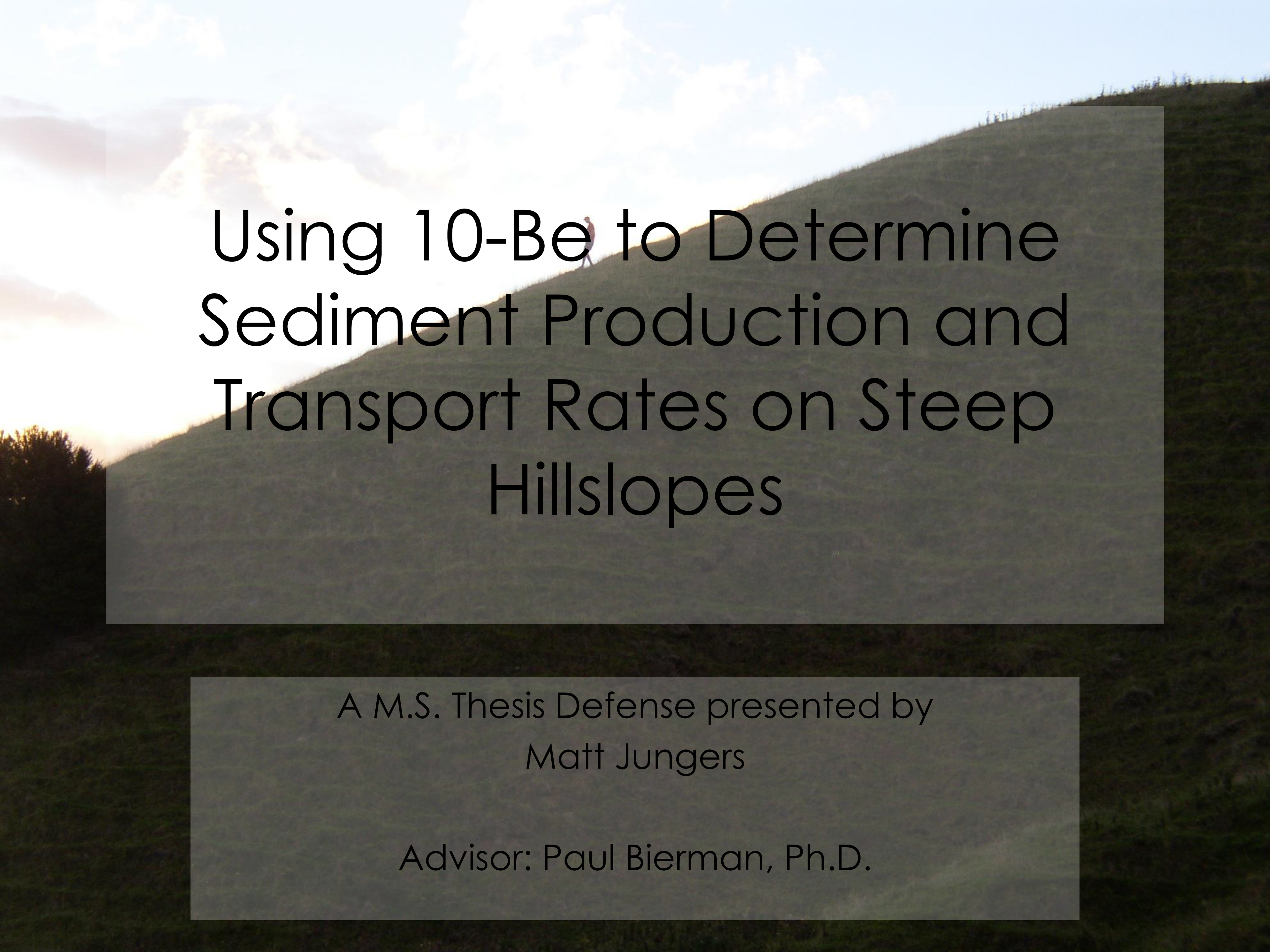


Using 10-Be to Determine Sediment Production and Transport Rates on Steep Hillslopes

A M.S. Thesis Defense presented by
Matt Jungers

Advisor: Paul Bierman, Ph.D.

Talk Outline

- Project Goals
- Background
- Methods
- Results
- Interpretations

Objectives of this Project

- Establish a new use of cosmogenic nuclides
- Determine ^{10}Be concentrations in sediment as a function of depth and distance downslope
- Build simple box models of sediment production from underlying rock and subsequent transport downslope
- Consider these results in the context of previous work in the Southern Appalachians

Why hillslopes?

- They are everywhere!
- Conservation of hillslope soil is necessary for agriculture, recreation, and engineering
- Important to every model of landscape development
- Despite their ubiquity, we still don’t fully understand the rates of hillslope processes

In the Beginning…

-Many consider Gilbert's "Geology of the Henry Mountains (Utah)" (1877) to be the "Bible of Geomorphology"

G.K. Gilbert
1843-1918

Soil Creep?

Soil is “stirred” by animal burrowing,
tree throw, and wet-dry cycles.
Downslope creep is analogous to particle diffusion.

Particle Diffusion?

Over time, a hillslope's entire soil mantle may be mixed by these stirring processes, and soil particles, once mobilized, move downslope.

Gilbert's Hypothesis

Rate of soil creep is proportional to slope gradient

Why quantify soil flux?

Current estimates by Wilkinson (2007) and Hooke (2000) place the rate of human-induced soil erosion at 10-15 times the natural rate. But what is the natural rate?

What is soil flux?

From Heimsath et al., 2005

Soil flux is considered in terms of a volume of soil moving per unit time and per unit contour length:

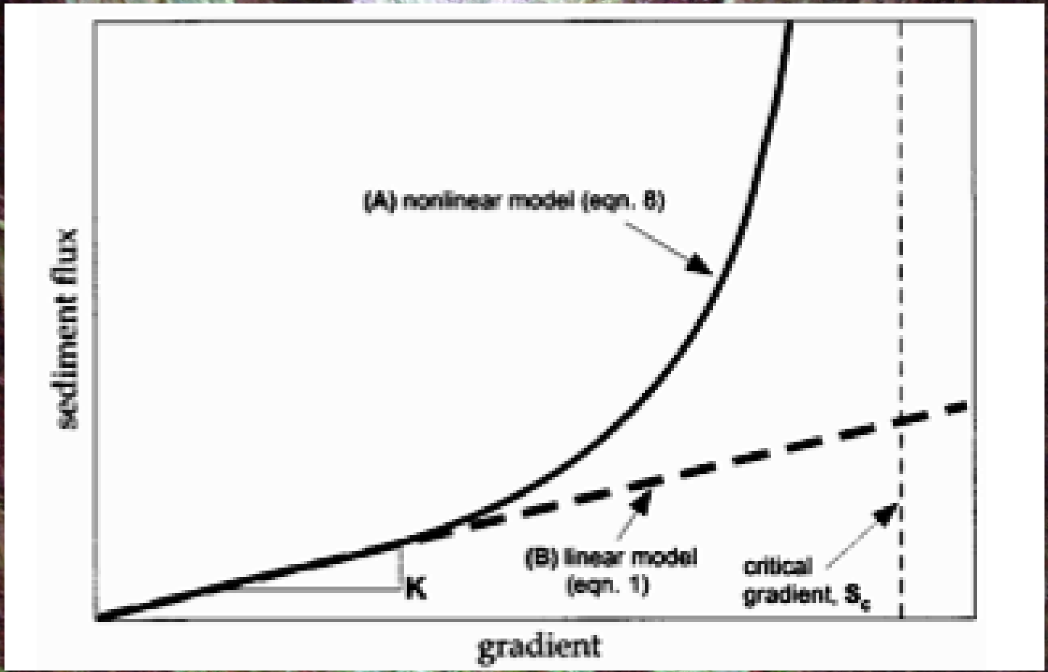
$cm^3\ yr^{-1}\ cm^{-1}$

- If Gilbert's hypothesis is correct, then:

soil flux = K * slope gradient

K = diffusion coefficient in $cm^3\ yr^{-1}\ cm^{-1}$

Beyond linear diffusion…



From Roering et al., 1999

-For some environments, the relationship between soil creep rate and slope gradient is not linear
-Nonlinear models for diffusion are largely based on high-resolution topographic data rather than field measurements of soil flux

