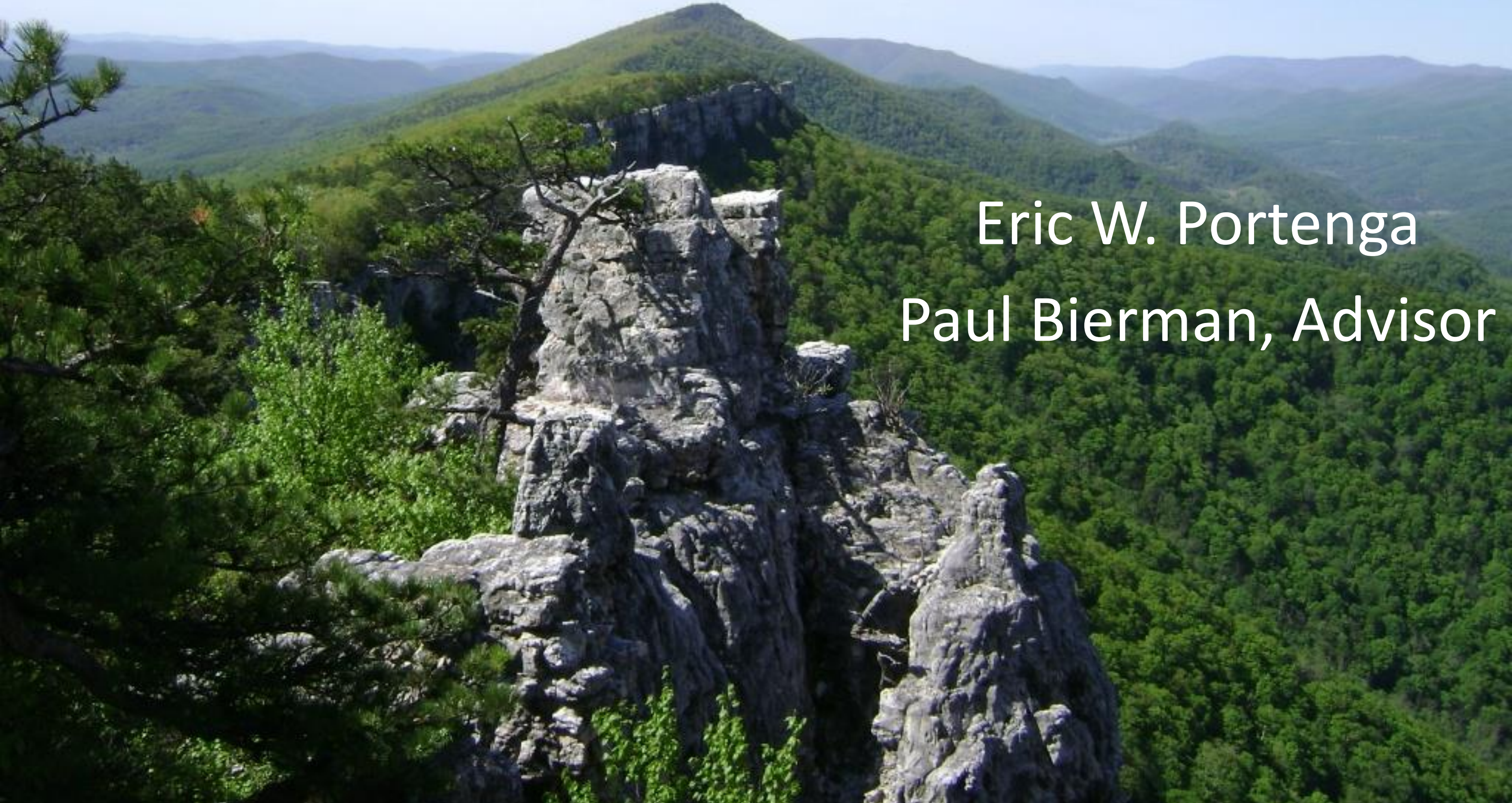
Using ^{10}Be to constrain erosion rates of bedrock outcrops, globally and in the Appalachian Mountains



