DETECTING LANDSCAPE RESPONSE TO PERTURBATIONS BY CLIMATE AND BASE LEVEL USING *IN-SITU* ^{10}Be AND ^{26}Al IN CENTRAL PENNSYLVANIA

Alison Denn, M.S. Candidate
Advisor: Paul Bierman
Department of Geology
The University of Vermont
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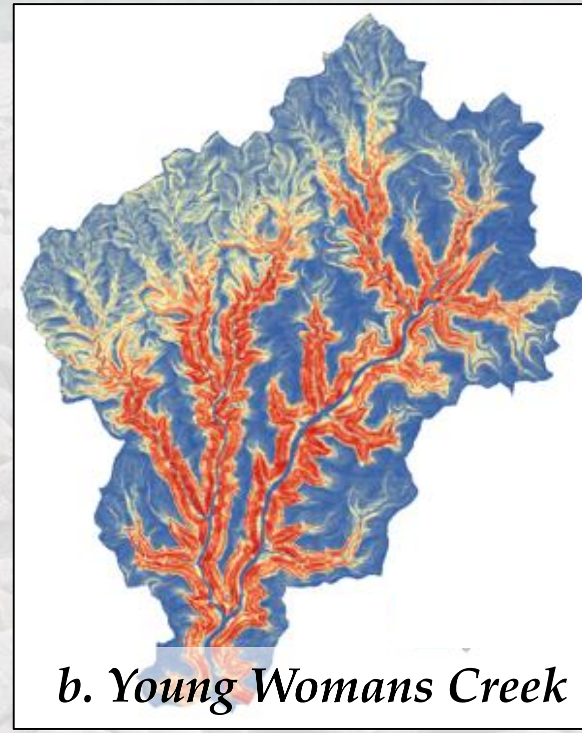
CZO | SUSQUEHANNA SHALE HILLS CRITICAL ZONE OBSERVATORY
NSF National Science Foundation WHERE DISCOVERIES BEGIN
The UNIVERSITY of VERMONT

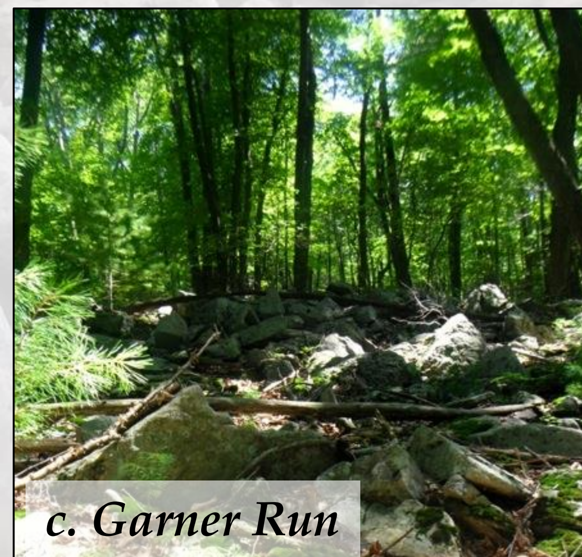
Today’s talk:

1. Introduction
2. Study Sites

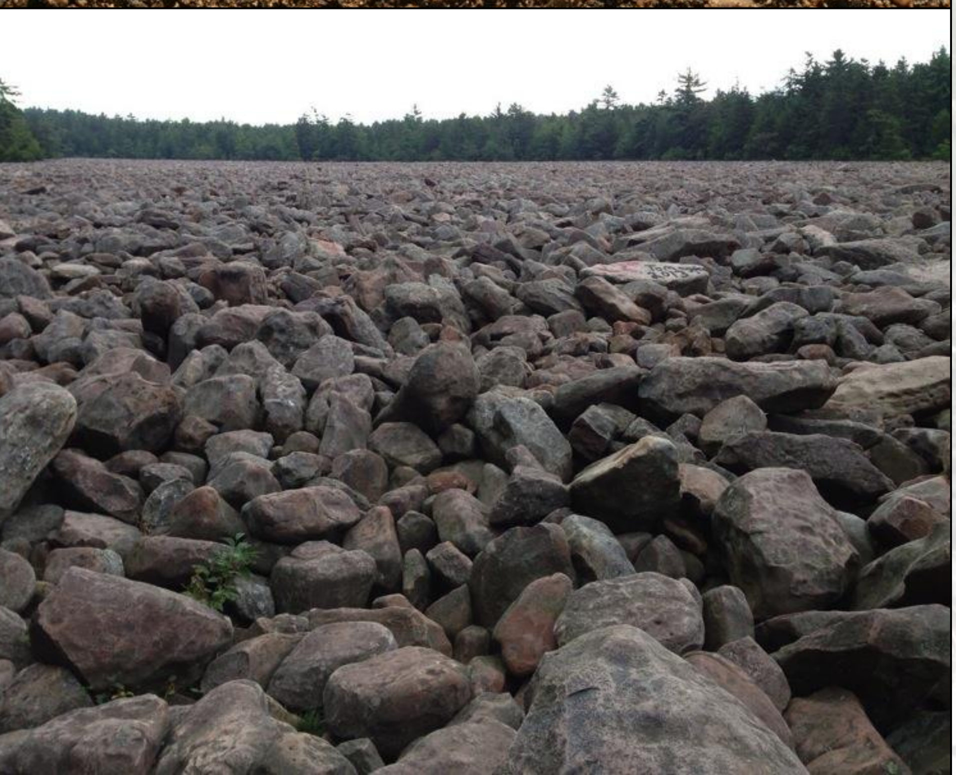
a. Hickory Run Boulder Field



b. Young Womans Creek



c. Garner Run



As a geomorphologist.