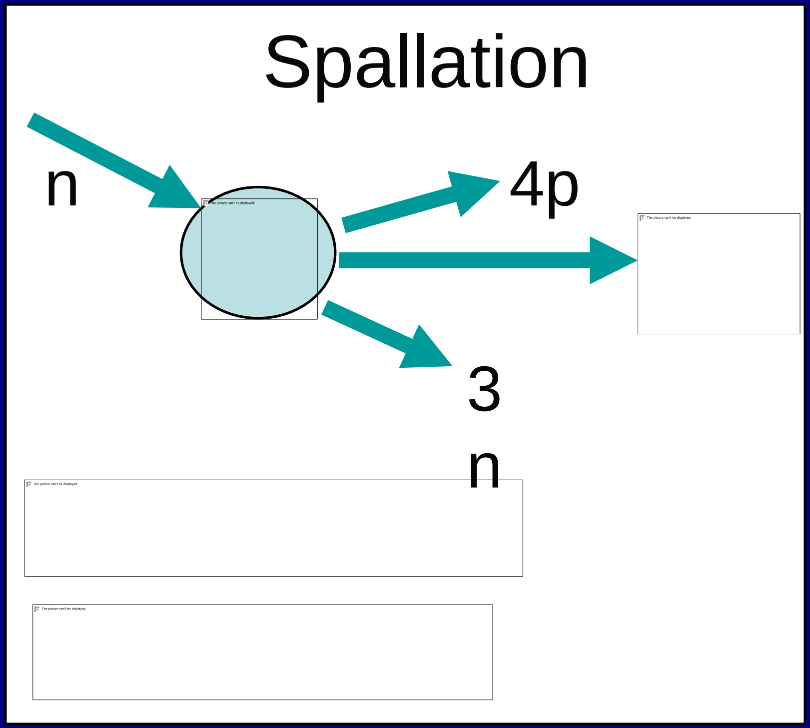
What about lower gradient planar slopes?

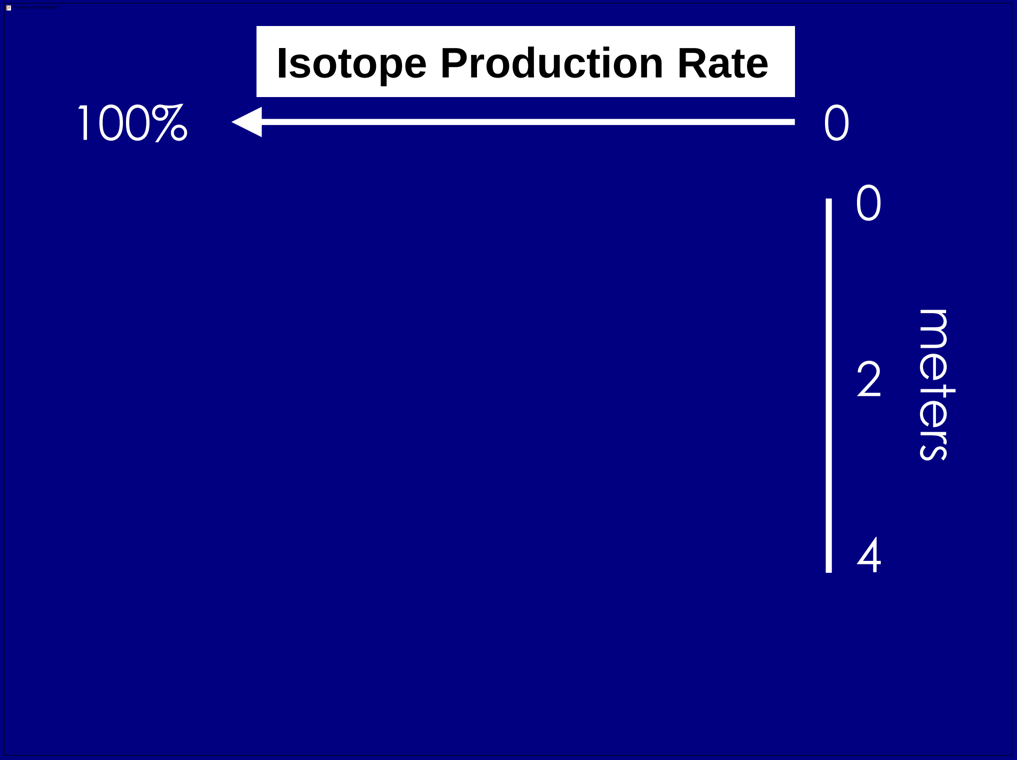
Existing soil transport laws may not be appropriate

So, what problem remains?

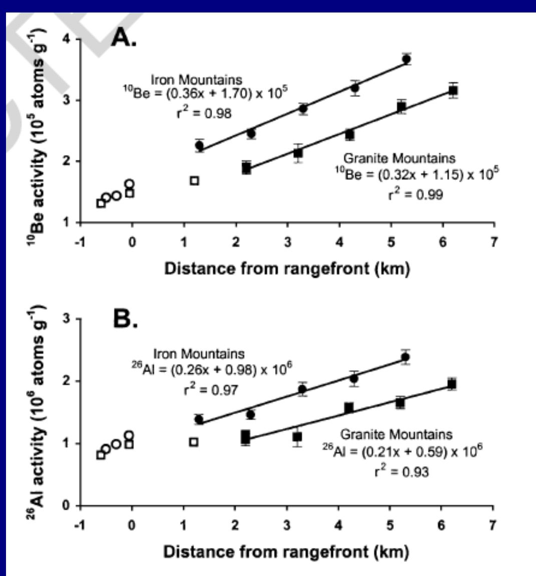
- Studies quantifying soil transport rates still rely heavily on the assumptions of steady-state hillslopes and linear diffusion
- Attempts to directly measure soil flux in the field are difficult due to the spatial complexities of hillslopes and temporal constraints of the average geologist's field season/lifespan.
- Could a unique sampling strategy and cosmogenic isotopes be the answer?