Eric W. Portenga

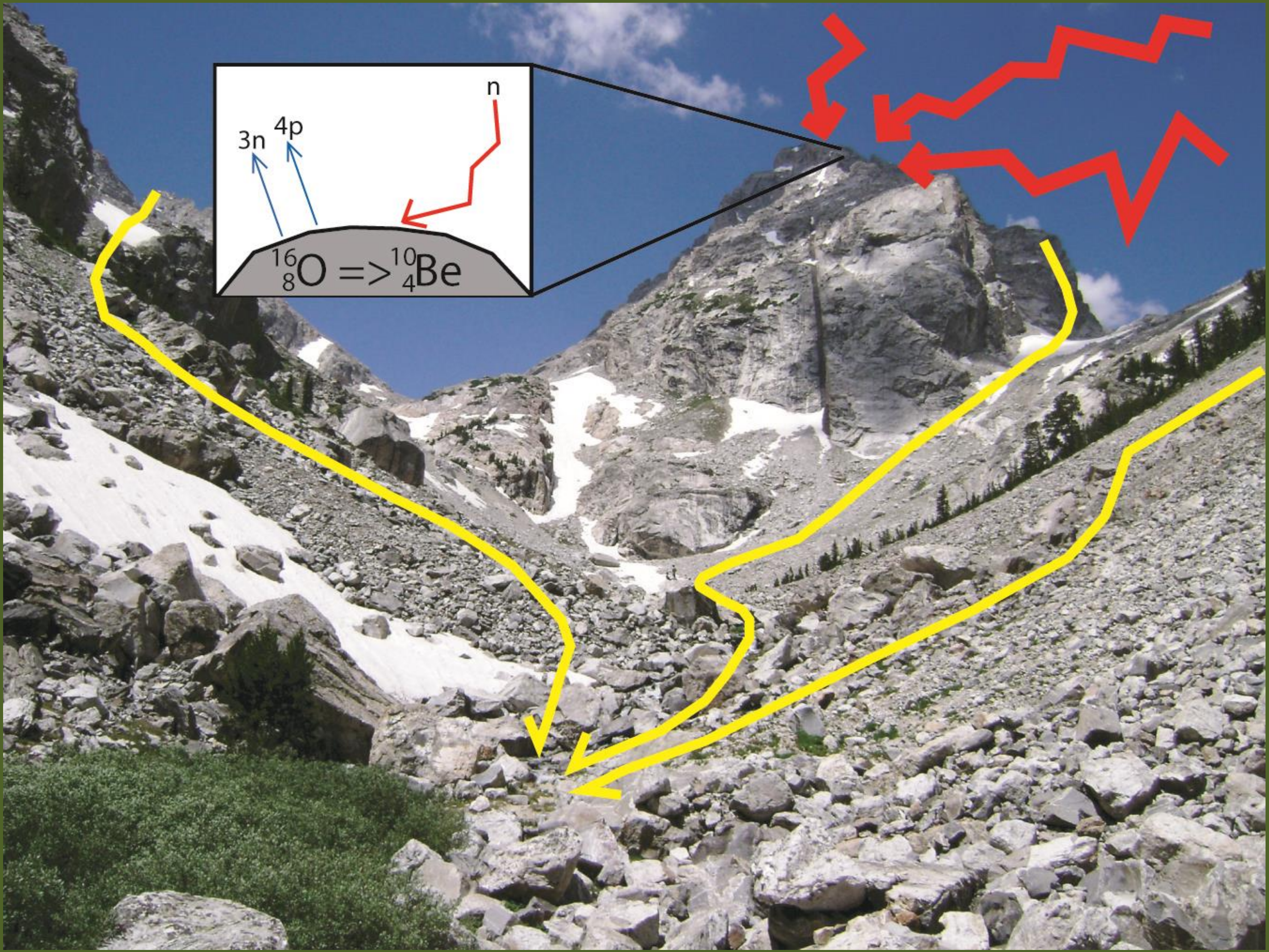
Paul Bierman, Advisor

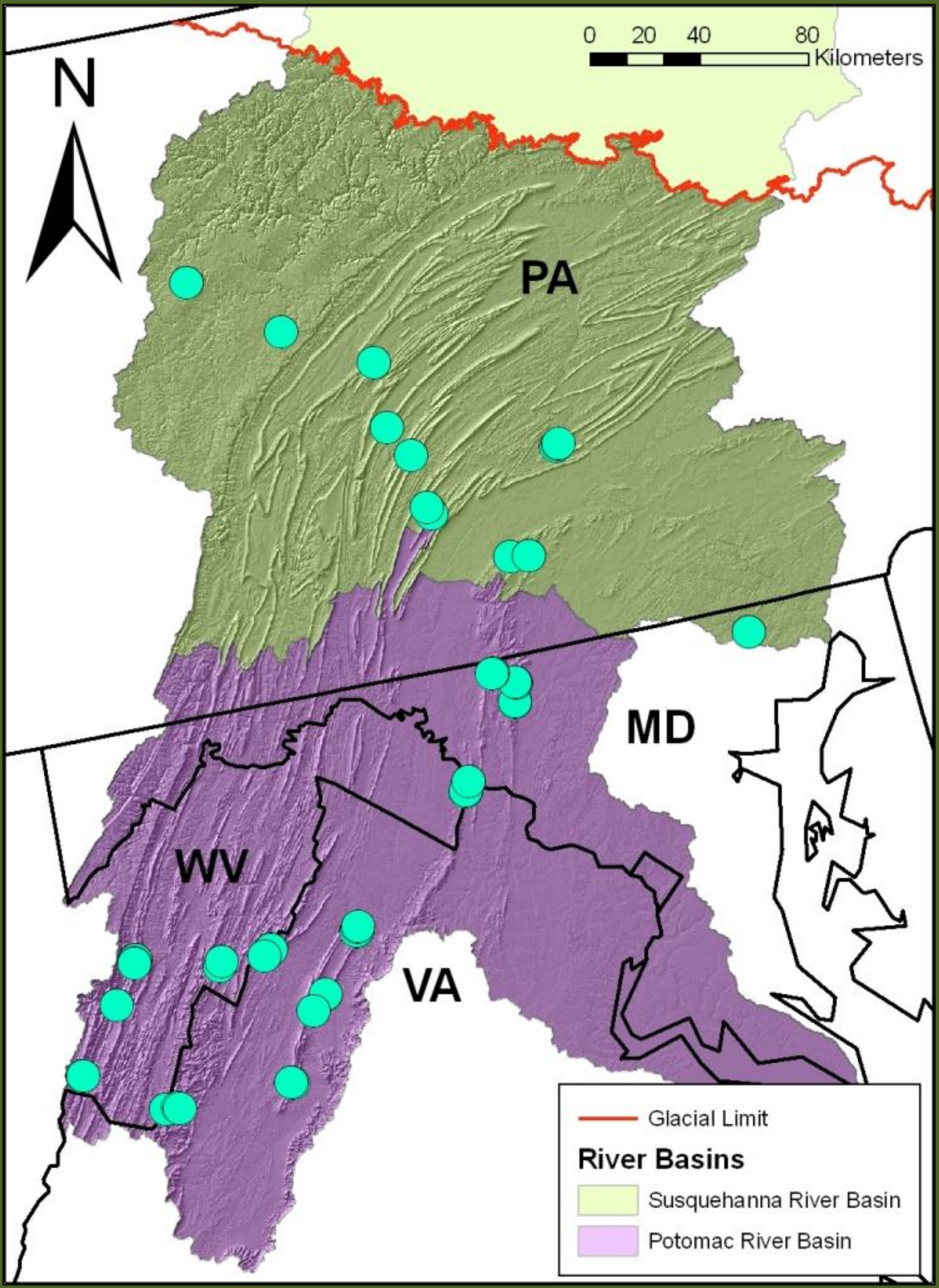
Outline

- Why bedrock?
- Work completed
  - Field work
  - Lab work
  - Global ^{10}Be erosion rate dataset compilation
- Initial results
  - Statistical analyses of global compilation
- Work to be done
  - Global compilation
  - Appalachian Sample lab work

Bedrock Erosion Rates

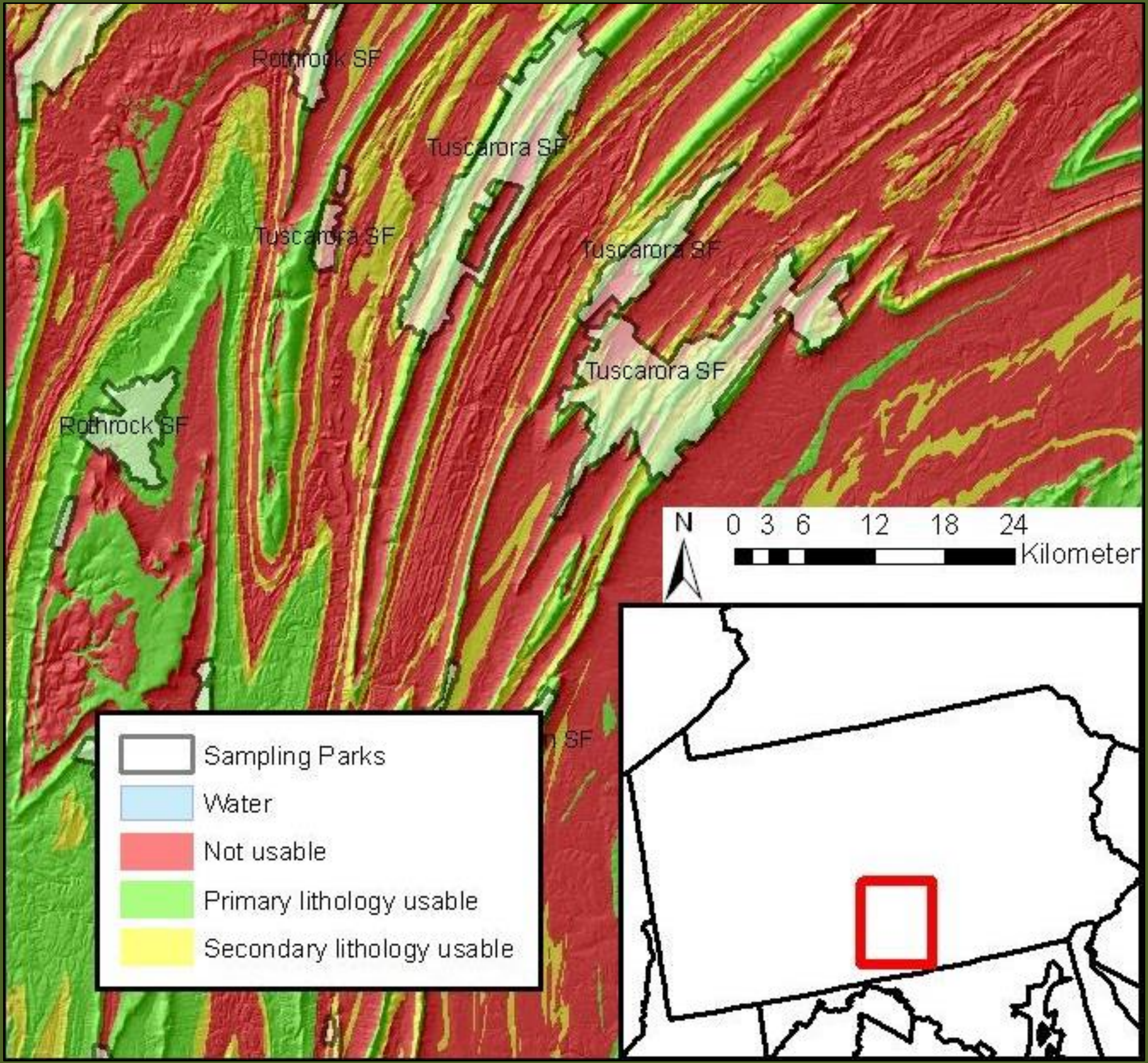
- Little is known about erosion rates
  - Slow → difficult to constrain
  - Focal point of few studies (focus on basin-averaged erosion rates)
- Ubiquitous features of landscapes, globally
- Sets the pace of landscape change


n
3n
4p
$^{16}_{8}O \Rightarrow ^{10}_{4}Be$



Field Work

- River basins in central Appalachian Mtns. studied with ^{10}Be on basin-scale
  - Potomac (n=48; Trodick/Duxbury)
  - Susquehanna (n=26; Reuter)
- Samples from 30 sites
- Multiple samples per site to study variance
- Unglaciated ridges outside glacial margin