I ask questions such as…

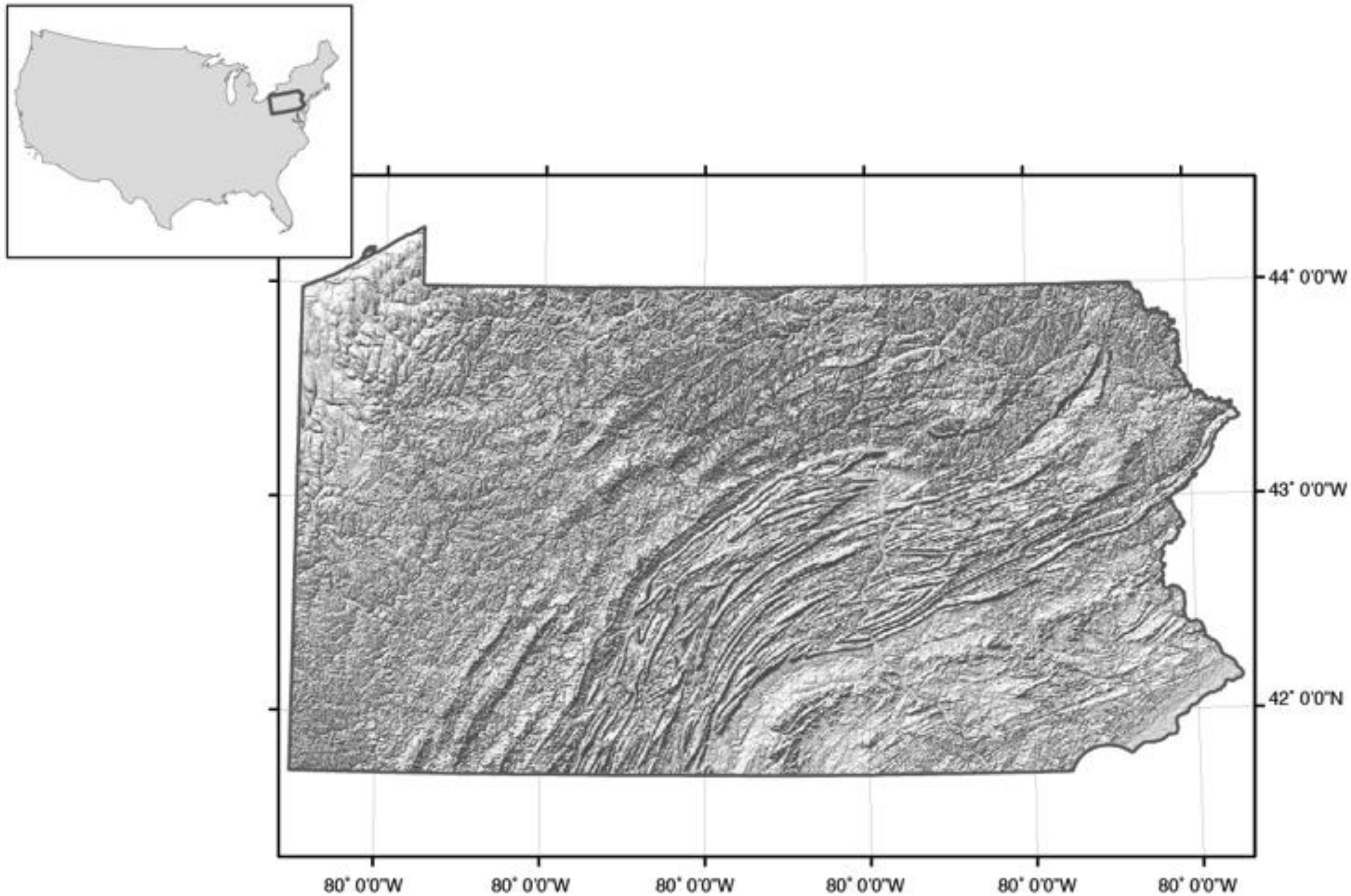
How long has that dirt been there?

How old are those boulders?

Do landscapes persist, or do they erode quickly?

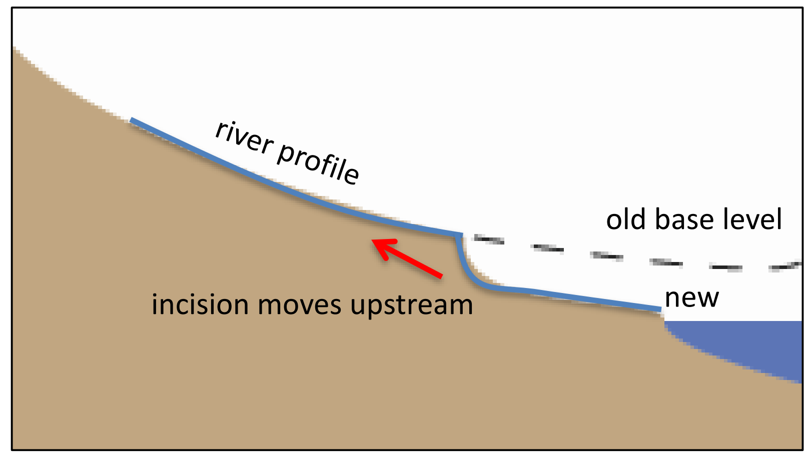
I think in timescales of 1,000's to 100,000's of years

