – A LONG-LIVED FEATURE OF THE SOUTHERN APPALACHAINS

A Thesis Progress Report Presented

by

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to

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1.0 ABSTRACT

Since completing my proposal, I have measured ^{10}Be concentrations and modeled erosion rates for 26 sediment samples from 8 streams on and near the Blue Ridge Escarpment in North Carolina and Virginia. All 26 samples analyzed so far contain significant ^{10}Be ($>10^5$ atoms/g) indicating that erosion rates are modest, ranging from 8.8-19.7 m/My in sand size fractions. Therefore, when my cosmogenic data are considered along with existing thermochronologic data, it appears that the majority of erosion that shaped the Blue Ridge escarpment occurred immediately following rifting, and since then, the escarpment has remained relatively stable. Only 1 of 6 samples shows any consistent relationship between grain size and ^{10}Be concentration strongly suggesting that, in this environment, all grain sizes of fluvial sediment are similarly dosed by cosmic rays. The erosion rates I have calculated are consistent with cosmogenic erosion rates found elsewhere in the southern Appalachians, and are generally consistent with thermocholologically derived erosion rates for areas near the Blue Ridge escarpment. I have completed the collection and processing of an additional 24 sediment samples and 3 bedrock samples; results should be available in late Fall 2006. I have completed the preparation of a GIS database that was used for sample site selection and will be used for spatial data interpretation.

2.0 INTRODUCTION

The Blue Ridge escarpment, located within the southern Appalachian Mountains of Virginia and North Carolina, forms a steep and distinct boundary between the less-rugged surfaces of the low-elevation Piedmont and higher-elevation Blue Ridge physiographic provinces (Figure 1). The escarpment is located within the southern Appalachian Mountains of Virginia and North Carolina, and forms the drainage divide between the Gulf of Mexico and the Atlantic Ocean (Dietrich, 1959; Spotila et al., 2004). This unique feature is located within a single lithology of schist and mica-rich gneiss and thus cannot be attributed to differences in bedrock erodability (Spotila et al., 2004). The Brevard Fault zone cross cuts the Blue Ridge escarpment, only coinciding with it for 50 to 60 km, deviating from the escarpment both to the northeast, where it is farther east in the Piedmont, and to the southwest, where it is within the Blue Ridge Mountains (Figure 2) (Hack, 1982; Roper and Justus, 1973).

While most researchers agree that passive margin escarpments are the result of rifting with morphology maintained by ongoing erosion, the rugged topography of the Blue Ridge escarpment and the antiquity of the passive margin of eastern North America have lead some to question the processes that have sustained this feature as a distinct landform over tens of millions of years (Dietrich, 1957; Hack, 1982; Matmon et al., 2002; Ollier, 1984; Pazzaglia and Gardner, 1994; Spotila et al., 2004). To investigate the recent geomorphic behavior of the Blue Ridge escarpment, I am using cosmogenic ^{10}Be, measured in stream-transported sediment, to estimate erosion rates on the scale of 10^4-10^5 years. These data build upon previous investigations that have attempted to explain the morphology and erosion of the Blue Ridge escarpment as well as its migration over time using other techniques, primarily thermochronology (Bank, 2002; Dietrich, 1957, 1959; Hack, 1982; Ollier, 1984; Pazzaglia and Gardner, 1994; Spotila et al., 2004).

Many other continental margins have similar escarpments, although none are quite as old as the Blue Ridge. Escarpments exist on nearly all continents, along active and recently rifted margins as well as along older margins (Matmon et al., 2002; Spotila et al., 2004). It is generally agreed that all escarpments are erosionally formed, although there are many hypotheses about how they evolve after formation (Spotila et al., 2004). Some favor the evolution of great escarpments from slow, irregular inland erosional retreat of the primary rift shoulder and drainage divide (Ollier, 1984; Spotila et al., 2004), with morphology maintained by erosion and consequent isostatic adjustment (Spotila et al., 2004). Others favor a model of rapid and significant erosion immediately following rifting, and subsequent stability of the resulting passive margin escarpment (Matmon et al., 2002).

3.0 PRIMARY OBJECTIVES

My primary objective is to answer the fundamental question of how quickly this part of the southern Appalachian landscape is changing over time. My data may suggest which, if either, of the existing theories cited above best describe the tempo of passive margin escarpment retreat over time (Matmon et al., 2002; Ollier, 1984; Spotila et al., 2004). I am addressing my objective by measuring ^{10}Be concentrations in stream sediment and calculating erosion rates in 32 basins spanning the escarpment. Bedrock erosion rates along the escarpment will be calculated by measuring ^{10}Be concentrations in three samples collected from outcropping bedrock. I have also considered the effects of sediment grain size on ^{10}Be concentrations in the humid, temperate southern Appalachian environment.

