$^{10}$BE EROSION RATES AND LANDSCAPE EVOLUTION OF THE BLUE RIDGE ESCARPMENT, SOUTHERN APPALACHIAN MOUNTAINS

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Outline

• Objectives
• Background
• Methods
• Results
• Interpretations
• Conclusions
Objectives

• to determine whether grain size influences $^{10}$Be concentration in fluvial sediment on and near the Blue Ridge escarpment (BRE);
• to quantify basin-scale $^{10}$Be erosion rates for the BRE and the surrounding provinces;
• to test for relationships between $^{10}$Be erosion rates and specific landscape characteristics;
• to determine whether the BRE has evolved according to a model of ongoing & parallel retreat or by a model of rapid erosion following rifting and subsequent landscape stability.
Appalachian Mountains

- Paleozoic orogenic events created rugged mountain range
- Erosion during the Permian and Triassic
- Continental rifting and rift margin uplift in the Mesozoic (origin of BRE from rift fault)
- Followed by denudation and isostatic compensation
The southern Appalachian Mountains

Mesozoic Rift Basins

Escarpment

Blue Ridge

Piedmont
The Blue Ridge Escarpment

- Distinct boundary between less rugged Blue Ridge and Piedmont
- >450 km long
- Can be >500 m high
- Slopes up to 20-30°
- Asymmetric drainage divide
- Generally within lithology of micaceous schist and gneiss; thus morphology cannot be attributed to differences in bedrock erodability
- Oriented SW-NE
- Extends ~600 km from AL to VA
- Activated during all Appalachian orogenies, well before the rifting events that formed the BRE
- The BFZ only coincides with the BRE for 50-60 km
Great escarpments

The Earth today.
Escarpment evolution

A) Ongoing & steady retreat

B) Significant retreat following rifting, then stability
What is $^{10}\text{Be}$?

- $^{10}\text{Be}$ accumulates within rock that becomes sediment as it approaches surface.
- Time scale of $10^4$-$10^5$ years.
Inferring erosion rates with $^{10}\text{Be}$

- Rivers mix sediment moving out of drainage basins, thus the concentration of $^{10}\text{Be}$ in fluvial sediment indicates sediment production rates on basin hillslopes.
- Cosmic ray dosing as bedrock is exposed can be used to model bedrock lowering rates.
Assumptions

- Well mixed sediment
- No inheritance from prior period of near-surface irradiation
- Sediment transport and production are in steady state
Basin Selection

• Selected basins based on:
  – size
  – slope
  – province

• I used a GIS database to select basins for Transects B & D

• Manually selected basins from topo maps for Transects A & C
Field methods

• Collected fluvial sediment from 32 basins:
  – Transects B & D field sieved (0.25-0.85 mm)
  – Transects A & C collected mixed grain sizes and sieved in the lab

• Collected 3 bedrock samples from escarpment
Lab methods

• Purified quartz for 53 samples:
  – 32 basins
  – 6 grain size splits
  – 3 bedrock

• Jennifer Larsen isolated $^{10}$Be from all samples
AMS at Lawrence Livermore National Laboratory

Photo: https://cams.llnl.gov/aboutus.php
Objective

• to determine whether grain size influences $^{10}$Be concentration in fluvial sediment on and near the BRE;
• Brown et al. (1995) suggested that lower $^{10}$Be concentrations in larger grain sizes could result from mass wasting events that excavate and carry previously shielded coarse material rapidly down slope.

• 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.
Grain Size Doesn’t Matter for the Blue Ridge escarpment

- 4 samples largest grain size has most $^{10}\text{Be}$;
- 1 sample from the escarpment has a monotonic decrease in $^{10}\text{Be}$ with increasing grain size. Escarpment is most likely to be affected by debris flows due to steep slopes, high relief, and precipitation;
- Differences from Matmon (2003) may be due to varying lithologic properties of study areas.
Objective

- to quantify basin-scale $^{10}$Be erosion rates for the BRE and the surrounding provinces;
Bedrock samples

• Heavy vegetation in June
• 3 sample sites along escarpment
• Highly variable results
  – CSB-1 (gneiss) 56.8 m My$^{-1}$
  – CSB-2 (gneiss) 1.7 m My$^{-1}$
  – CSB-3 (mica schist) 17.4 m My$^{-1}$
• Lack of natural amalgamation
Erosion rates are slow! Consider that Wobus et al. (2005) measured 180-770 m My$^{-1}$ in the central Nepalese Himalaya.
Objective

• to test for relationships between $^{10}\text{Be}$ erosion rates and specific landscape characteristics;
Basin size is not significant
Physiographic province shows slight relationship with erosion, not statistically separable.
Basin slope is significant