My project focuses on Pennsylvania, a complex landscape



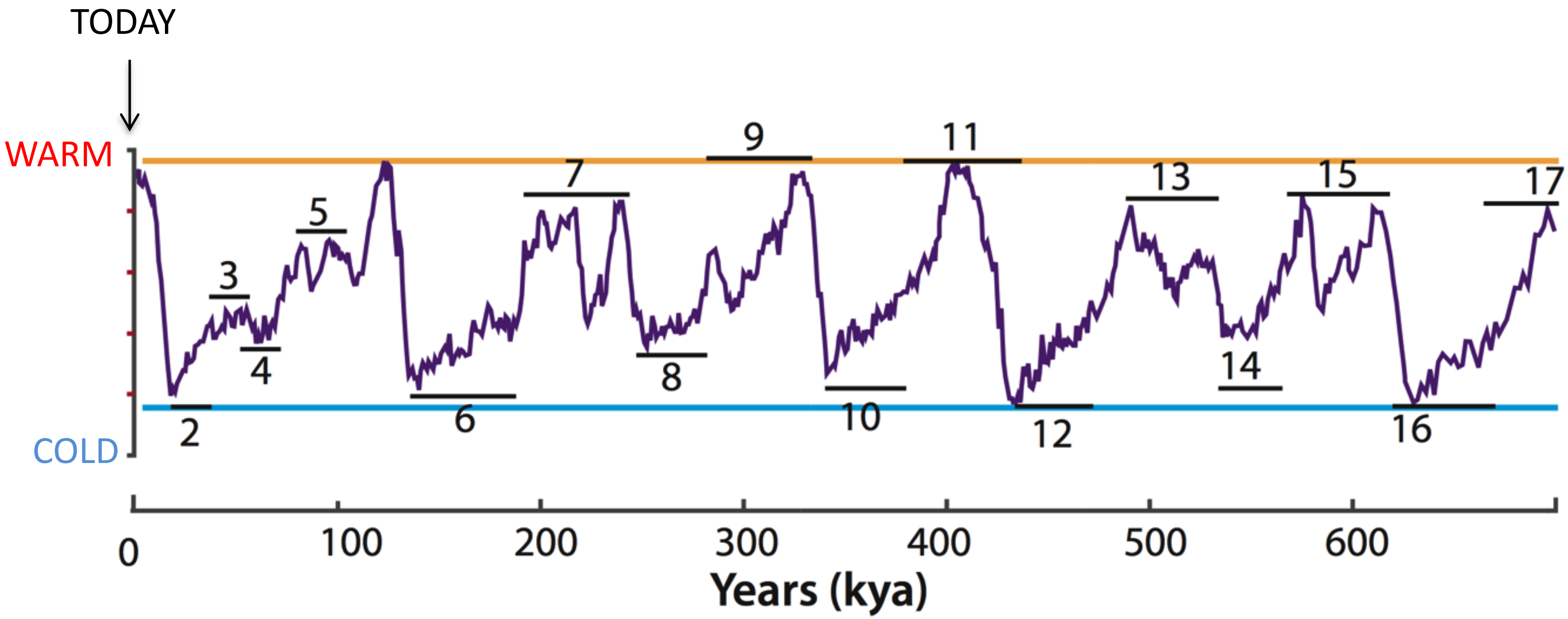
My project investigates the influence of two perturbations in the 'recent' geologic past in PA