The results of my work can be compared with conclusions drawn from previous investigations of the evolution of the Blue Ridge escarpment (Davis, 1889; Hack, 1960; Spotila et al., 2004). I can also compare my results with cosmogenic studies that have taken place in nearby regions of the Appalachian Mountains (Matmon et al., 2003; Reuter, 2005) in order to determine how the Blue Ridge escarpment fits within the broader context of the behavior of the southern Appalachians. Finally, I can compare my results with findings from similar studies that have focused on other great escarpments of the world in order to quantify the processes that sustain such dramatic geomorphic features (Matmon et al., 2002; Ollier, 1984; Seidl et al., 1996; Summerfield et al., 1997).

4.0 SUMMARY OF COMPLETED WORK

4.1 Field Work: I have visited the Blue Ridge escarpment three times and I have collected sediment samples from a total of 32 stream basins and three bedrock outcrops

(Figure 2). Multiple grain size fractions (sand to cobbles) were collected from six basins to determine if grain size influences ^{10}Be concentrations in the southern Appalachian fluvial sediment. Sampled basins are located within four transects oriented normal to the escarpment, spanning all three physiographic provinces: the Blue Ridge, the Escarpment and the Piedmont (Figure 2). Basins were selected as a function of basin size, slope and physiographic province from a GIS database that I created for that purpose. Specific basin parameters are presented in Table 1.

4.2 Laboratory Work: I have purified quartz according to standard techniques (Bierman & Caffe, 2002) for all 53 of my collected samples (32 basins, 6 grain size splits, and 3 bedrock samples), and as of September, 24, 2006, Jennifer Larsen has isolated ^{10}Be from 26 of my samples (Figure 3) (8 basins and 6 grain size analyses from Transect C) in the cosmogenic laboratory at the University of Vermont. These same 26 samples were analyzed for ^{10}Be concentration in July 2006 at the Lawrence Livermore National Laboratory (LLNL), in Livermore California.

4.3 Data Analysis: Using measured nuclide activities of sand size fractions (n=8), I have normalized ^{10}Be concentrations using the altitude-latitude scaling function of Lal (1991) and modeled erosion rates using methods presented in Bierman and Steig (1996). I have applied a one-way analysis of variance (ANOVA) test to measured ^{10}Be concentrations with respect to different grain size fractions for the six basins sampled for this purpose.

5.0 Initial Results

All 26 samples analyzed so far contain significant ^{10}Be ($>10^5$ atoms/g) (Table 2). Considering the sand size fraction (250-800 μm), the mean erosion rate for the four analyzed basins in the Piedmont province is 11.0 +/-1.3 m/My (1σ). Piedmont basins that I sampled range from 1-21 km^2 in area with average slopes of 12-19°. The mean erosion rate for two basins in the Blue Ridge province is 9.8 +/-1.4 m/My (1σ), with basin sizes ranging from 2-4 km^2 and slopes of 8-9°. The mean erosion rate for two basins draining only the escarpment is 15.1 +/-6.5 m/My (1σ), with basin sizes ranging from 0.5-1 km^2 and slopes of 16-22°.

Sediment from 6 of these 8 basins was split into four grain-size fractions in order to investigate the relationship between sediment grain size and ^{10}Be concentration. Only 1 of these 6 samples (CS-01) shows any monotonic relationship between sediment grain size and ^{10}Be concentration (Figure 4, Table 2). Amalgamating the results for all grain sizes of all 6 samples, no statistically significant relationship exists between ^{10}Be concentrations and grain size fractions ($F_{3, 20}$=0.246, P=0.86).

6.0 Initial Interpretations

The lack of correlation between grain size and ^{10}Be concentration strongly suggests, in this environment, that all grain sizes are similarly dosed by cosmic rays. Brown et al. (1995) suggested that lower ^{10}Be concentrations in larger grain sizes could result from mass wasting events that excavate and carry coarse material rapidly down slope. There is neither field nor isotopic evidence indicating that mass wasting events such as landslides and debris flows are common in this part of the southern Appalachians, perhaps due to the heavily vegetated nature of the region. Matmon et al. (2003) suggested that the systematic difference in ^{10}Be concentrations between small and large grains in the Great Smoky Mountains results from source area elevation and clast transport distance. My results indicate that clast transport processes and exposure histories near the Blue Ridge escarpment are different than in the Great Smoky Mountains, since near the escarpment all grain sizes are similarly dosed by cosmic radiation.

The ^{10}Be concentrations measured in samples from the first 8 basins indicate that erosion rates on and near the Blue Ridge escarpment are modest. Generally the basins with the steepest slopes exhibit faster erosion rates than less steep basins (Figure 5). Based on this limited preliminary data, basin size seems to have little effect on erosion rates, and there is no discernable difference between provinces in terms of erosion rates.