Rothrock SF
Tuscarora SF
Tuscarora SF
Tuscarora SF
Tuscarora SF
Rothrock SF
n SF
N
0 3 6 12 18 24
Kilometer
Sampling Parks
Water
Not usable
Primary lithology usable
Secondary lithology usable

Work Completed: Lab Work

- Rock Room – produce monomineralic grains
  - Crush/Grind
  - Sieve (<250µm, 250-850µm, >850µm)
  - 250-850µm fraction magnetically separated
- Mineral Separation Lab – remove non-quartz minerals
  - 24hr etch in 6N HCl (2x – or 3x if needed)
  - 24hr etch in 1% HF/HNO_3 (3x)
  - Heavy-liquid density separation
  - 36hr etch in 0.5% HF/HNO_3
  - Week-long etch in 0.5% HF/HNO_3
- Meteoric Beryllium Lab – test quartz purity
  - 0.250g aliquot of each sample digested in HF/H_2SO_4
  - HF evaporates overnight
  - Bring up H_2SO_4 to 1%
  - Run on ICP-OES

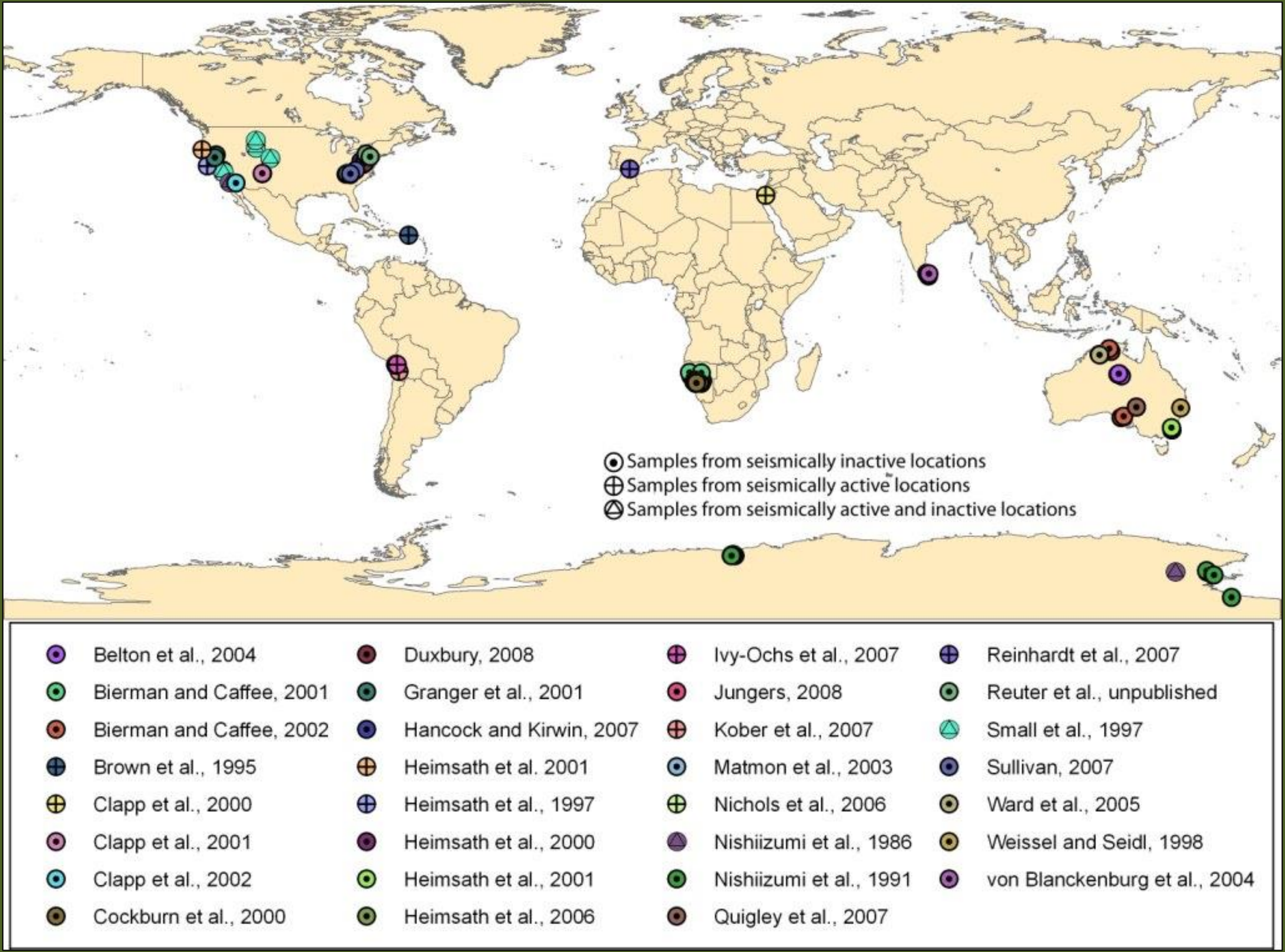
Work to be Done: Appalachian Sample Laboratory Work

- 66 samples have passed quartz purity tests
  - 6 samples in week-long 0.5% HF/HNO_3 etch
  - Will be tested once more
- *In-situ* Laboratory
  - Sample Digestion
  - Cation/Anion exchange columns
- Overall, 66 samples will be prepared for AMS at Lawrence Livermore National Laboratory

Work Completed

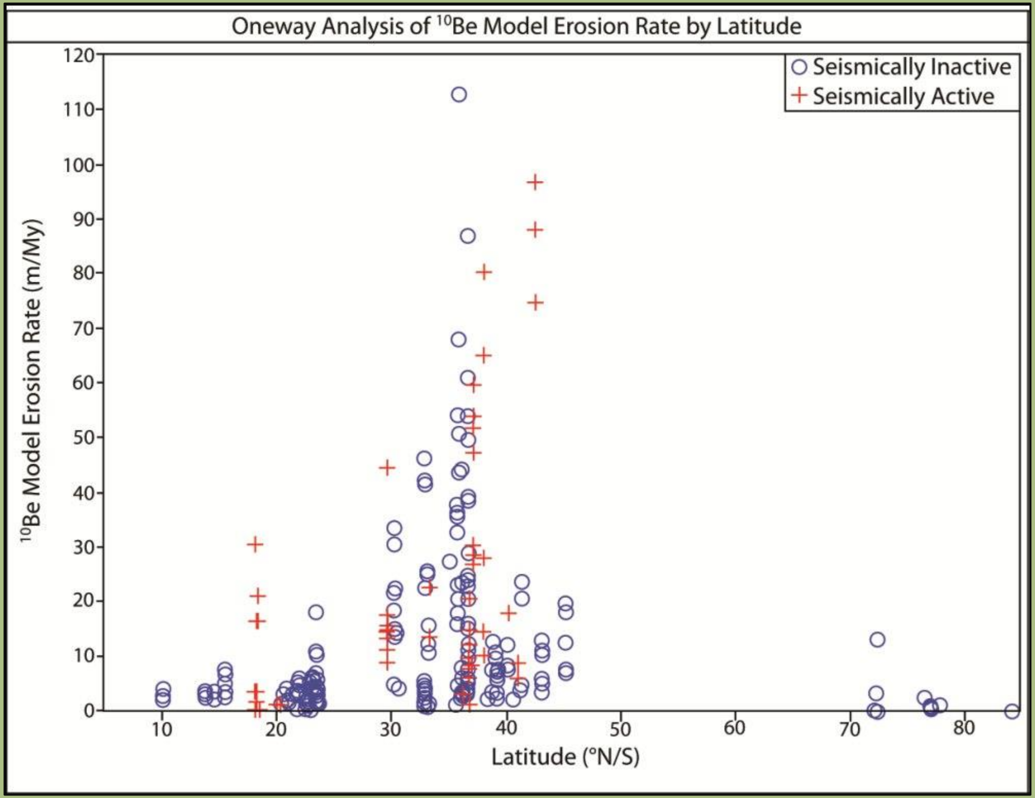
- Global ^{10}Be erosion rate compilation
  - Data from 31 sources
    - Raw ^{10}Be concentrations
    - Lithology
  - Global datasets