1. CLIMATE



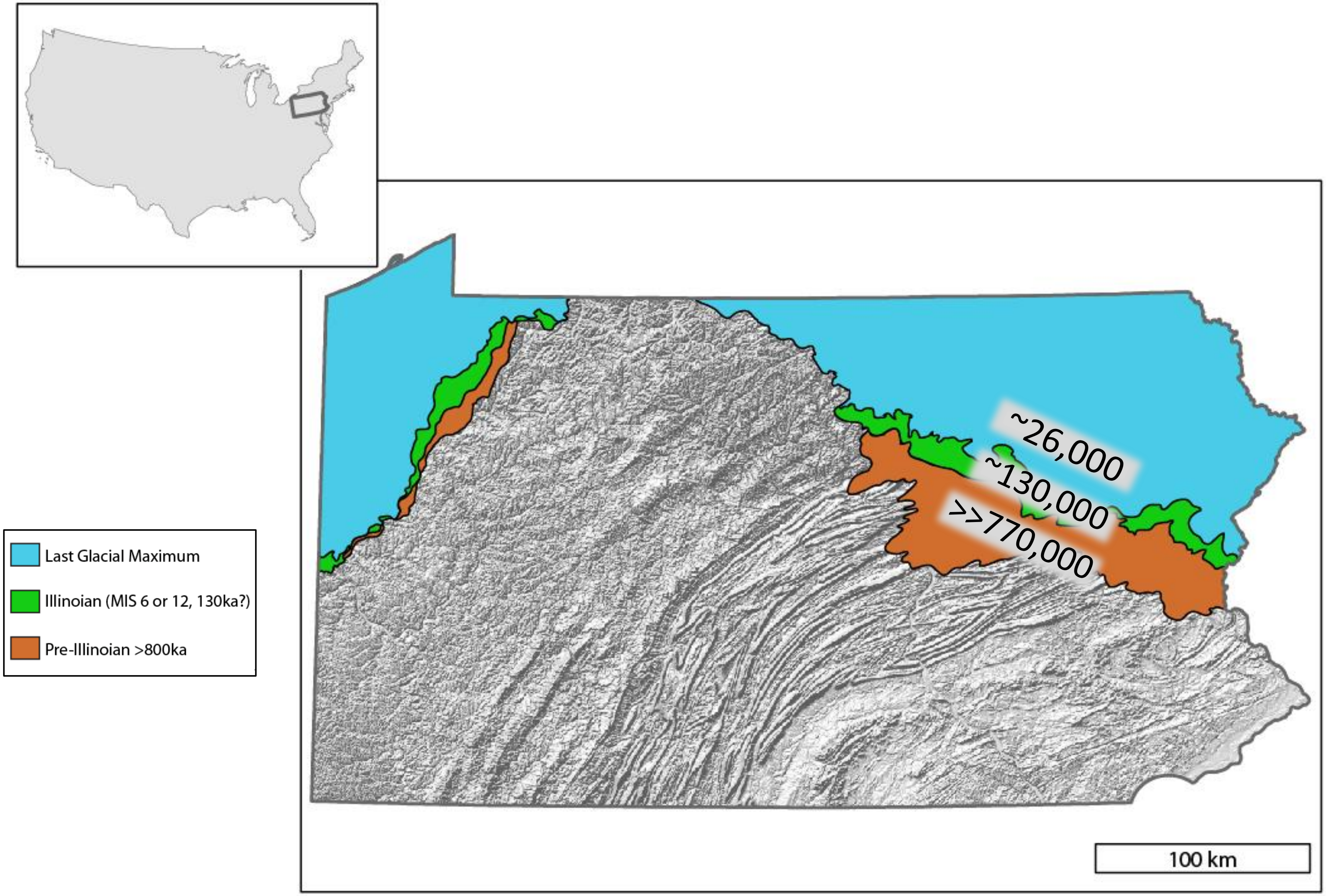
2. BASE LEVEL FALL

1. CLIMATE: GLACIAL/INTERGLACIAL CYCLES

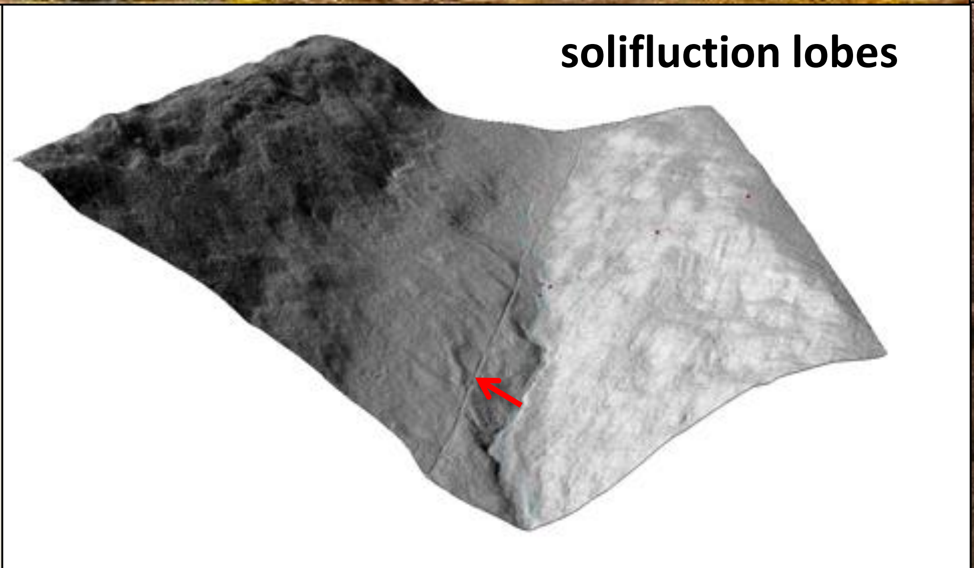


Adapted from Railsback et al. 2015

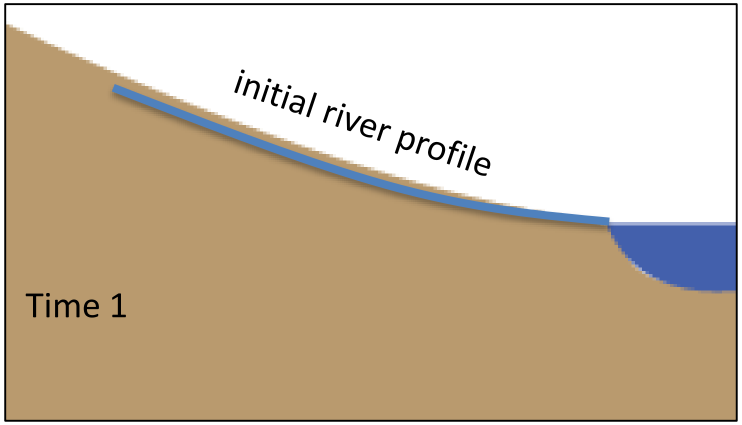
Pennsylvania glacial advances followed similar paths