The initial cosmogenic results for the Blue Ridge escarpment are consistent with cosmogenic erosion rates that have been modeled for the southern Appalachian Mountains (Figure 6) (Duxbury et al., 2006; Matmon et al., 2003; Reuter, 2005). Matmon et al. (2003) calculated spatially homogeneous erosion rates of 25-30 m/My throughout the Great Smoky Mountains in the Southern Appalachians using measured concentrations of cosmogenic ^{10}Be and ^{26}Al in quartz separated from alluvial sediment (Matmon et al., 2003). Reuter (2005) found erosion rates of 4-54 m/My in ^{10}Be concentrations of fluvial sediment samples from non-glaciated basins of the Susquehanna River of the Appalachian Highlands (Reuter, 2005). Duxbury et al. (2006) have inferred erosion rates ranging from 4.3-13.8 m/My for four fluvial sand samples in Shenandoah National Park (Duxbury et al., 2006).

Long and short-term geologic rates of erosion in the Blue Ridge province appear similar. ^{10}Be-determined rates of erosion integrated over 10^4-10^5 years (8.8-19.7 m/My in sand size fraction) are similar to those reported by Spotila et al. (2004), who used apatite (U-Th)/He dates to calculate long-term (10^8 years) erosion rates of 11-18 m/My across the escarpment from the Blue Ridge toward the inner Piedmont. In contrast to Spotila's findings, we do not find cosmogenic evidence for a rapidly eroding inner Piedmont. Based on the similarity of the U/He and cosmogenically-based erosion rates, it seems that the majority of erosion that shaped the Blue Ridge escarpment occurred immediately following rifting, and since then, this feature has remained relatively stable, eroding only a few tens of m/My over both the 10^8 and 10^5 year time scales.

7.0 Work Remaining

27 samples are currently in the cosmogenic lab undergoing ^{10}Be extraction and awaiting analysis by accelerator mass spectroscopy. Paul Bierman and I are planning to visit LLNL this November to measure ^{10}Be nuclide activity in all remaining samples. I will then model erosion rates for these samples.

Once I have erosion rate data for all 53 samples, I will be able to more rigorously test and consider patterns of erosion spatially. With the exception of the bedrock samples, results will be analyzed as two distinct populations: (1) erosion rates confined within the four distinct escarpment-normal transects, and (2) erosion rates extrapolated to the escarpment scale, based on escarpment-parallel transects. Sampling site distance from the escarpment will be evaluated along with the relative position of the nearby Brevard fault zone (Figure 2). I will apply several methods of inferential statistics, such as independent sample t-tests, one-way ANOVA tests, and multiple linear regression analyses, in order to test the significance of erosion rates within both populations as a function of basin size, slope, and sample media (sediment or bedrock). Conclusions drawn from ^{10}Be results and inferred erosion rates will then be analyzed in the context of: (1) other erosional studies of the Blue Ridge escarpment, (2) other such studies in the southern Appalachians, and (3) erosional models that have been applied to other great escarpments.

Findings from these data will be submitted to a special issue of the peer-reviewed journal *Earth Surface Processes and Landforms* dedicated to the evolution of passive margins. My results will contribute to the understanding of the long-term landscape evolution of passive margins given the antiquity of the Blue Ridge escarpment when compared with other such landforms.

8.0 TIMELINE

Work Completed To Date:

December 2005: Visited field area and sampled 8 basins along Transect C (26 samples with grain size splits)
January 2006: Etching and mineral separation of initial 26 samples
March 2006: Visited field area and sampled 7 basins along Transect A
April 2006: Defended MS thesis proposal
May 2006: Completed GIS database and prepared field sampling plan
June 2006: Completed all field sampling
July 2006: Received ^{10}Be data from Livermore for initial samples and submitted GSA abstract for Philadelphia national meeting
August 2006: Completed all quartz making and sample preparation
September 2006: Wrote progress report and continued sample clean up

Work Remaining

<u>Fall 2006:</u>
Submit draft abstract to special issue of *Earth Surface Processes and Landforms*
Present poster at GSA annual meeting
Present progress report
^{10}Be data collection at Livermore National Laboratory
Begin writing thesis
<u>Winter 2007:</u>
Analyze all ^{10}Be data
Submit paper to *Earth Surface Processes and Landforms*
<u>Spring 2007:</u>
Complete thesis, defend and complete edits
Submit additional paper(s) for publication
<u>Fall 2007</u>
Present at GSA annual meeting