Variable	Dataset
Elevation	Gtopo_30: provided by ESRI Software at University of Vermont
Local Relief	Same as Elevation
Peak Ground Acceleration	Global Seismic Hazard Assessment Program (Giardini et al., 1999)*
Climate Zone	Köppen-Geiger Climate System (Peel et al., 2007)
Mean Annual Precipitation	WorldClim Climate Model (Hijmans et al., 2005) †
Mean Annual Temperature	Same as Mean Annual Precipitation†

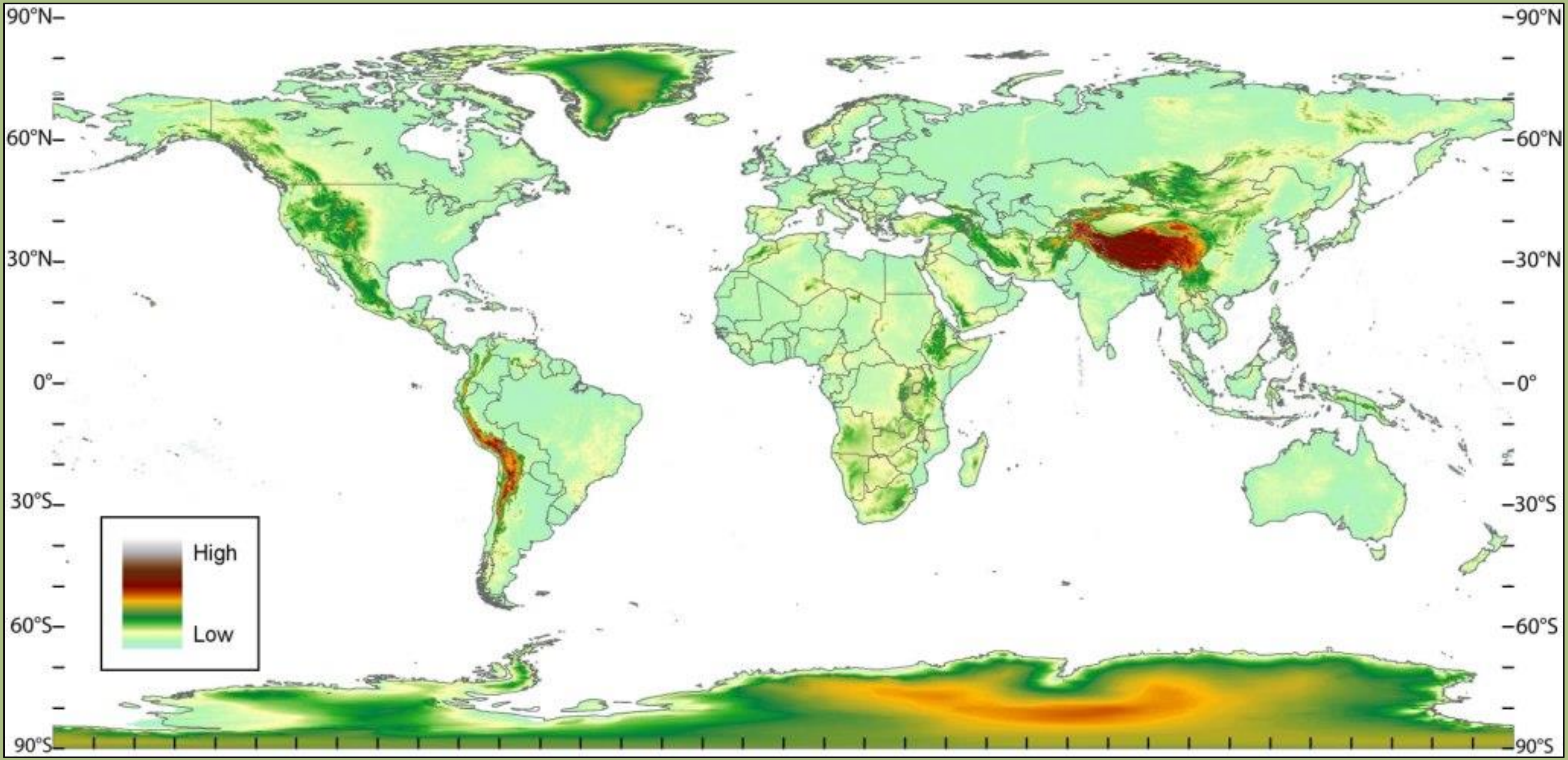

⊙ Samples from seismically inactive locations
⊕ Samples from seismically active locations
△ Samples from seismically active and inactive locations
⊙ Belton et al., 2004
⊙ Bierman and Caffee, 2001
⊙ Bierman and Caffee, 2002
⊕ Brown et al., 1995
⊕ Clapp et al., 2000
⊙ Clapp et al., 2001
⊙ Clapp et al., 2002
⊙ Cockburn et al., 2000
⊙ Duxbury, 2008
⊙ Granger et al., 2001
⊙ Hancock and Kirwin, 2007
⊕ Heimsath et al. 2001
⊕ Heimsath et al., 1997
⊙ Heimsath et al., 2000
⊙ Heimsath et al., 2001
⊙ Heimsath et al., 2006
⊕ Ivy-Ochs et al., 2007
⊙ Jungers, 2008
⊕ Kober et al., 2007
⊙ Matmon et al., 2003
⊕ Nichols et al., 2006
△ Nishiizumi et al., 1986
⊙ Nishiizumi et al., 1991
⊙ Quigley et al., 2007
⊕ Reinhardt et al., 2007
⊙ Reuter et al., unpublished
△ Small et al., 1997
⊙ Sullivan, 2007
⊙ Ward et al., 2005
⊙ Weissel and Seidl, 1998
⊙ von Blanckenburg et al., 2004

Initial Results: Latitude

- Erosion rates peak between 30-50°
- Sampling gap between 50-70°
  - Glacial complications in the north
  - Presence of Southern Ocean in the south