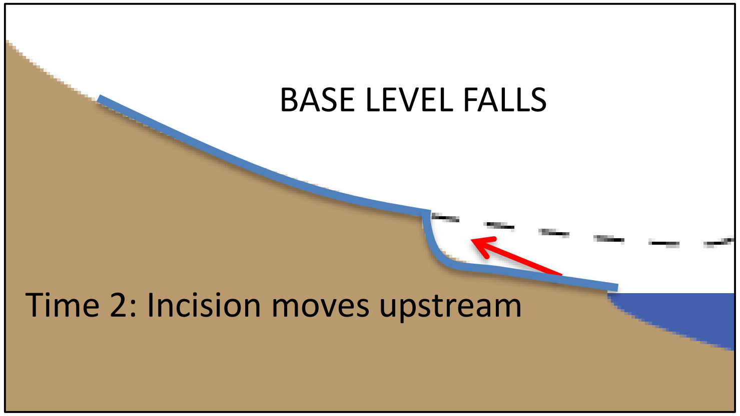


Most of Pennsylvania was 'periglacial' at glacial maxima



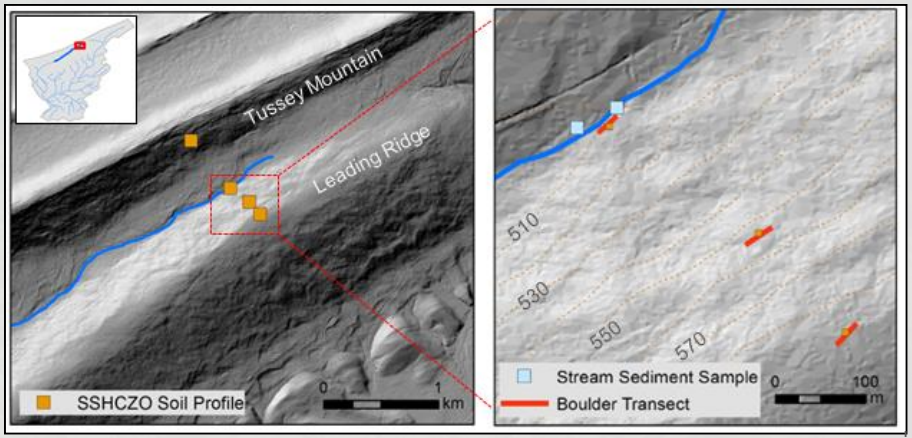
2. BASE LEVEL FALL





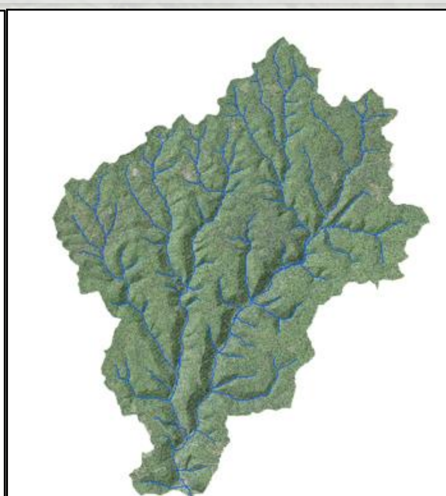
'**Base level**': elevation of land relative to ultimate drainage. Changes with tectonics, sea level, stream capture, or glacial drainage rearrangement.

My central question : *How have changes in climate and base level influenced the development of the landscape in Pennsylvania?*



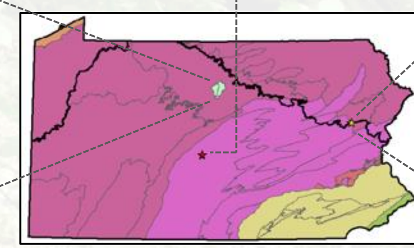
I analyze *in-situ* cosmogenic ^{10}Be in soils, boulder transects, and stream sediments at **Garner Run (CZO) and two endmember sites.**

BASE LEVEL

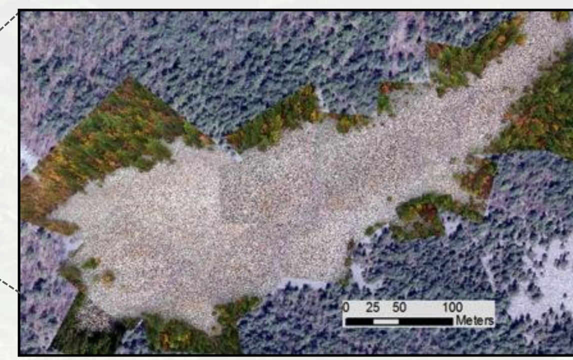


Young Womans Creek Watershed

What are erosion rates like in a landscape adjusting to base level change?