9.0 FIGURES

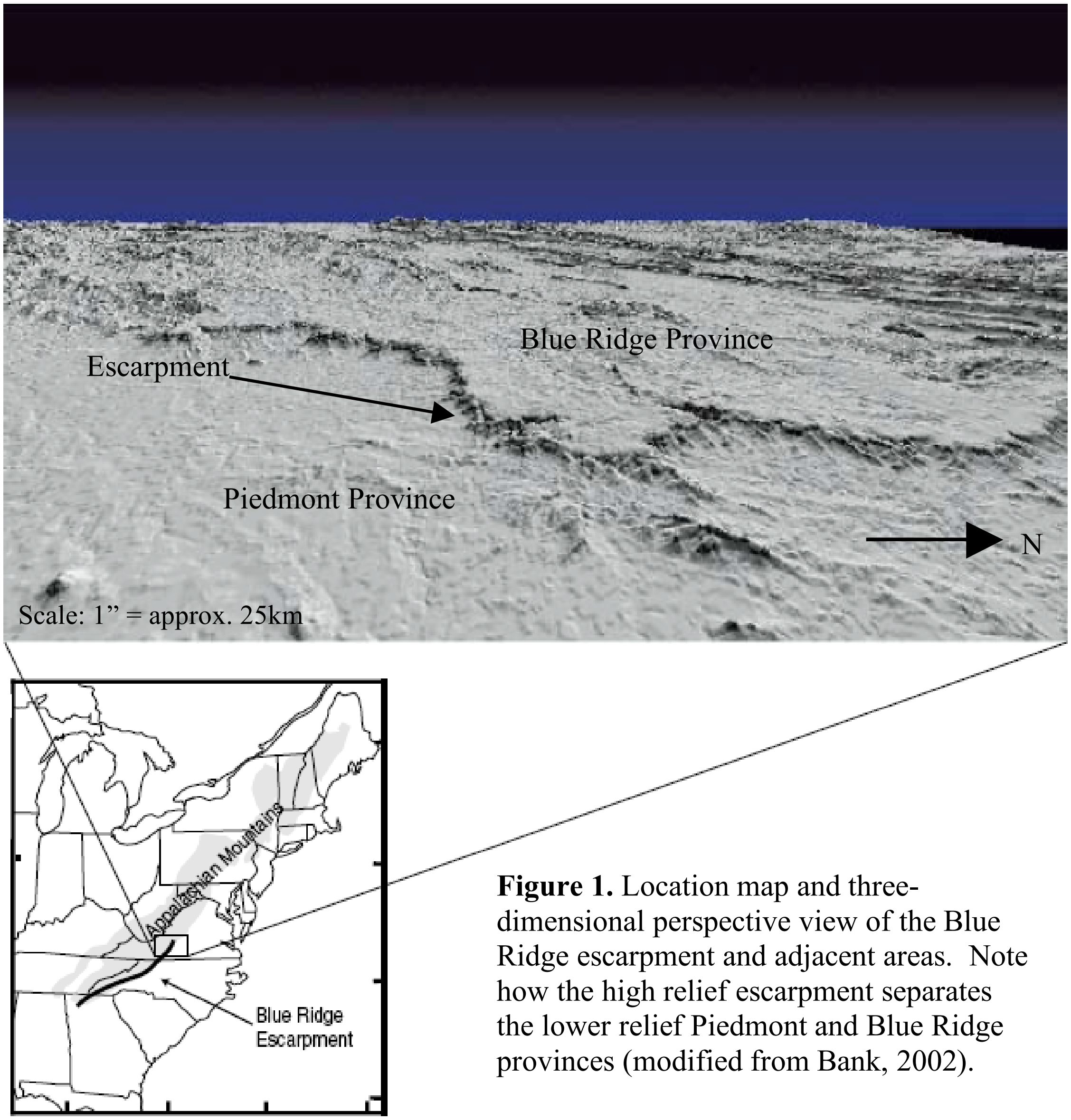

Figure 1. Location map and three-dimensional perspective view of the Blue Ridge escarpment and adjacent areas. Note how the high relief escarpment separates the lower relief Piedmont and Blue Ridge provinces (modified from Bank, 2002).