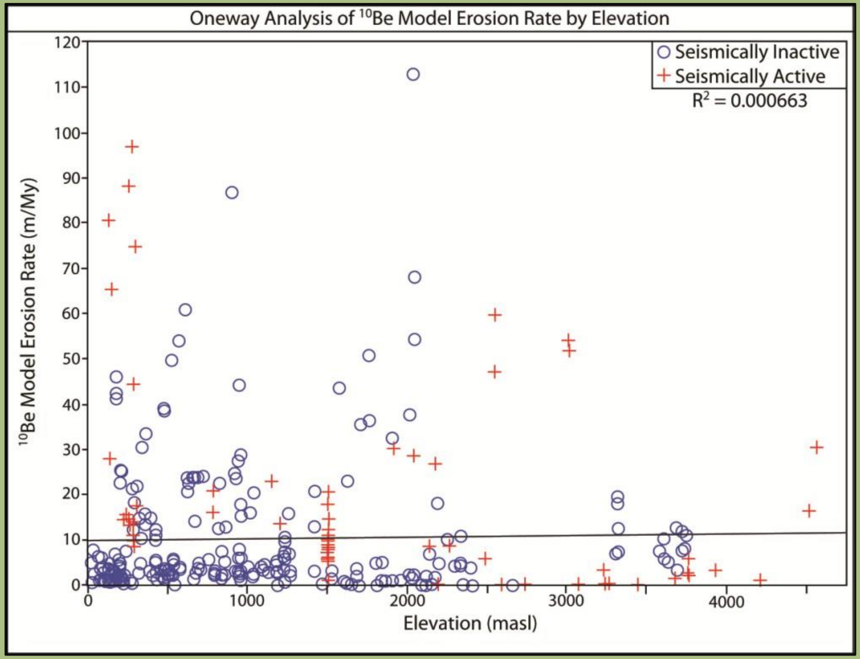


Gtopo_30 elevation dataset



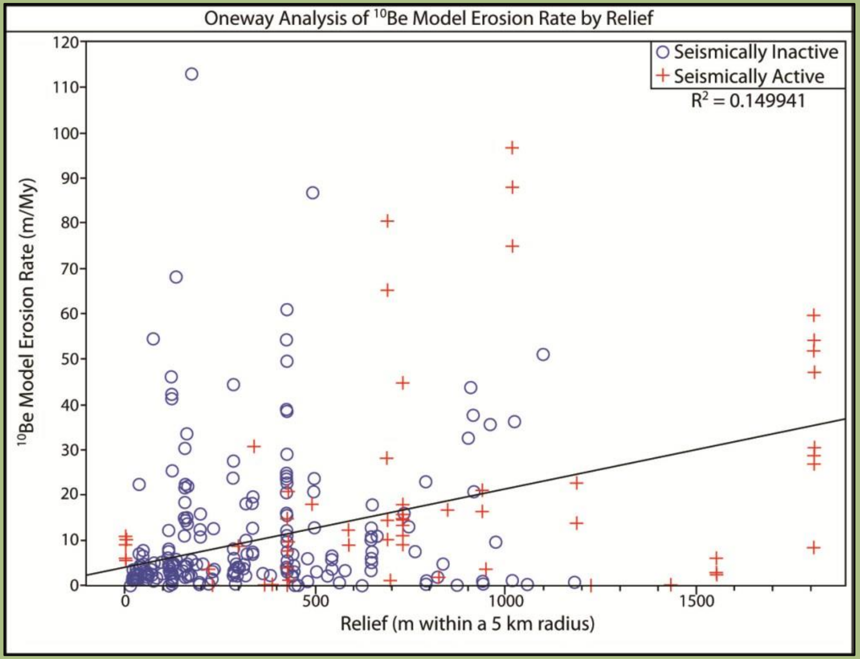
Initial Results: Elevation & Relief

- Elevation yields the weakest correlation with erosion rate



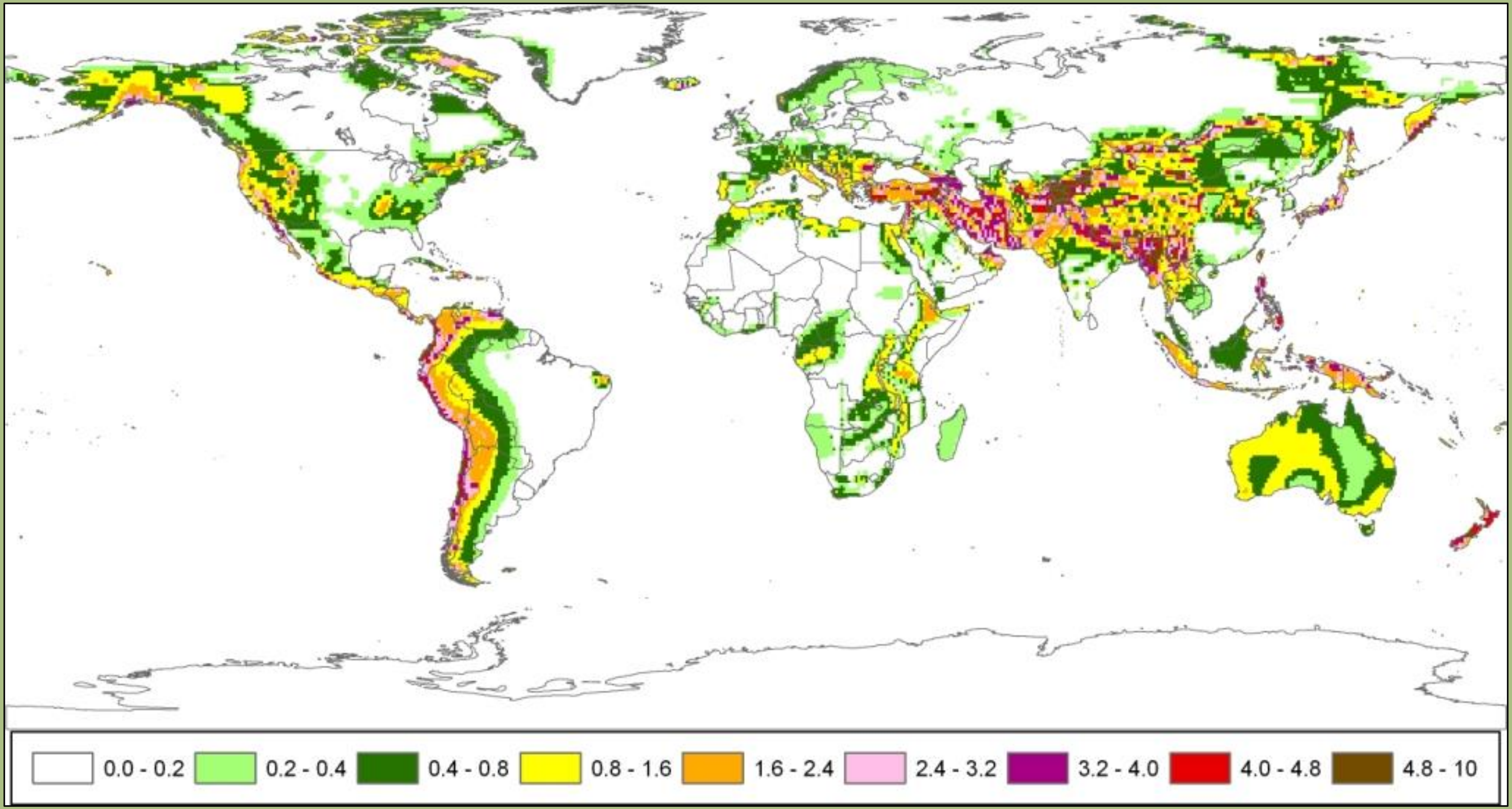
(R^2=0.001; *p*=0.6176)

- Local relief (r=5km) yields a weak correlation



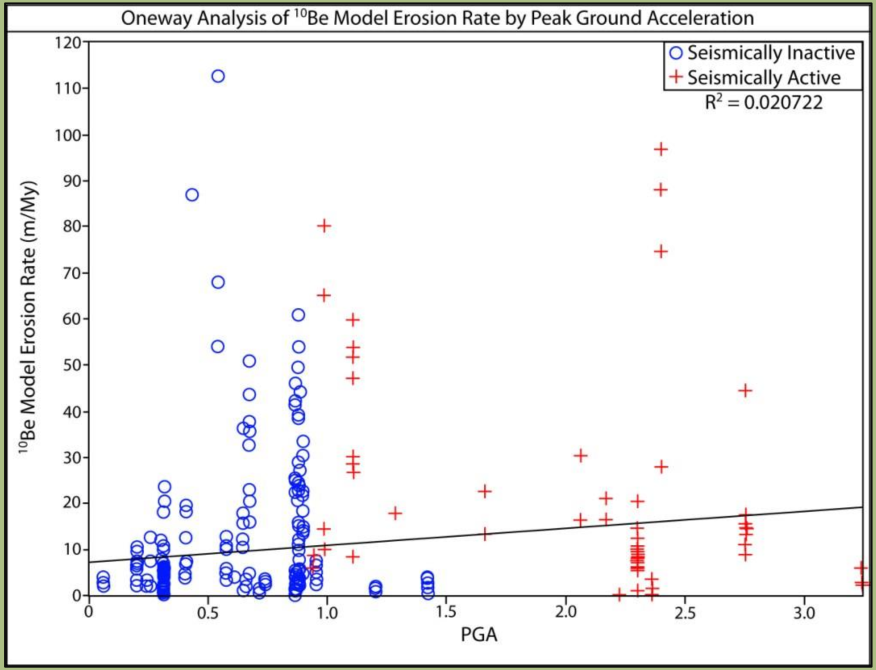
(R^2=0.150; *p*<0.0001)