Cosmogenic Radionuclides





Quantifying Sediment Transport Rates with ^{10}Be



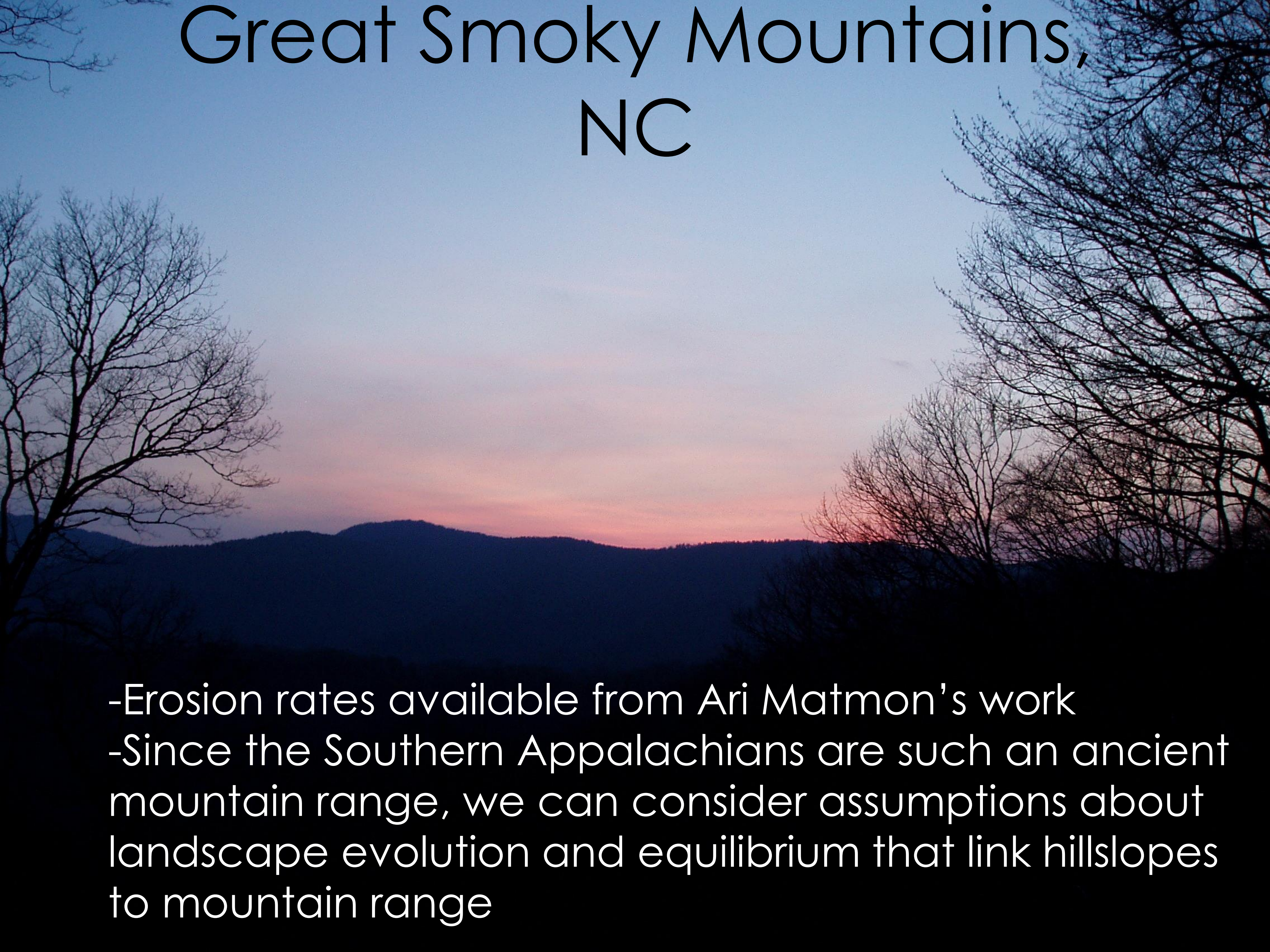
- Previous work done by Nichols et al. (2002) on desert piedmonts

-Common sense tells us that sediment should be generated in the river basins of the range front, and subsequently march down piedmont from points of generation

-Concentrations of cosmogenic nuclides in piedmont sediment support this hypothesis showing a direct relationship between distance from rangefront and and nuclide concentrations

-Will sediment on steep hillslopes show this same

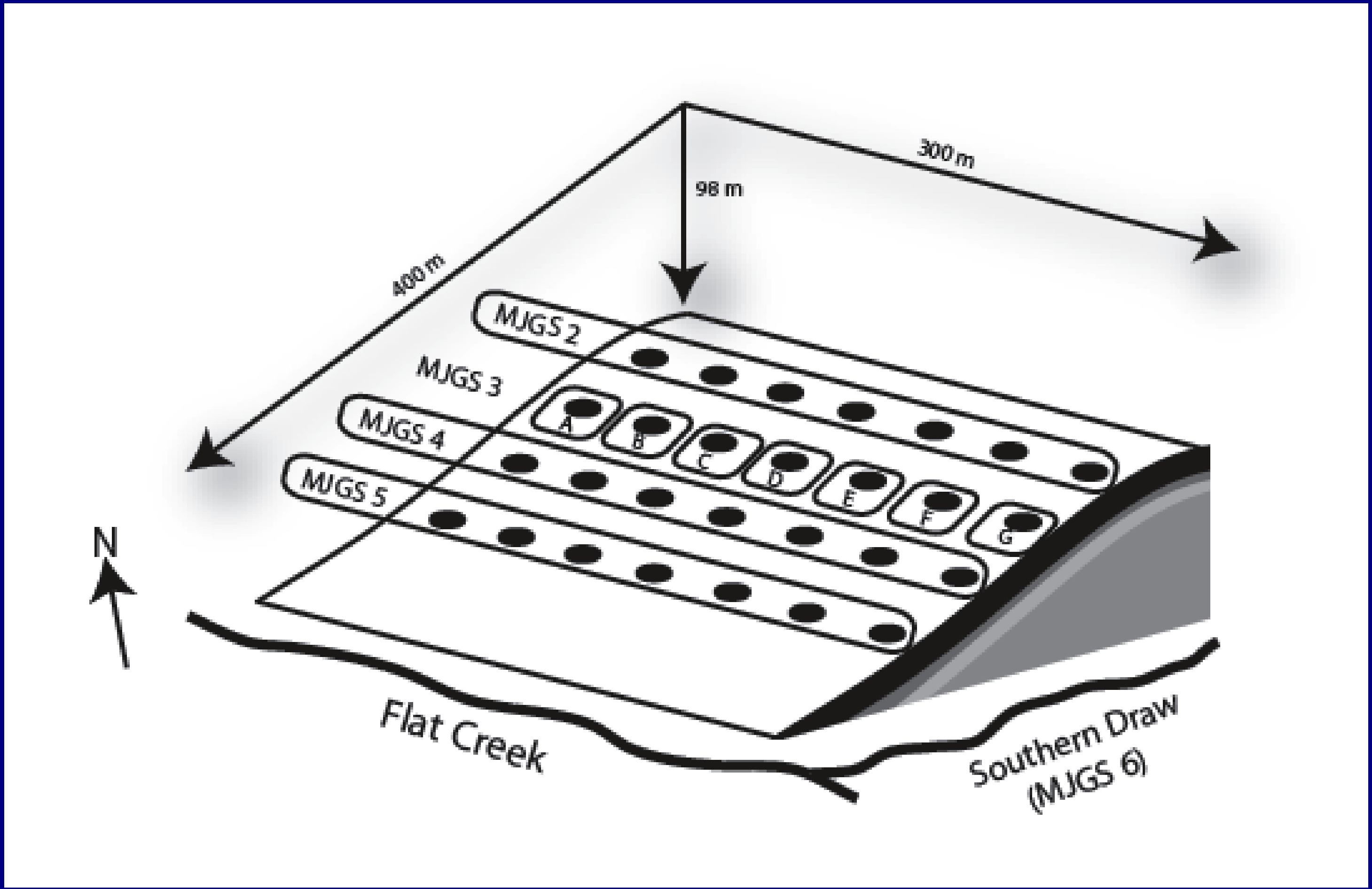
Great Smoky Mountains, NC



-Erosion rates available from Ari Matmon's work
-Since the Southern Appalachians are such an ancient mountain range, we can consider assumptions about landscape evolution and equilibrium that link hillslopes to mountain range