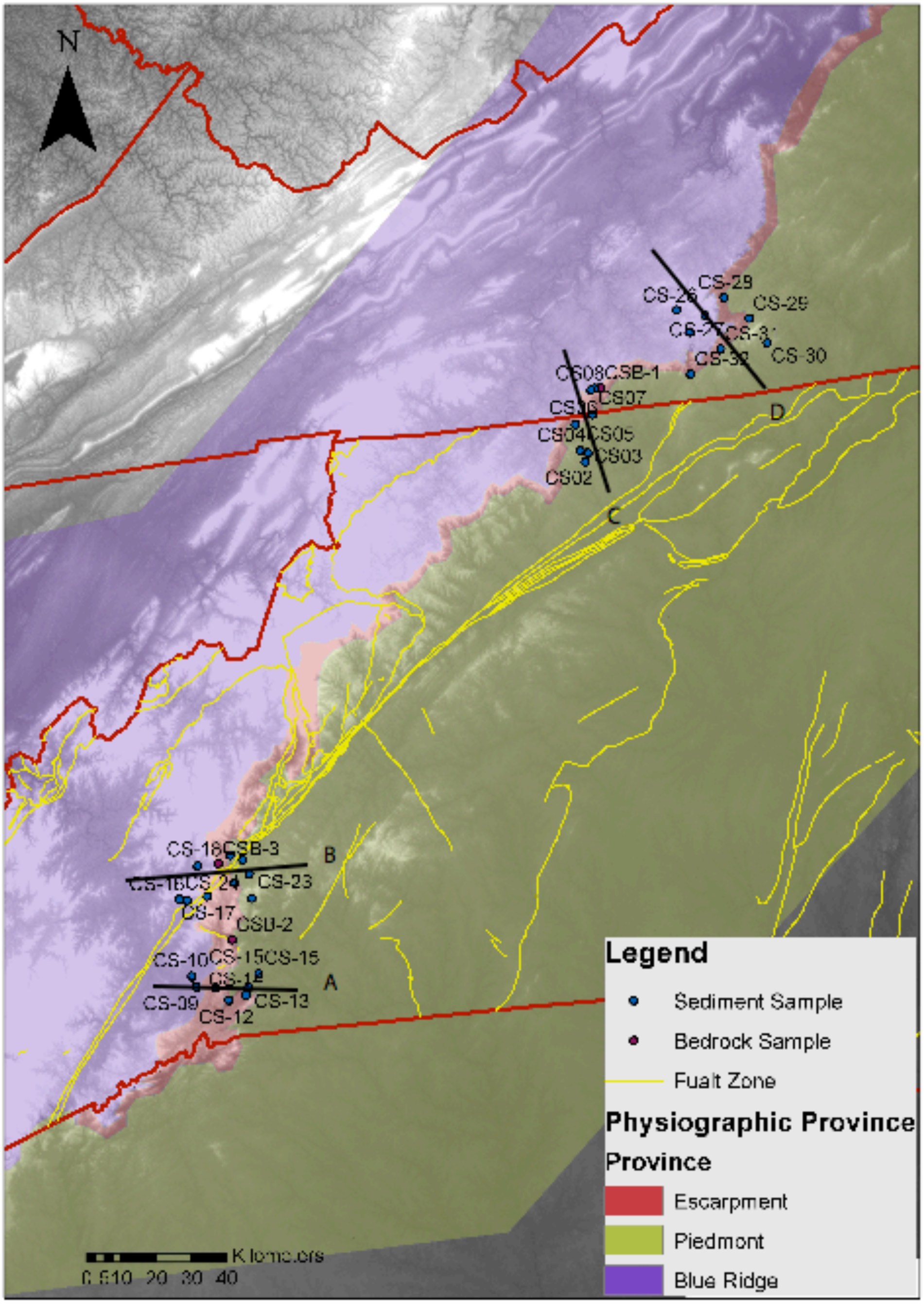

Figure 2: Location map showing provinces, sampling transects, sample sites and Brevard fault zone.