Peak Ground Acceleration

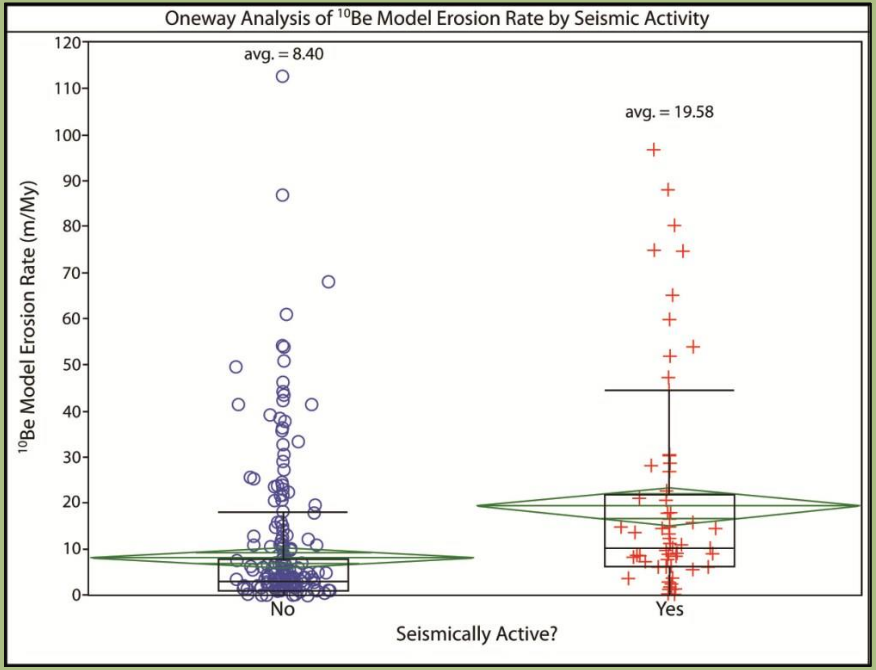


(Giardini et al., 1999)

Initial Results: Seismicity



$(R^2=0.021;\ p=0.007)$

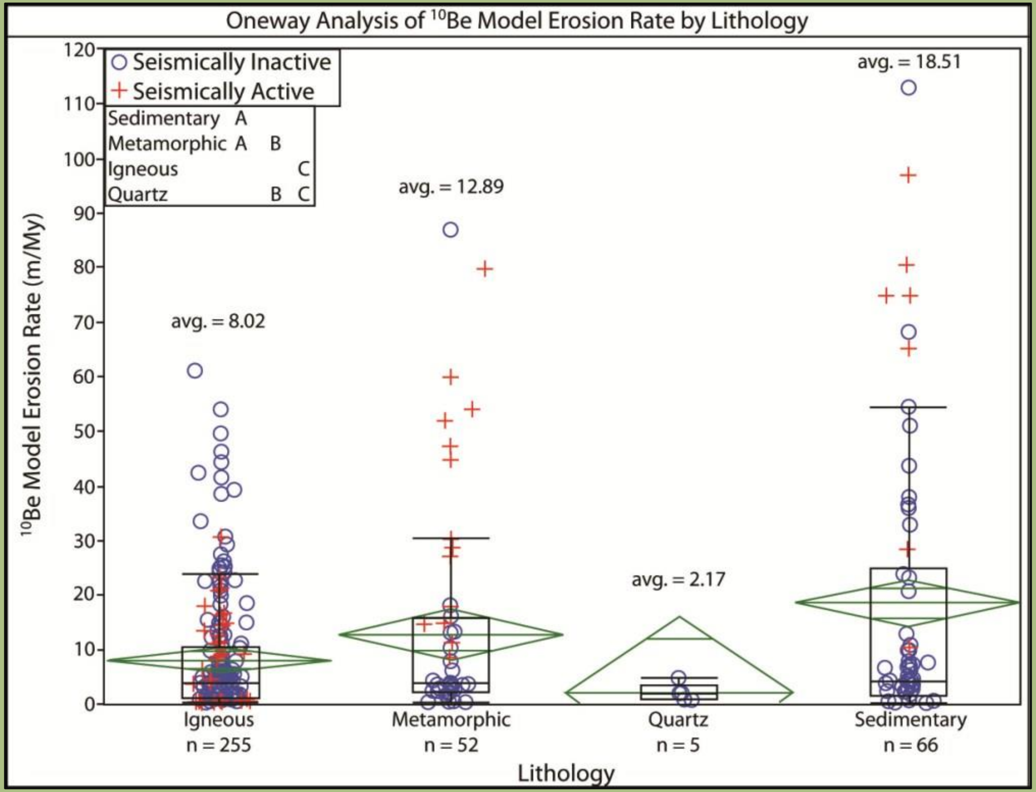


Active (n=69): 19.6±3.0 m My^{-1}

Inactive (n=309): 8.4±1.2 m My^{-1}

Initial Results: Lithology

- Specific lithologies generalized to four categories
- Weaknesses along bedding and foliation planes
- Note: sample populations vary