Great Smoky Mountains, NC

Field Methods
Sample Collection



Field Methods

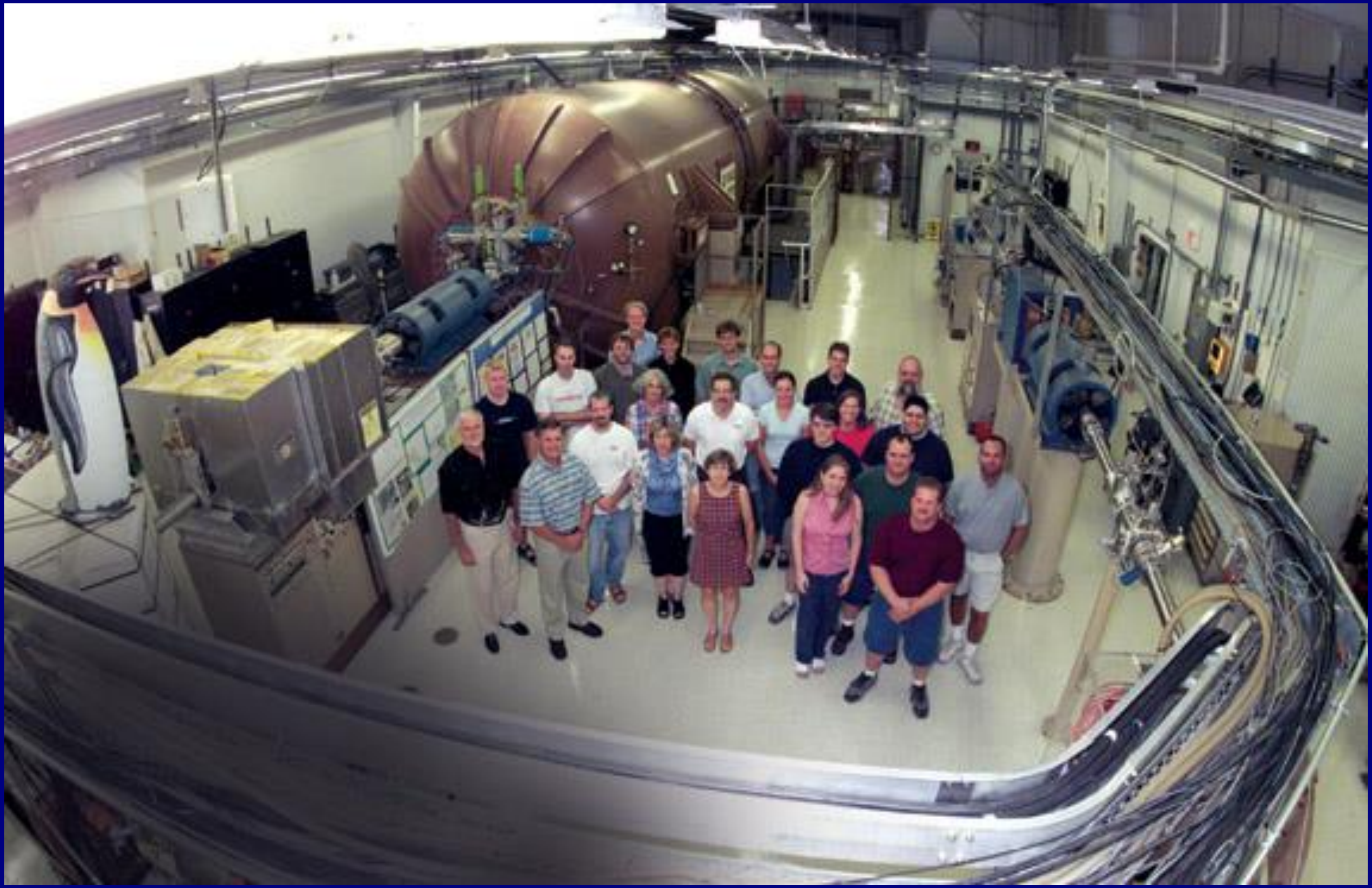
Description of Soil Pits

For each pit:
-depth of horizons measured
-horizon colors described
-horizon textures described