CLIMATE

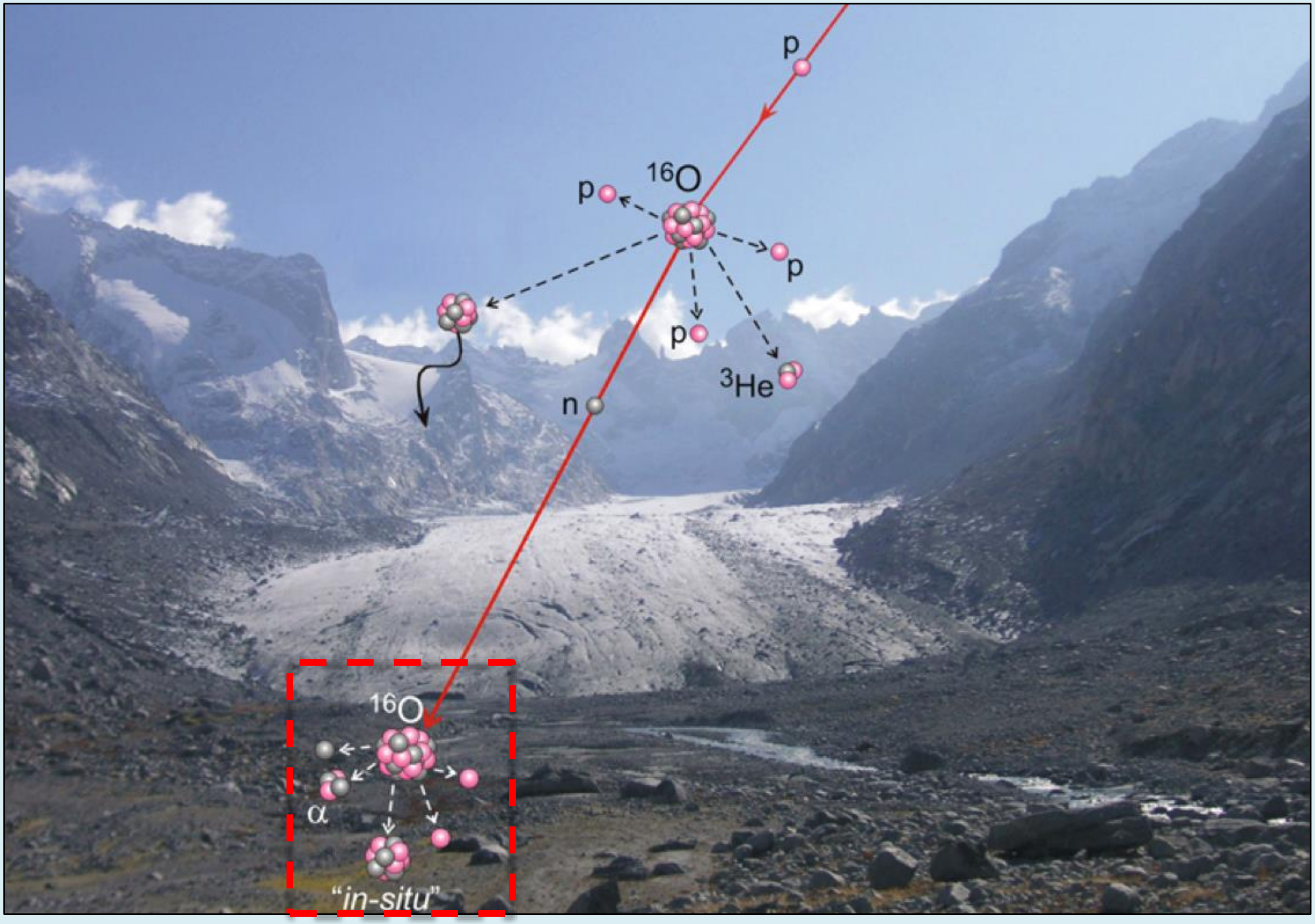


Hickory Run Boulder Field

How have glacial/interglacial cycles impacted the generation of regolith from bedrock?