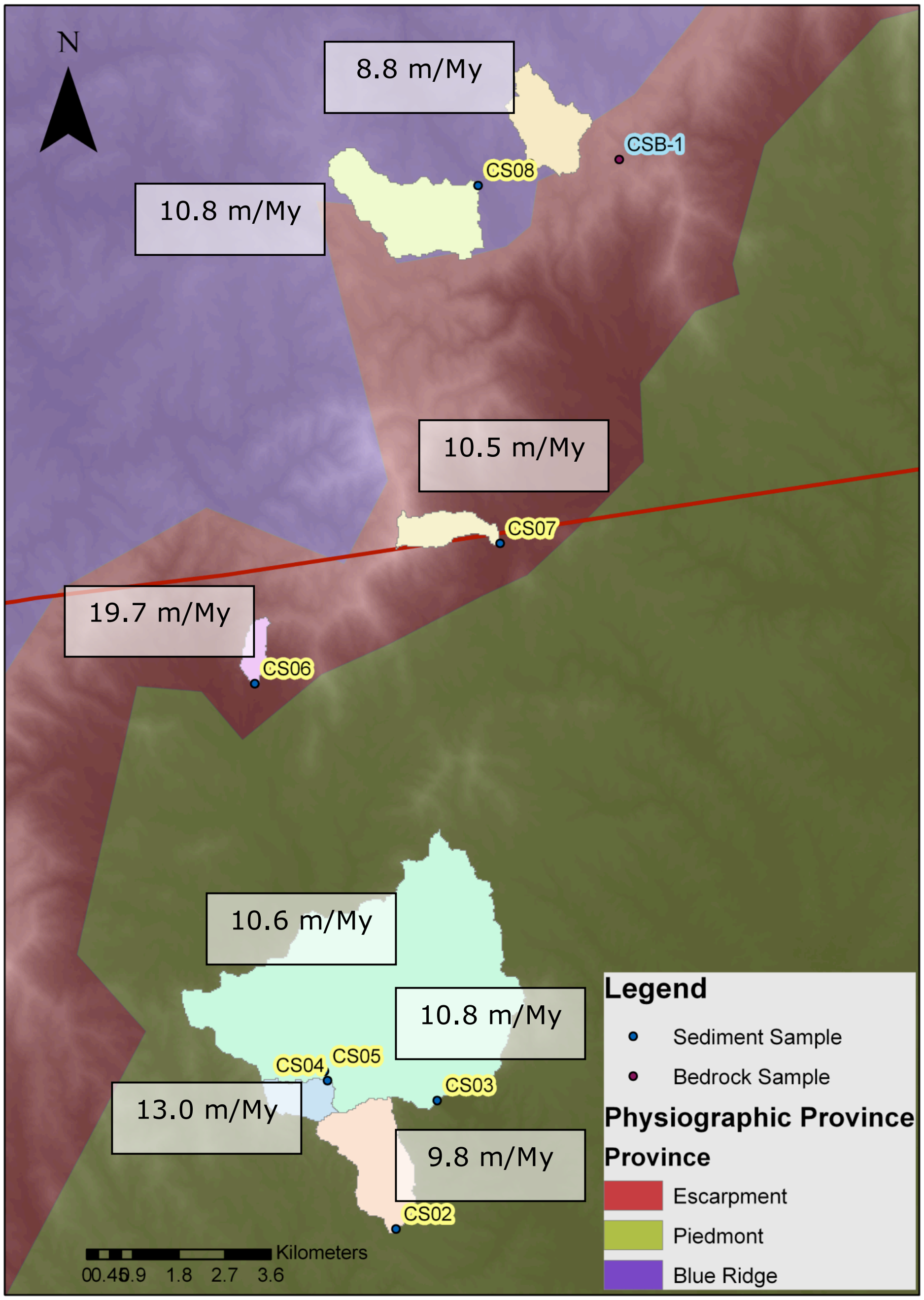

Figure 3: Transect C map of delineated basins and sample locations with modeled erosion rates (sand sized fraction only).

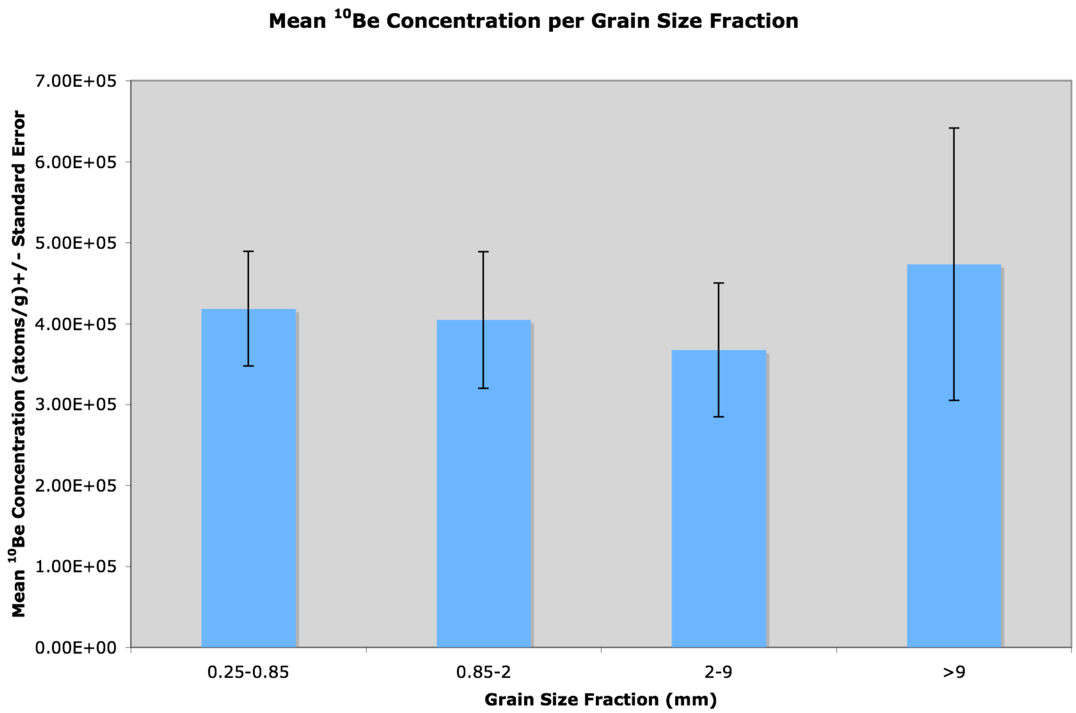

Figure 4: Graph of mean ^{10}Be concentrations for each grain size fraction +/- standard error ($F_{3,20}$=0.246, P=0.86, n=4).