Lab Methods

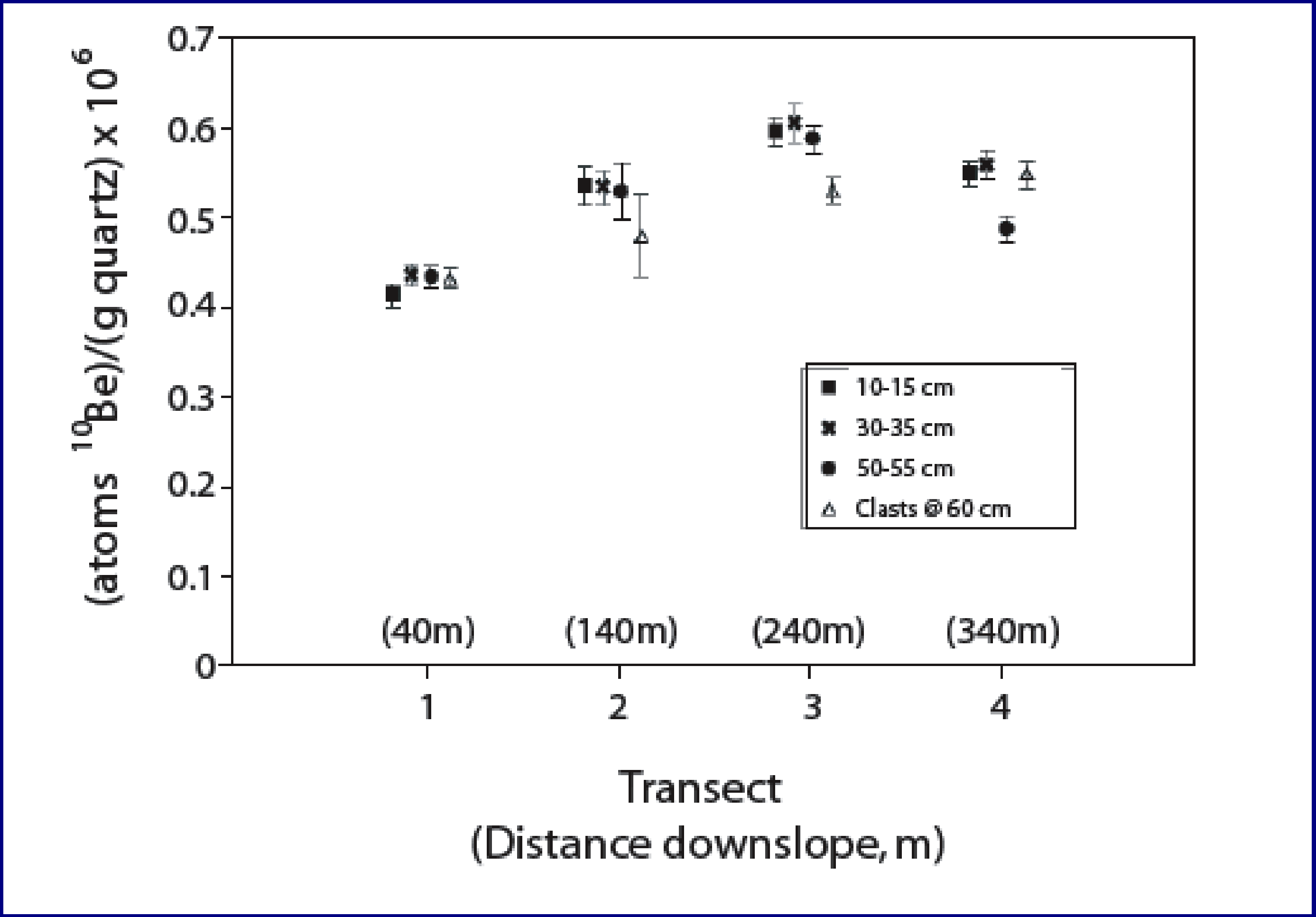
Quartz Purification

Lawrence Livermore National Lab



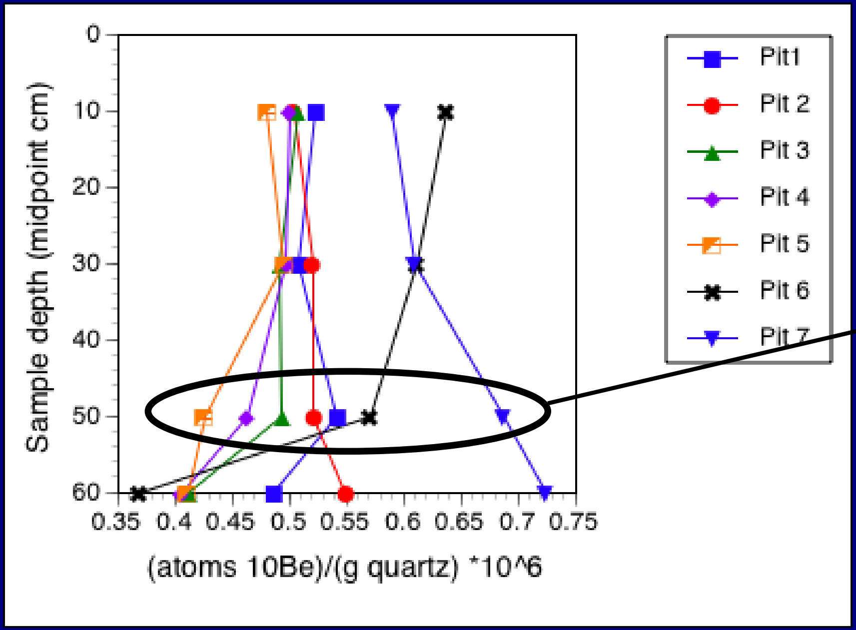
Results

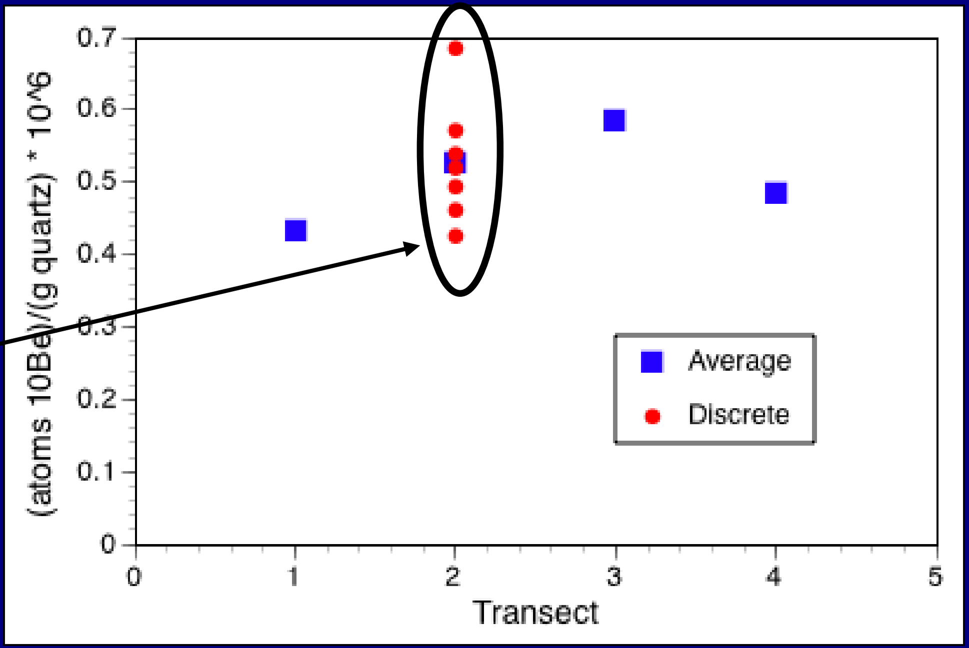
[^{10}Be] vs. Distance Downslope



Error bars represent 1sigma analytical error for T1, T3, and T4
On T2, error bars are 1 standard error of the mean (n=7)

Spatial Variation





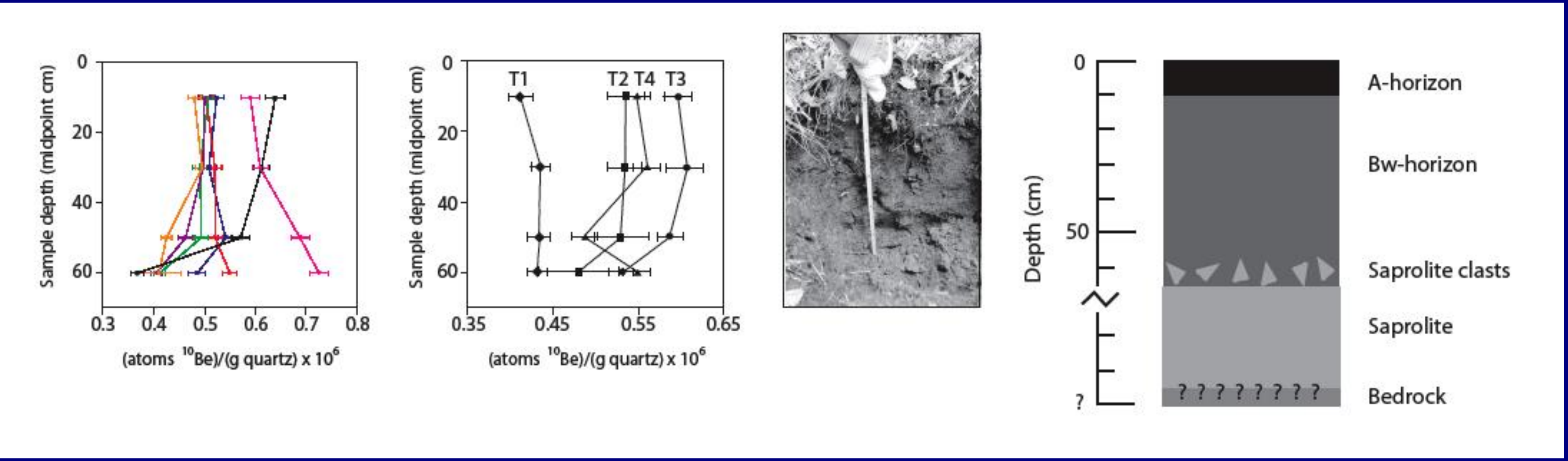
Cross-slope variation

Physical mixing vs. Arithmetic mean

-does our physical mixing integrate the unique histories of grains across the slope