Average Basin Erosion Rate (m My⁻¹) vs. Average Basin Slope (degrees)

erosion = 0.821 * slope + 2.324
R² = 0.9994

erosion = 0.912 * slope + 0.782
R² = 0.41

Blue Ridge
Escarpmment
Piedmont
Used GIS to assess average basin slope for the entire population of basins

<table>
<thead>
<tr>
<th>Region</th>
<th>Population Slope</th>
<th>Sample Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Ridge</td>
<td>12.8° n=968</td>
<td>12.0° n=10</td>
</tr>
<tr>
<td>Escarpment</td>
<td>17.7° n=428</td>
<td>21.7° n=7</td>
</tr>
<tr>
<td>Piedmont</td>
<td>9.0° n=738</td>
<td>15.3° n=12</td>
</tr>
<tr>
<td>Mean</td>
<td>5.6 km²</td>
<td>8.1 km²</td>
</tr>
<tr>
<td>Median</td>
<td>4.6 km²</td>
<td>5.0 km²</td>
</tr>
</tbody>
</table>
Probability Density Function

Cumulative Probability vs. Average Basin Slope (degrees)

- **Piedmont** (diamonds)
- **Escarment** (squares)
- **Blue Ridge** (triangles)

Inset histograms show the distribution of slope values for each region.

Slope values range from 0 to 30 degrees.
How can I model representative erosion rates?

- Erosion rate is dependant on slope:
  - Erosion rate = \( ^\circ \text{slope} \times (0.912) + 0.78 \)

- I calculated a model erosion rate for each province based on the average basin slope of the population.
Integrated Model
Erosion Rates

Blue Ridge (n=968)
12.5 m My⁻¹

Escarpment (n=428)
17.1 m My⁻¹
20.1 ± 6.6 m My⁻¹

Piedmont (n=738)
9.7 m My⁻¹
15.0 ± 9.0 m My⁻¹

(n=10)
12.2 ± 6.3 m My⁻¹
Objective

- to determine whether the BRE has evolved according to a model of ongoing & parallel retreat or by a model of rapid erosion following rifting and subsequent landscape stability.
Comparing Cosmogenic and Thermochronologic Erosion Rates

• $^{10}$Be erosion rates are integrated over $10^4$-$10^5$ years
• Thermochronologic erosion rates are integrated over $10^8$ years.
• Erosion Rate = Depth (integrated geothermal gradient and closure temp)/Age (U-Th)/He or # fission tracks.
  – AHE- (U-Th)/He closure temp 40-90°C
  – AFT- fission tracks closure temp 60-110°C
Thermochronologic data consistent with Cosmogenic data

Both datasets are relatively slow
• Base level for the escarpment is set by the Piedmont therefore the difference in lowering rates can be taken as the retreat rate
• Piedmont is eroding more slowly than the Blue Ridge therefore relief is decreasing
• Using calculated retreat rate (~7 m My\(^{-1}\)), total escarpment retreat distance would be ~1.4 km over 200 Ma at constant pace.
• Nearest possible rift boundary fault is ~35 km to the east.
• Retreat and erosion must have been faster at some point between rifting and thermo time span (10\(^8\) years).
Ongoing & steady retreat

Significant retreat following rifting, then stability
Other escarpments

• These results agree with studies from other passive margin escarpments such as:
  – Namibia (Bierman and Caffee, 2001; Brown et al., 2000)
  – South Africa (Fleming et al., 1999; Summerfield et al., 1997)
  – Southeastern Australia (Heimsath et al., 2006; Persano et al., 2002)
  – Sri Lanka (Vanacker et al., 2007)
Conclusions

• Grain size does not affect $^{10}$Be concentration on and near the BRE
• Overall the BRE is lowering and retreating very slowly
• Average slope is the only basin characteristic that influences erosion on and near the BRE
• The BRE appears to have evolved through a period of significant and rapid erosion immediately following rifting and has remained a fairly stable feature of the landscape since that time.
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Cosmogenic isotope production with depth

\[ P_x = P_0 e^{-\left(\frac{x \rho}{\Lambda}\right)} \]

Variables:
- \( P_x \): nuclide production rate at depth \( x \)
- \( P_0 \): sediment production rate (5.17 atoms g\(^{-1}\) y\(^{-1}\))
- \( \rho \): density of material (2.7 g cm\(^{-3}\) for rock)
- \( \Lambda \): attenuation factor (165 g cm\(^{-2}\))
Erosion rate calcs...

\[
m/\rho = \varepsilon = \Lambda (P - N) / \rho N
\]

Variables:
\( \varepsilon \) = erosion rate
\( P \) = basin effective production rate
\( \rho \) = density of material (2.7 g cm\(^{-3}\) for rock)
\( \Lambda \) = attenuation factor (165 g cm\(^{-2}\))