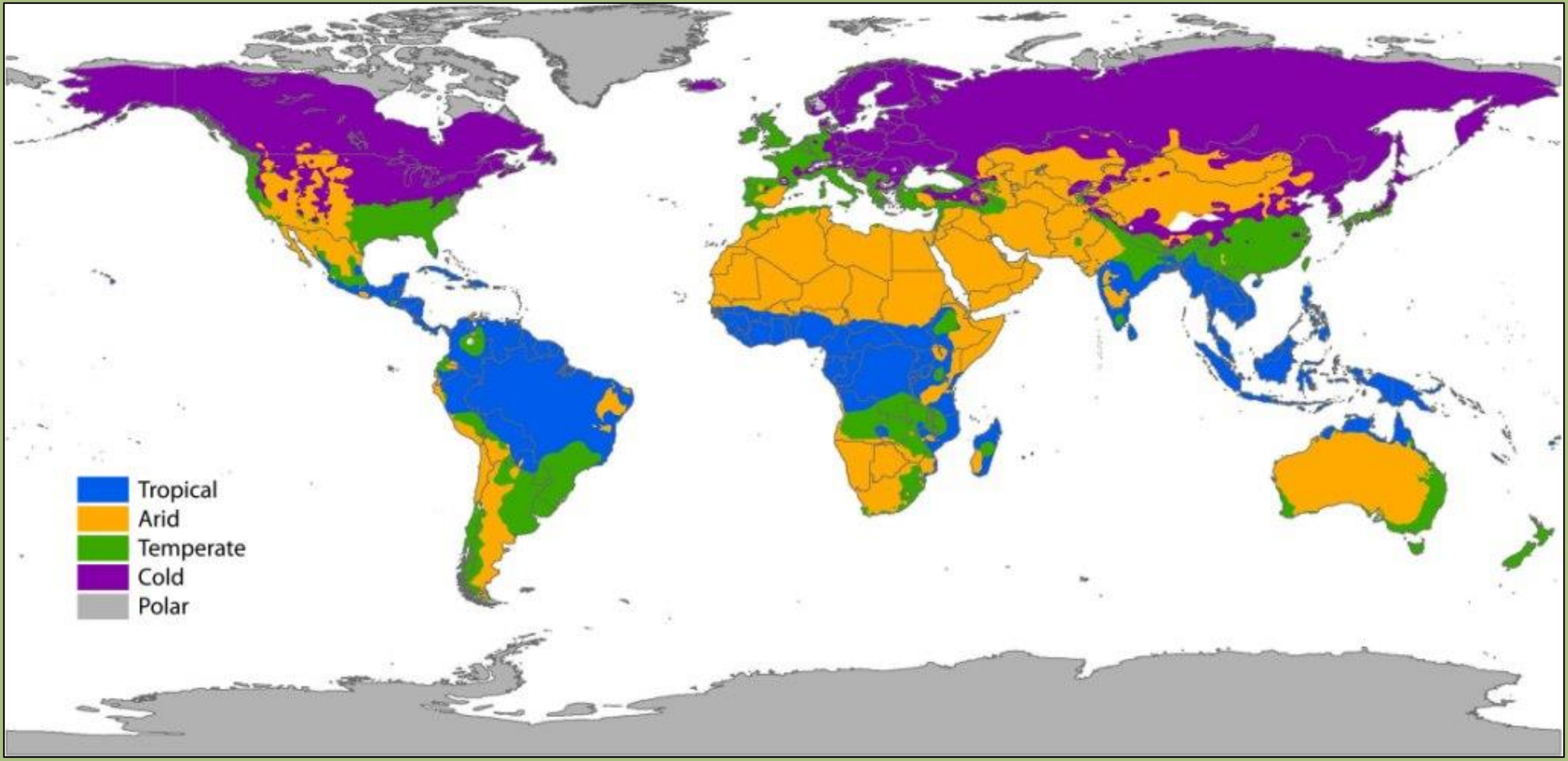
Igneous (n=255): 8.0±1.2 m My^{-1}

Metamorphic (n=52): 12.9±1.9 m My^{-1}

Quartz (n=5): 2.2±0.3 m My^{-1}

Sedimentary (n=66): 18.5±2.8 m My^{-1}

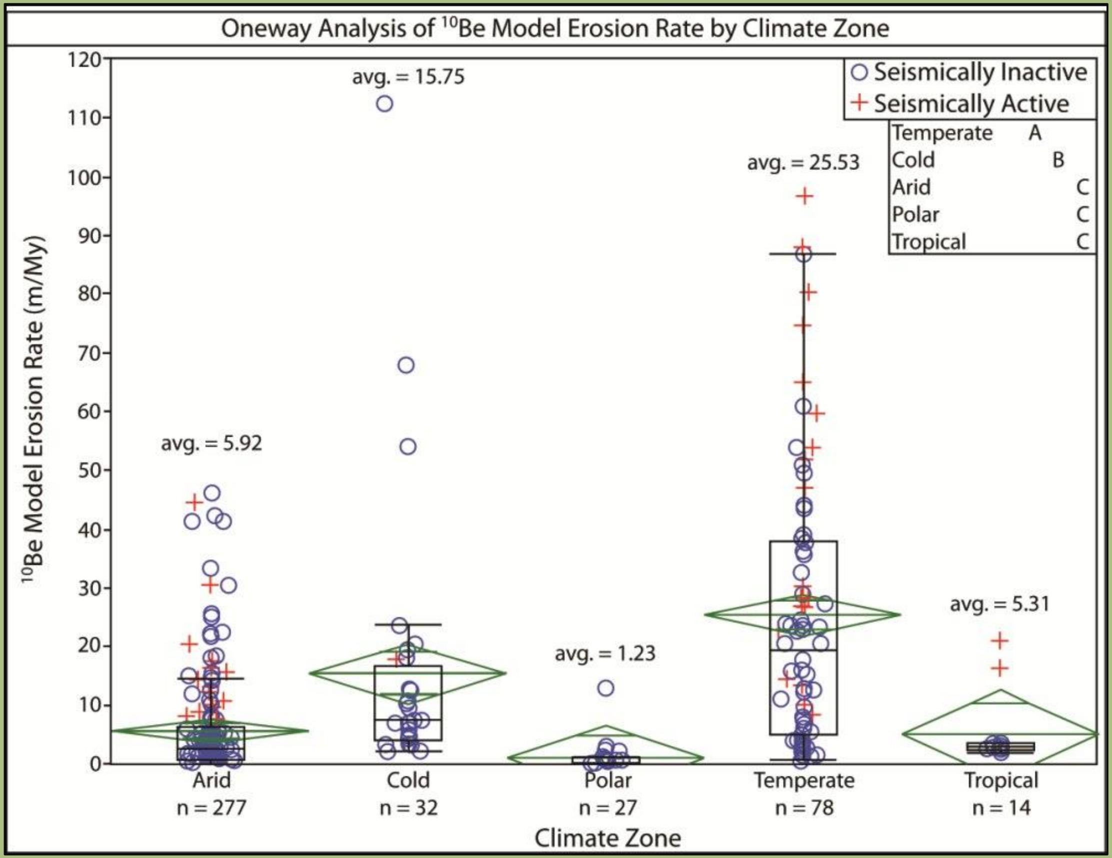
Köppen-Geiger Climate Classification



(Peel et al., 2007)

Initial Results: Climate Zone

- Utilize five generalized zones
- Note: sample populations vary
- Climates with temperature fluctuations see highest erosion rates



Arid (n=277): 5.9±0.9 m My^{-1}

Cold (n=32): 15.8±2.4 m My^{-1}

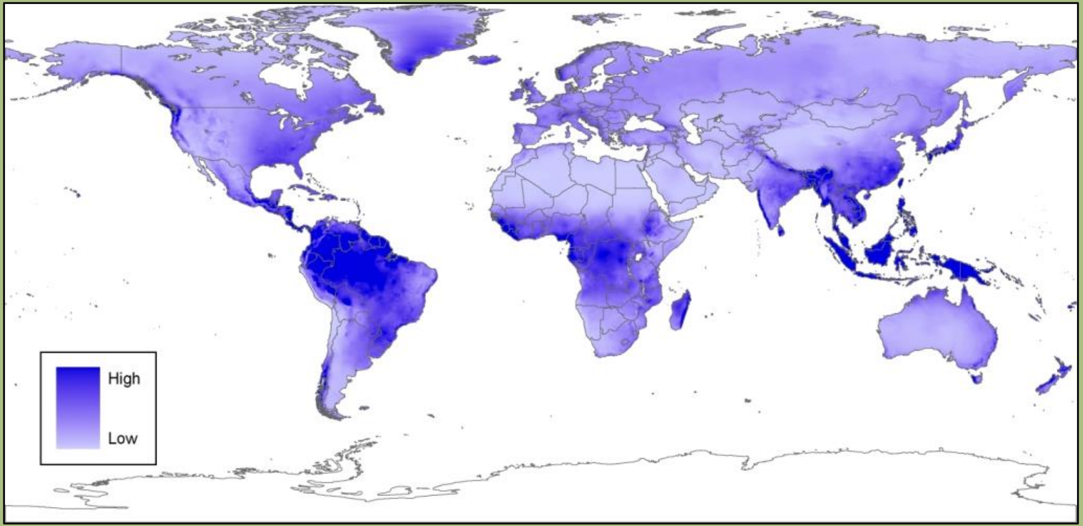
Polar (n=27): 1.2±0.2 m My^{-1}

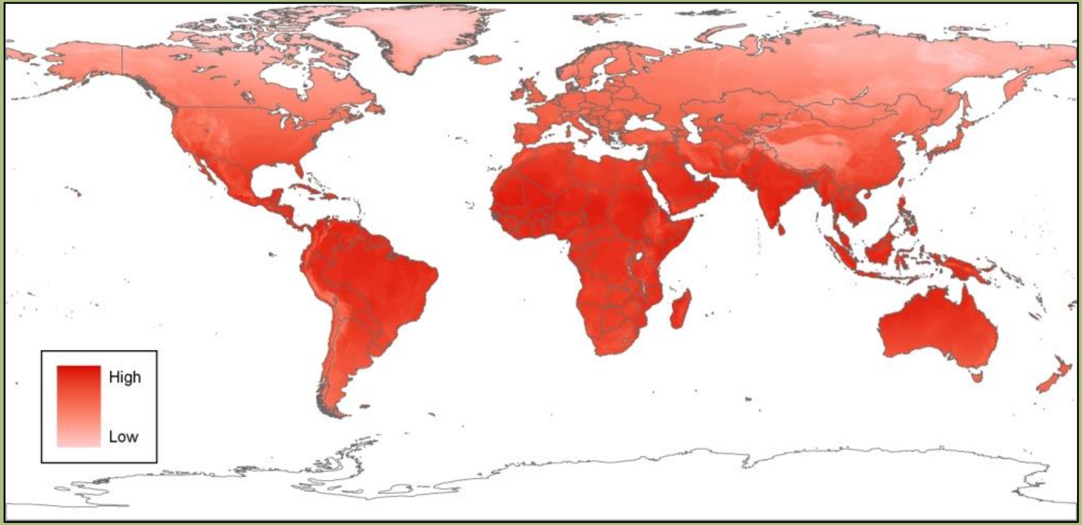
Temperate (n=78): 25.5±3.7 m My^{-1}

Tropical (n=14): 5.3±0.3 m My^{-1}

Individual Climate Components

Mean Annual Precipitation (mm/yr)