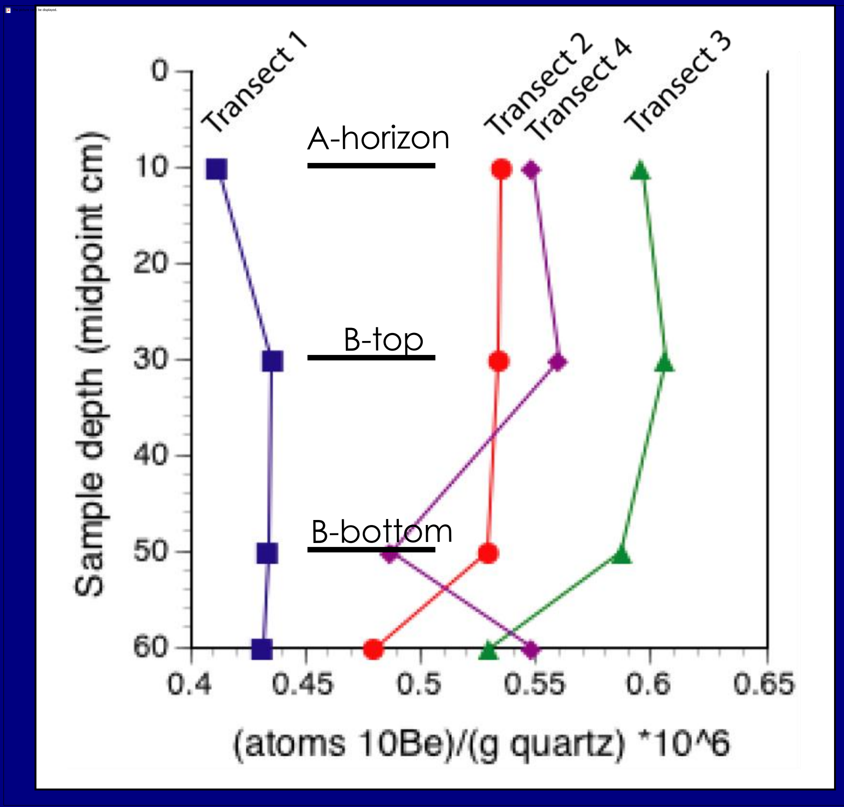
Yes

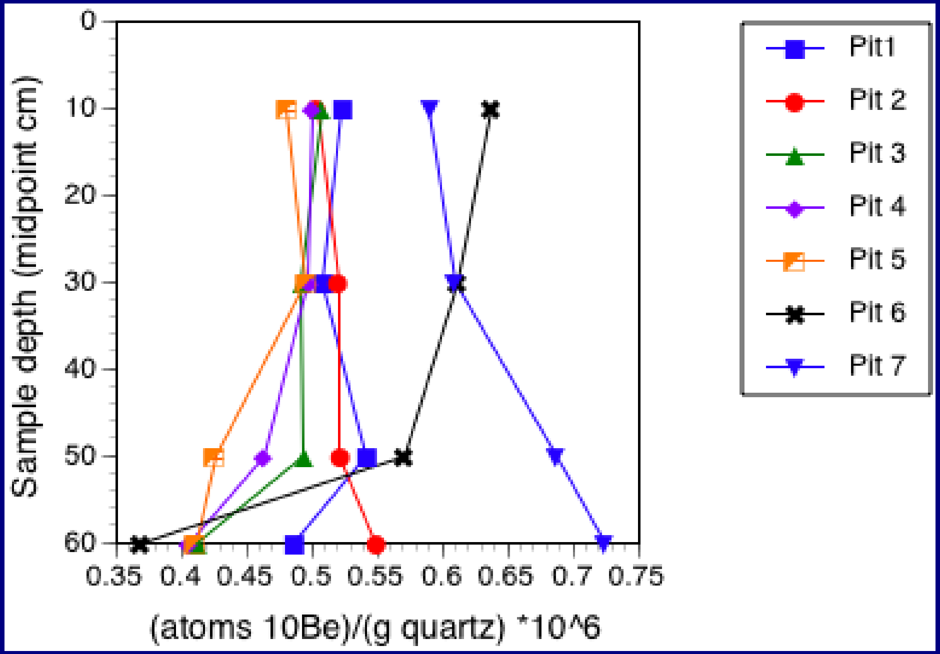
Results (cont.)



Great Smoky Mountains, TN

[^{10}Be] vs. Sample Depth

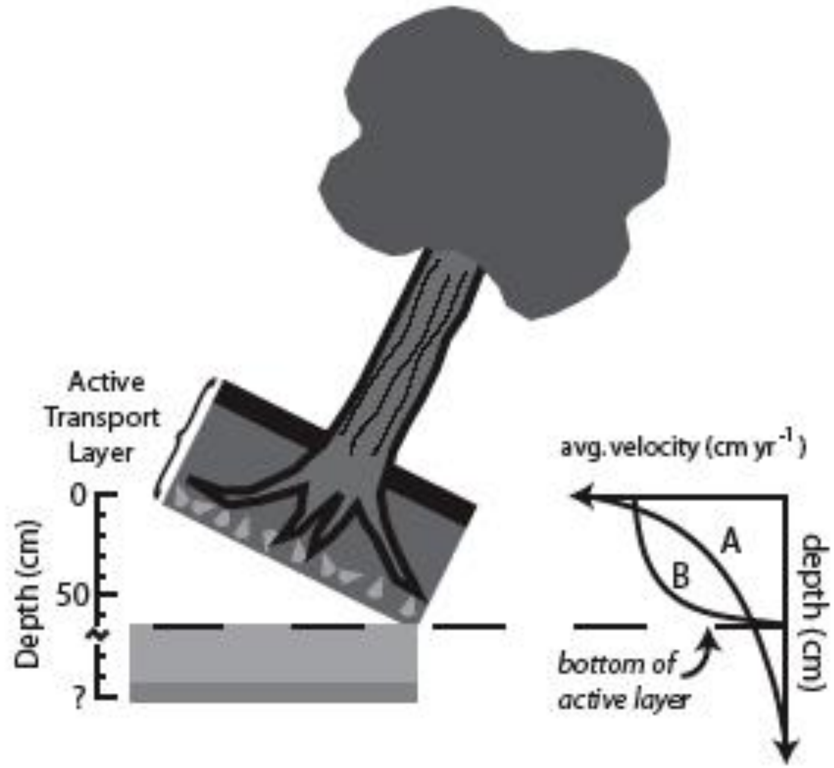




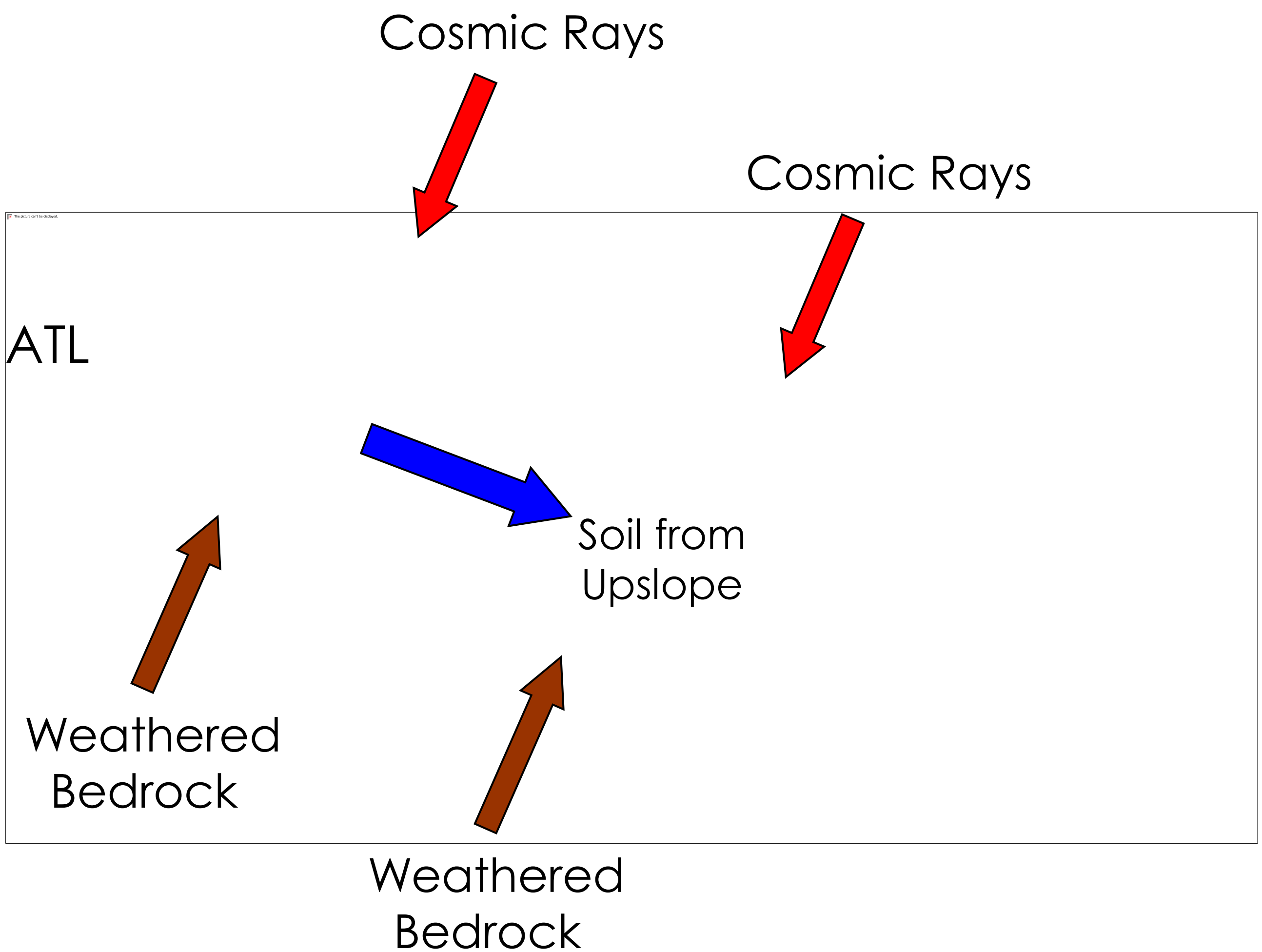
Across Slope

Depth of effective mixing?