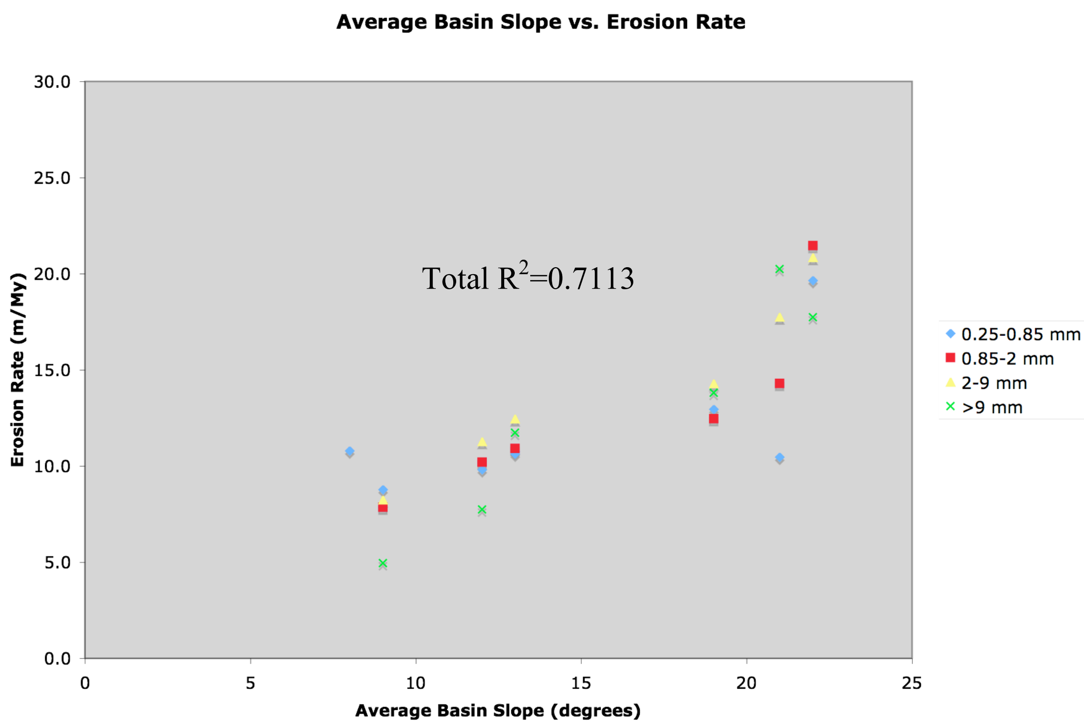

Figure 5: Plot of average basin slope vs. ^{10}Be erosion rates for all samples including grain size splits (size fractions designated ◆=0.25-0.85 mm, ■=0.85-2 mm, ▲=2-9 mm, ✕=>9 mm).