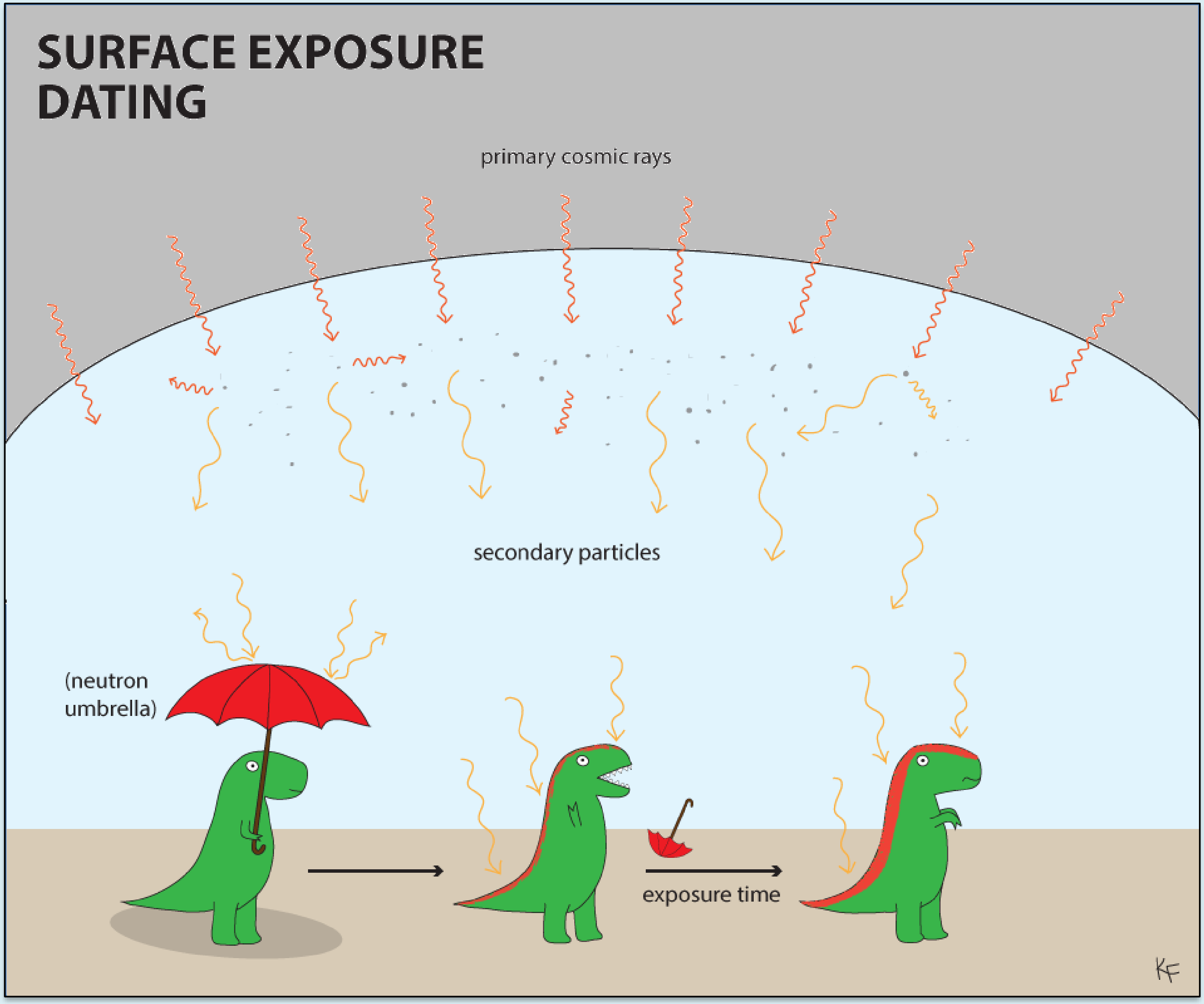
My tool: *in-situ* cosmogenic nuclides

Isotopes produced by cosmic rays within the crystal structure of quartz;
I use ^{10}**Be and** ^{26}**Al**.



http://www.gfz-potsdam.de/en/media-communication/news/details/article/ehrung-fuer-prof-f-v-blanckenburg/

Nuclides are used to date rocks



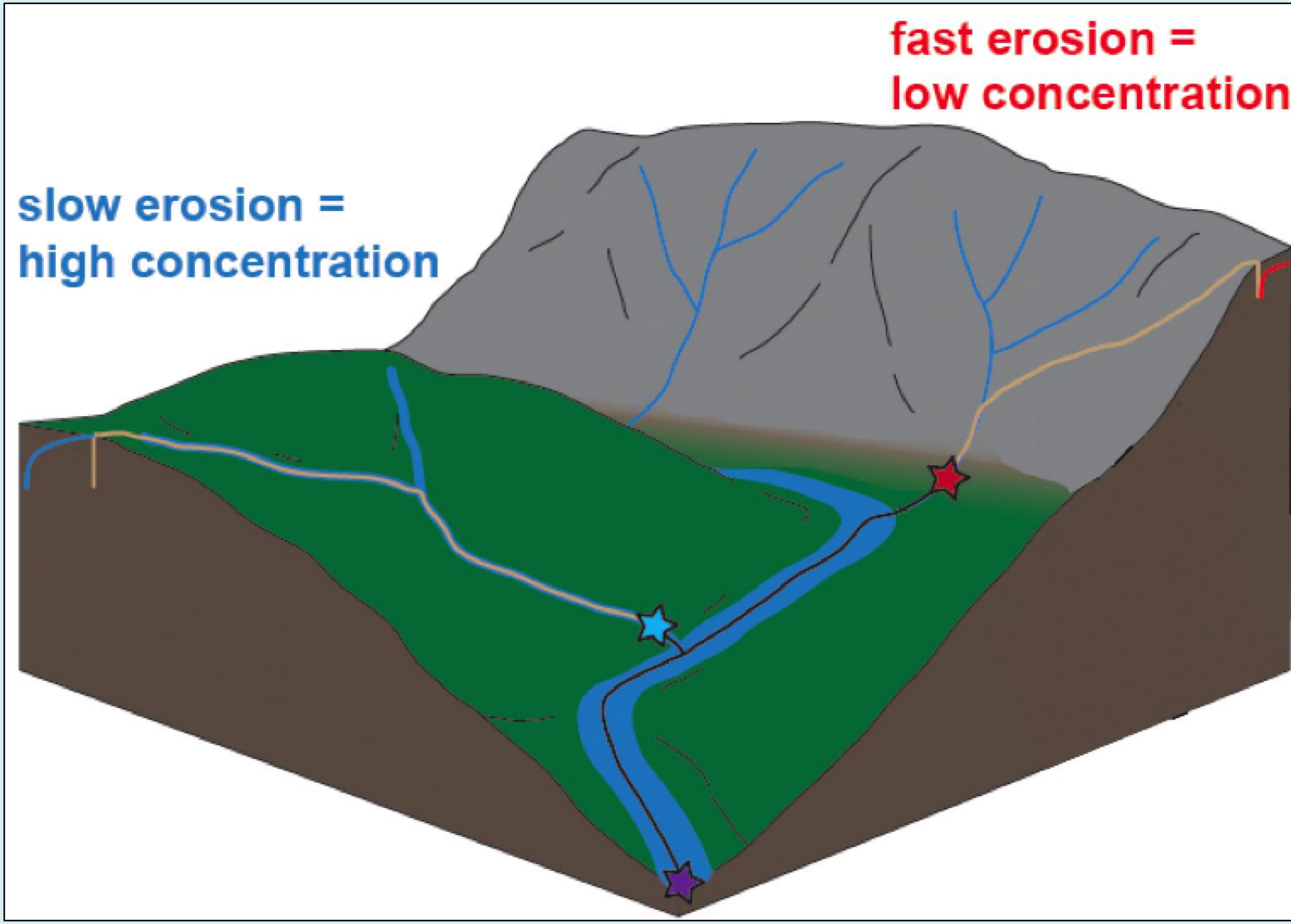
https://dinotopes.files.wordpress.com/2015/03/surface-exposure-dating-copy.png