Mechanism for Soil Mixing



How can we quantify soil transport rates?



Soil Production Rate

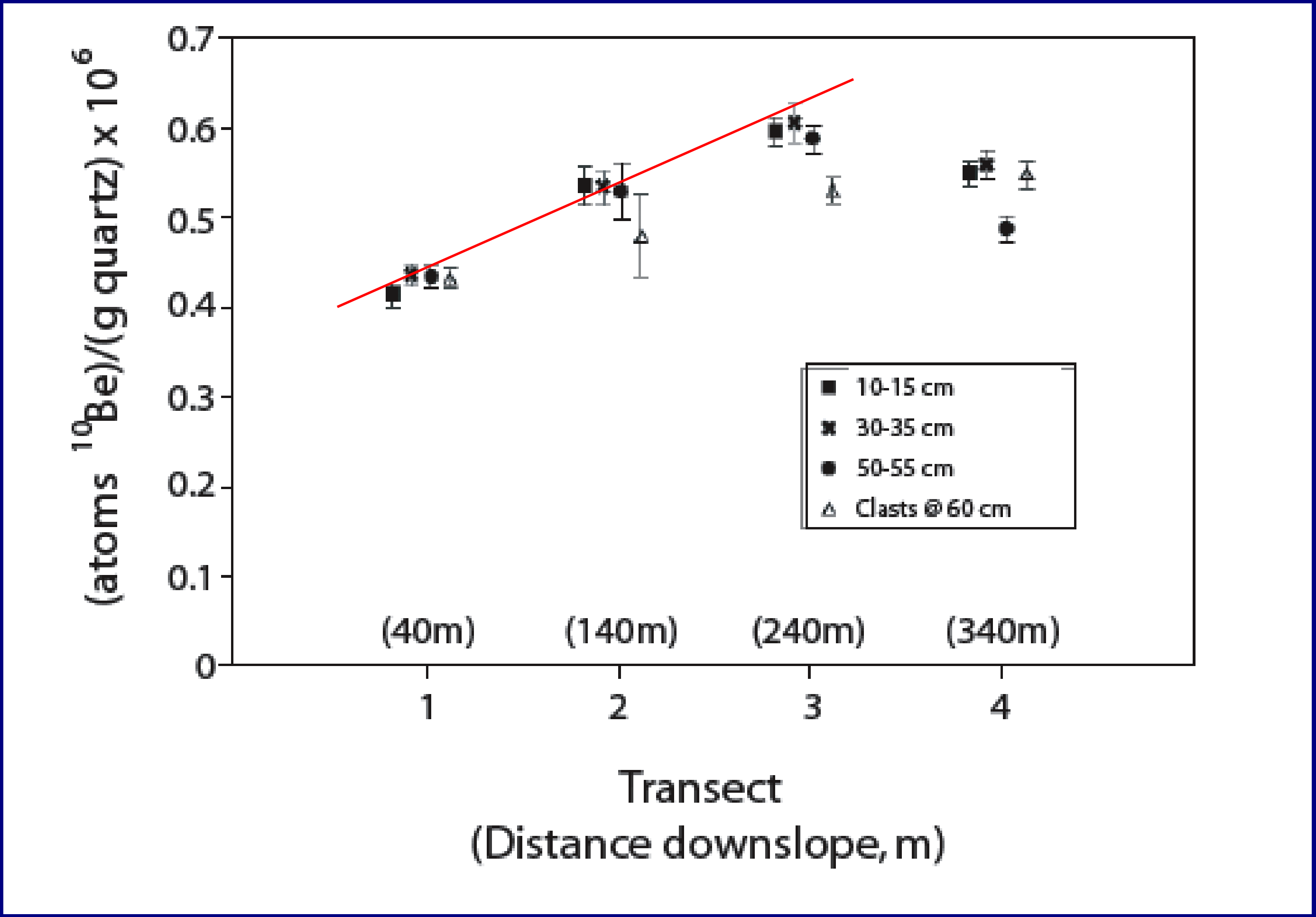
-from Heimsath et al., 1997
-use ^{10}Be concentrations at the soil-bedrock contact to
model the rate at which the contact is lowering
-rate of contact lowering = rate of soil production

Soil Production Rate for the Great Smoky Mountains, NC

-No relationship between soil production rate and distance downslope from the hillcrest -- i.e., uniform rate for entire hillslope

-Average soil production rate = 12 m/My or 0.0012 cm/yr

Initial Soil Velocity?



-Inferred from ^{10}Be accumulation rates assuming plug flow

-Downslope soil velocity = about 1 cm/yr

Soil Flux Rates for Great Smoky Mountains, NC

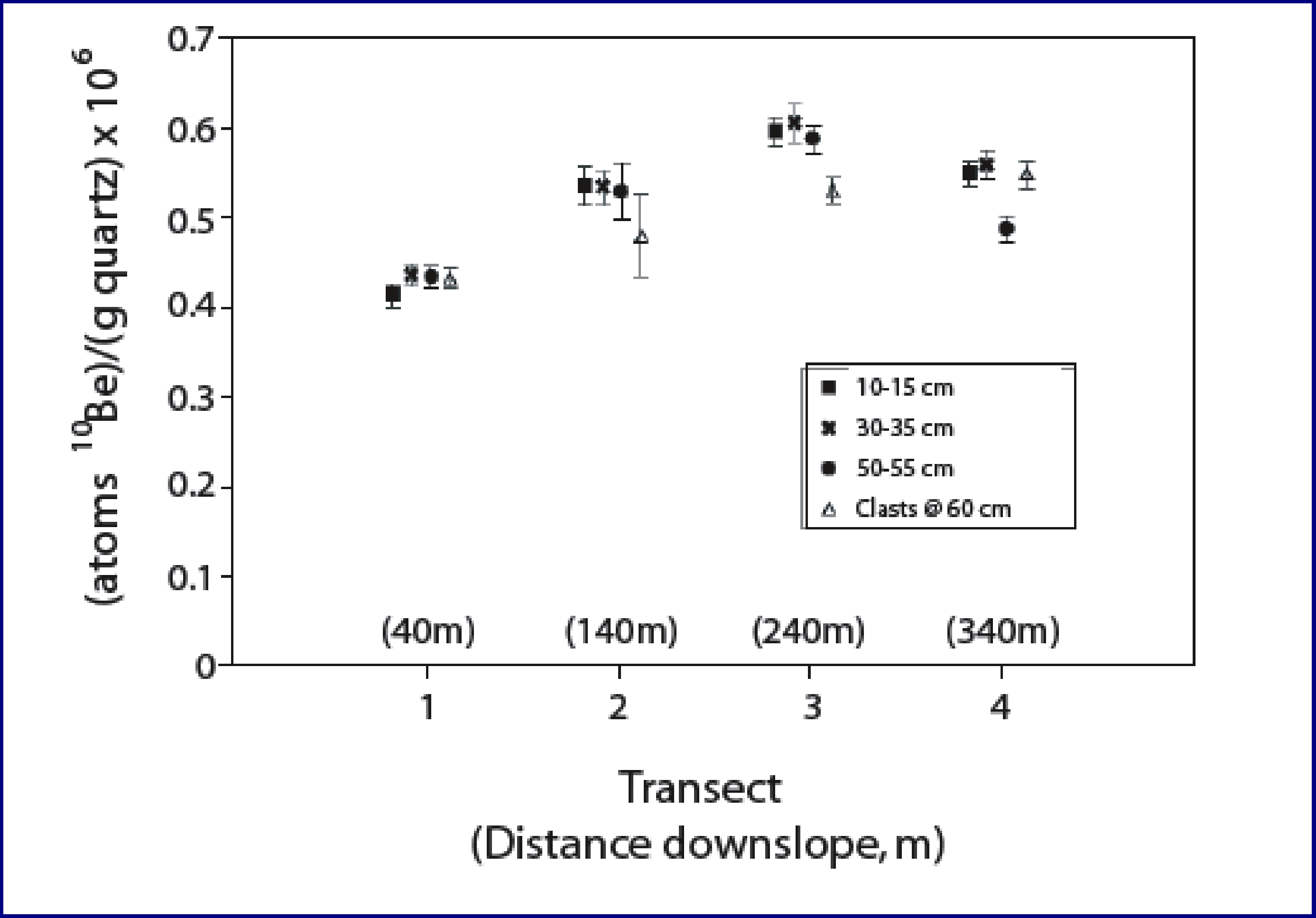
- Based on our mass balance model, there are two ways to achieve the ^{10}Be concentrations which we have measured:
  - Either the soil velocity remains constant at 1 cm/yr and the Active Layer Thickens by an additional 60 cm
    - Soil Flux = 55-115 $cm^3\ yr^{-1}\ cm^{-1}$
  - Or, soil velocity increases from 1-2 cm/yr near the hillcrest to 3-3.5 cm/yr at the bottom of the slope while the thickness of the Active Transport Layer stays constant
    - Soil Flux = 55-190 $cm^3\ yr^{-1}\ cm^{-1}$