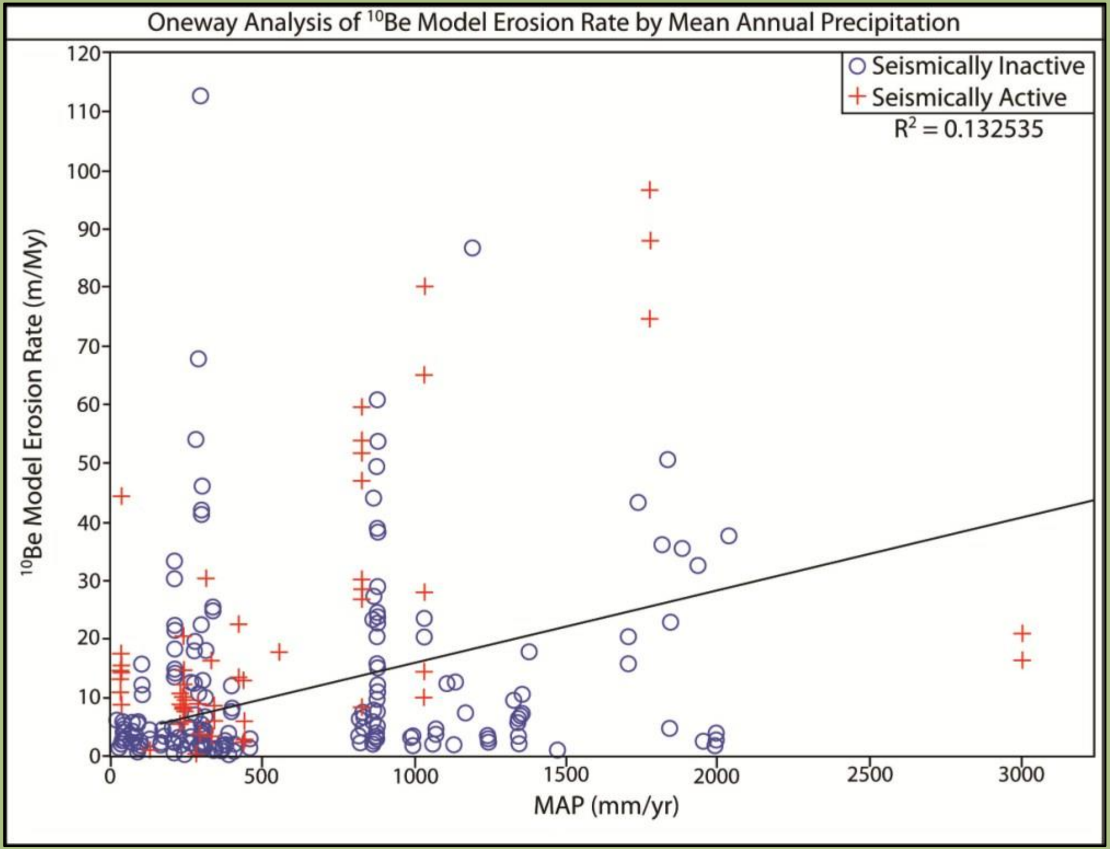


Mean Annual Temperature (°C)

WorldClim model (Hijmans et al., 2005)

Initial Results: MAP

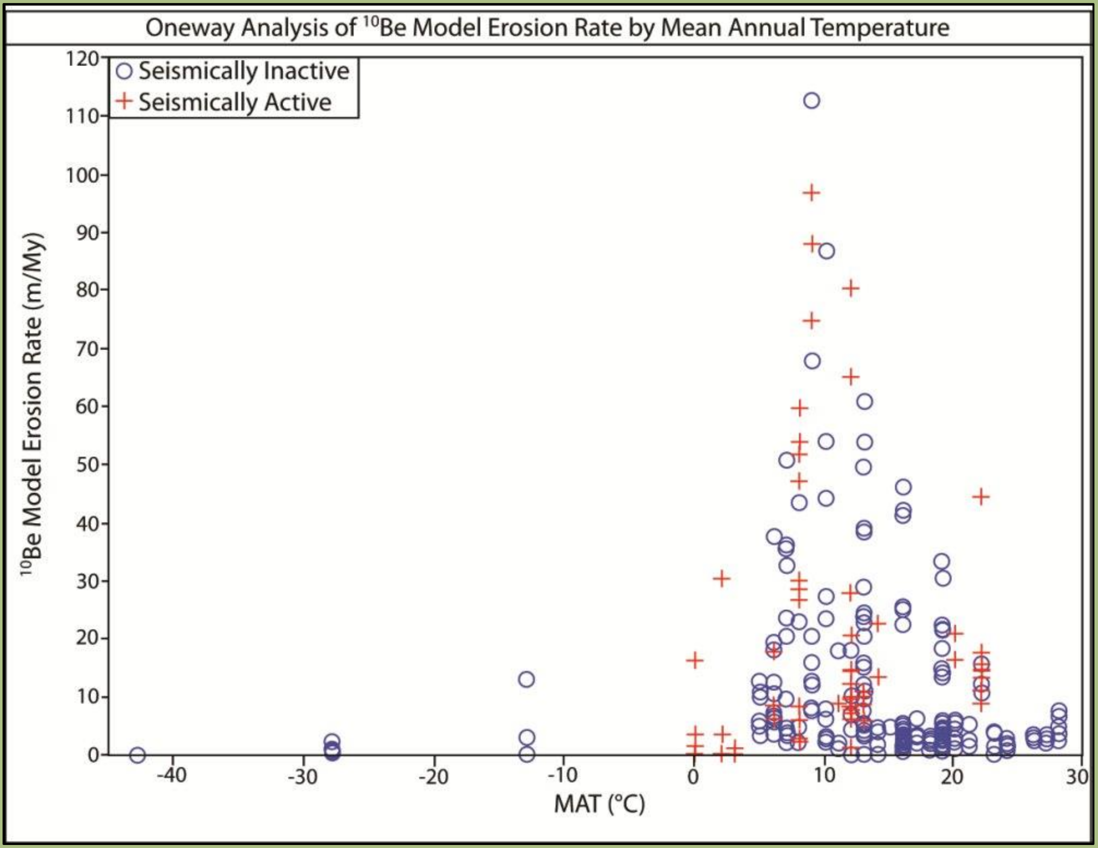
- MAP shows a weak correlation with erosion rates
  - Freeze-thaw cycling (Cold & Temperate)?
  - Chemical weathering (Temperate & Tropical)?



(R^2=0.133; p<0.0001)

Initial Results: MAT

- Erosion rates spike between 0-25°C
  - Where Cold and Temperate climates are dominant
  - Extremely high and low temperatures are not favorable for retaining moisture



Initial Results: Multivariate Regression

- Forward Step-wise Regression
  - Categorical data
    - Lithology
    - Climate Zone
    - Seismic Activity
  - Global Scale

1. *p*-values are ranked
2. If p<Probability to Enter →variable is entered into regression
3. Variables entered one at a time
4. New *p*-values generated
5. If p>Probability to Leave →variable is removed

Forward Stepwise Regression Summary

Probability to Enter: 0.250
Probability to Leave: 0.100

	Igneous	Metamorphic	Quartz	Sedimentary	Arid	Cold	Polar	Temperate	Tropical	Active	Inactive	Global
n =	255	52	5	66	227	32	27	78	14	69	309	378
Latitude (°N/S)	①	②		④	①	③		③		②		②
Elevation (masl)				③	⑤		①			④		④
Relief (r = 5km)	③	①		①		④		④	①	③	④	①
MAP (mm/yr)	②		①		③	②	②	②		①	②	③
MAT (°C)			②	⑤	④	①				⑤	①	
PGA				②	②		N/A	①	②		③	⑤
R^2 =	0.146	0.444	0.998	0.644	0.099	0.737	0.174	0.448	0.968	0.559	0.159	0.279

Initial Results: Multivariate Regression

- Stratification of global erosion rates by categorical data improves the regression
- Important parameters stand out
  - Relief, MAP, Latitude also best-fit one-way parameters
- Six variables used do well explaining variation in some categories but not others

Biases Inherent to the Data

- Glaciation limits ^{10}Be interpretive power
- Limited data for regions of political unrest and weak economies
- Quartz-bearing lithologies limits distribution of potential sampling sites
- Climate Zones and Lithologies are underrepresented
- Joint spacing and fracture density information is not provided

Work to be Done: Global Erosion Publication

- Update database with few missed publications providing more bedrock samples
- Update basin-averaged ^{10}Be erosion rate summary compiled by Joanna Reuter (2005)
- Synthesize two global compilations as basis of first publication

Timeline

December 2009	• Finish bedrock and basin-averaged data compilation and begin writing manuscript • Continue quartz purity tests
January 2010	• Begin *in situ* laboratory methods • Submit global summary manuscript (journal TBA)
February 2009	• Finish *in situ* laboratory work
March 2010	• Run samples using AMS at Lawrence Livermore National Laboratory • Receive data
April 2010	• Data Analysis
Summer 2010	• Write thesis • Write manuscript for Appalachian bedrock paper
Fall 2010	• Defend thesis in early Fall • Submit Appalachian bedrock manuscript • Prepare for/give talk at GSA

Thank You