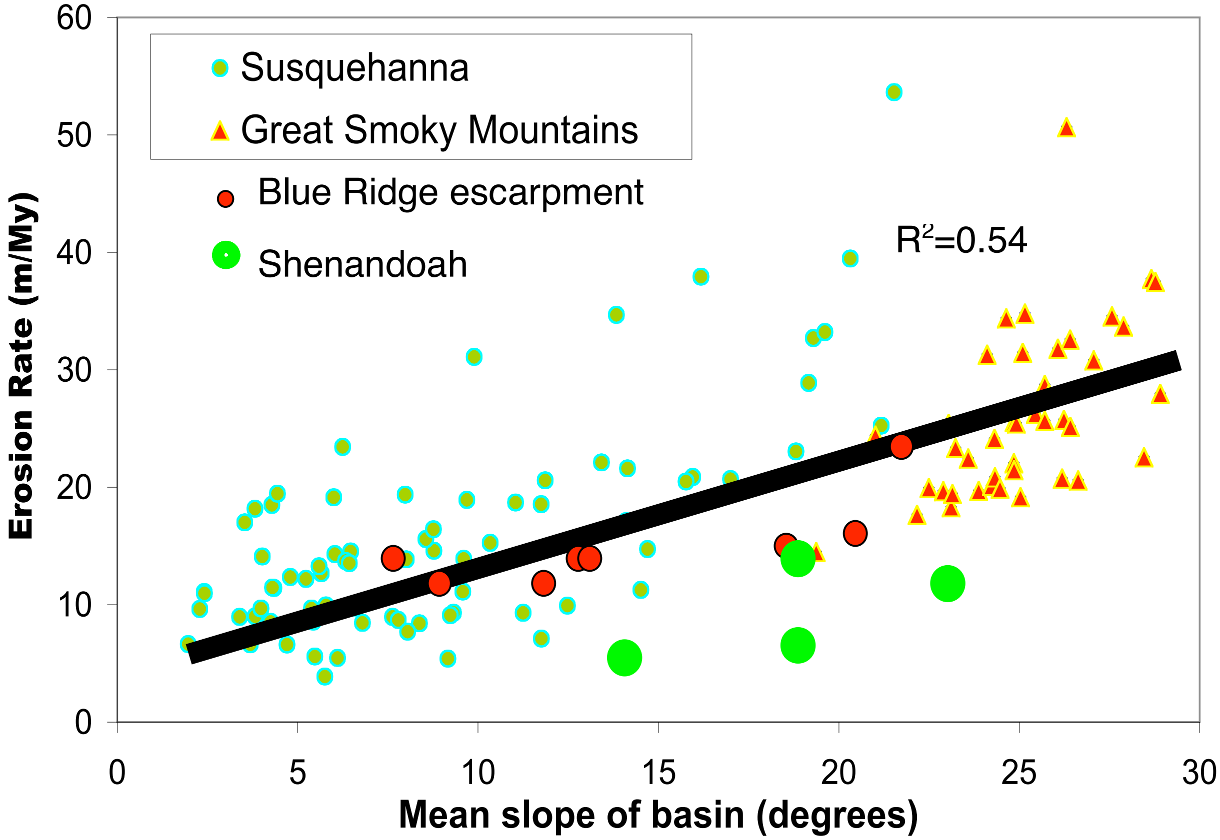

Figure 6: Plot of average basin slope vs. ^{10}Be erosion rates for all available Appalachian data (Susquehanna from Reuter, 2005; Great Smoky Mountains from Matmon et al., 2003, Blue Ridge from my data; Shenandoah from Duxbury et al., 2006).

10.0 TABLES

Table 1: Summary table of sampled basin parameters.

Sample ID	Province	Area (km^2)	Mean elevation (m)	Slope (°)
Transect A				
CS-09	Blue Ridge	4	678	11
CS-10	Blue Ridge	0.6	707	4
CS-11	Escarpment	18	786	15
CS-12	Escarpment	5	613	20.5
CS-13	Piedmont	3	377	10
CS-14	Piedmont	0.7	564	22
CS-15	Piedmont	18	443	12.5
Transect B				
CS-16	Blue Ridge	11	867	18.5
CS-17	Escarpment	7.6	1010	23
CS-18	Blue Ridge	3.6	796	13
CS-19	Escarpment	7	692	24
CS-20	Piedmont	35	663	19
CS-21	Piedmont	46	578	15
CS-22	Escarpment	10.6	698	19
CS-23	Piedmont	4.5	662	18.5
CS-24	Blue Ridge	5.3	1034	21
Transect C				
CS-01	Blue Ridge	2	860	9
CS-02	Piedmont	3	468	12
CS-03	Piedmont	21	430	13
CS-04	Piedmont	1	487	19
CS-05	Piedmont	21	430	13
CS-06	Escarpment	0.5	593	22
CS-07	Escarpment	1	710	21
CS-08	Blue Ridge	4	854	8
Transect D				
CS-25	Blue Ridge	5	896	10
CS-26	Blue Ridge	5	911	15
CS-27	Blue Ridge	9	945	10
CS-28	Escarpment	6	606	19
CS-29	Piedmont	5	596	21
CS-30	Piedmont	4.5	418	9
CS-31	Escarpment	5.5	671	23
CS-32	Escarpment	10	540	24
Bedrock				
CSB-1	Escarpment		400	
CSB-2	Escarpment		785	
CSB-3	Escarpment		949	

Table 2: Results of analyzed samples.

Sample ID	Grain Size fraction	mean elevation	Latitude	^{10}Be model erosion rate	^{10}Be concentration
	(mm)	(km)		(m My-1)	(atoms/g)
CS-01	.25-.85	0.86	37	8.8	6.50E+05
	.85-2	0.86	37	7.9	7.23E+05
	2-9	0.86	37	8.3	6.90E+05
	>9	0.86	37	4.9	1.13E+06
CS-02	.25-.85	0.468	37	9.8	4.26E+05
	.85-2	0.468	37	10.2	4.10E+05
	2-9	0.468	37	11.3	3.72E+05
	>9	0.468	37	7.7	5.36E+05
CS-03	.25-.85	0.43	37	10.8	3.78E+05
	.85-2	0.43	37	10.9	3.73E+05
	2-9	0.43	37	12.5	3.27E+05
	>9	0.43	37	11.7	3.47E+05
CS-04	.25-.85	0.487	37	13.0	3.30E+05
	.85-2	0.487	37	12.5	3.43E+05
	2-9	0.487	37	14.3	3.00E+05
	>9	0.487	37	13.8	3.10E+05
CS-05	.25-.85	0.43	37	10.6	3.82E+05
CS-06	.25-.85	0.593	37	19.7	2.39E+05
	.85-2	0.593	37	21.5	2.19E+05
	2-9	0.593	37	20.9	2.25E+05
	>9	0.593	37	17.7	2.64E+05
CS-07	.25-.85	0.71	37	10.5	4.87E+05
	.85-2	0.71	37	14.3	3.59E+05
	2-9	0.71	37	17.8	2.90E+05
	>9	0.71	37	20.2	2.55E+05
CS-08	.25-.85	0.854	37	10.8	5.29E+05

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