What does this mean in terms of processes on the hillslope?

- We can't be sure which transport scenario is correct
- We can infer that soil velocity and the thickness of the active transport layer are most dependent on tree throw frequency and the rooting depth of mature trees
- Soil velocity can increase without a steepening of hillslope gradient
- Depending on soil velocity, sediment travels from hillcrest to the stream below in 13,000-40,000 years
- What about the decrease in ^{10}Be concentrations for the final transect?

Results

[^{10}Be] vs. Distance Downslope



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Decrease in Soil ^{10}Be Concentrations at Final Transect

- A couple of possibilities…
  - A transition to fluvial processes low on the slope could lead to faster soil removal, and soil ^{10}Be concentrations would be closer to the signature of weathered bedrock
  - Soil low on the slope is [illegible] different transport [illegible] Glacial Maximum

How do these rates compare with other hillslope studies?

Authors	*Location*	*Lithology*	*Climate*	*Soil Velocity* (cm yr^{-1})
McKean et al., 1993	Black Diamond Mines, CA	Shale	Mediterranean	1
Small and Anderson, 1999	Wind River Range, WY	Granite	Periglacial	0 - 0.25
Heimsath et al., 2002	New South Wales, Australia	Granite	Dry (<900mm annual precip)	1 - 3.5
This project	Great Smoky Mountains, NC	Sandstone	Humid-temperate	1 - 3.5

How do these rates compare to those of the desert piedmont where this method was developed?

- Nichols et al. (2002) report down-piedmont transport rates of decimeters to a meter per year
- Persico et al. (2005) tracked pebble transport rates in the same environment and report rates of centimeters to decimeters per year
- Our rates are different, but so are the environments and transport mechanisms!
- However, the methods have proven versatile

Erosion in the Southern Appalachians

Conclusions

- New use of cosmogenic nuclides is successful!
- Long-term rates of soil production for this hillslope agree with other modeled erosion rates for the Southern Appalachians
- The conventional link drawn between soil creep velocity and slope gradient should be challenged

Acknowledgements

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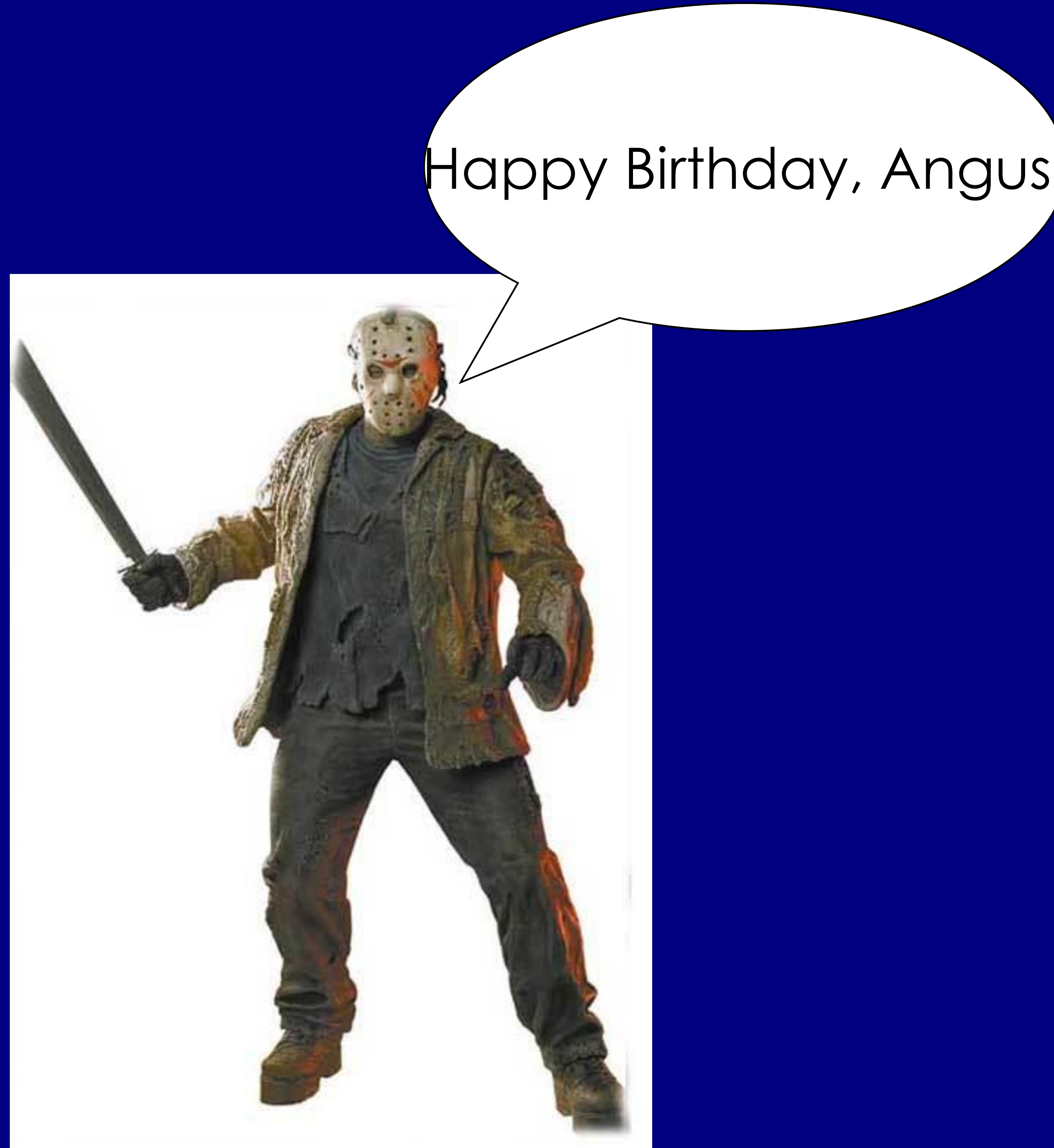
- Wendy-Sue Harper and Tom Neumann
- Luke Reusser, Jane Duxbury, and Colleen Sullivan
- The rest of the geo grads (past and present) and faculty
- Friends, family, and Angie Mae


Happy Birthday, Angus!