DATING AND ASSUMPTIONS

In order interpret ^{10}Be concentration as an exact age I have to assume:

- No erosion after exposure
- No inheritance of ^{10}Be at initial exposure
- No intermittent shielding or complex exposure history (rolling, re-exposure, burial)

Nuclides are also used for erosion rates



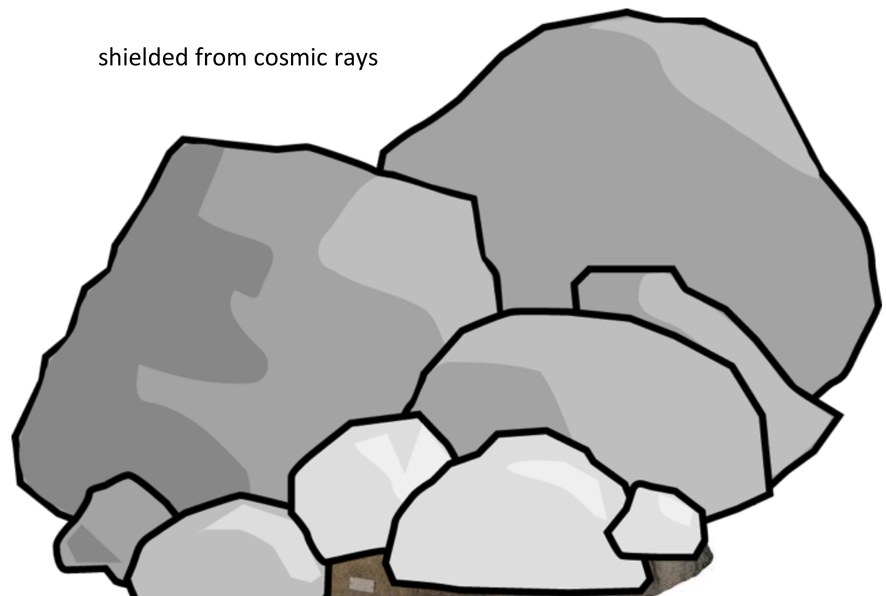
https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=imgres&cd=&ved=0ahUKEwjk9eihi8XSAhWH7YMKHTOtAHMQjxwIAw&url=https%3A%2F%2Fgeomaps.wr.usgs.gov%2Fbigfoot%2Ftask5.html&psig=AFQjCNEqLjMGTAWB7y42MZUq01vG-DioAA&ust=1488999965917230

Two isotopes can be used together for 'burial dating'

^{26}Al and ^{10}Be accumulate at a rate of ~7:1 at the surface

When an object is buried the ratio drops, as ^{26}Al half life (7.2×10^5) is shorter than ^{10}Be half life (1.4×10^6)

boulder exposed at surface
^{26}Al:^{10}Be = 7:1



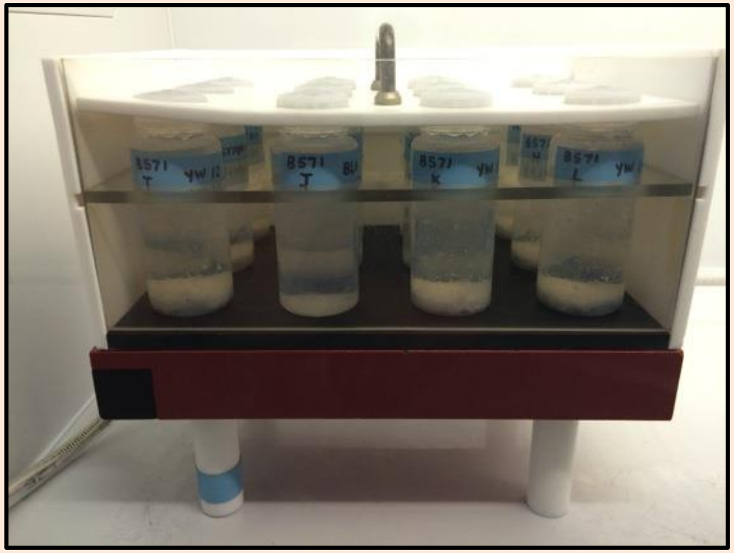
boulder gets covered for thousands of years
^{26}Al:^{10}Be << 7:1

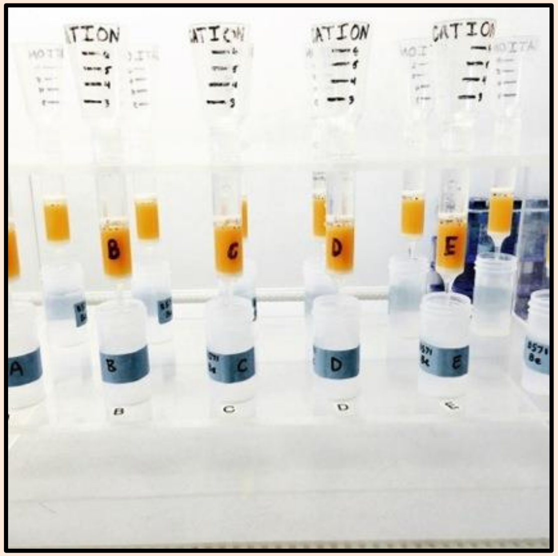
https://img.clipartfox.com/b7bf79ad8228f8551d551ea62155fe3d_boulders-clip-art-boulder-clipart-free_984-690.svg

http://www.nicros.com/wp-content/uploads/2011/02/boulders-lil-buddy.jpg

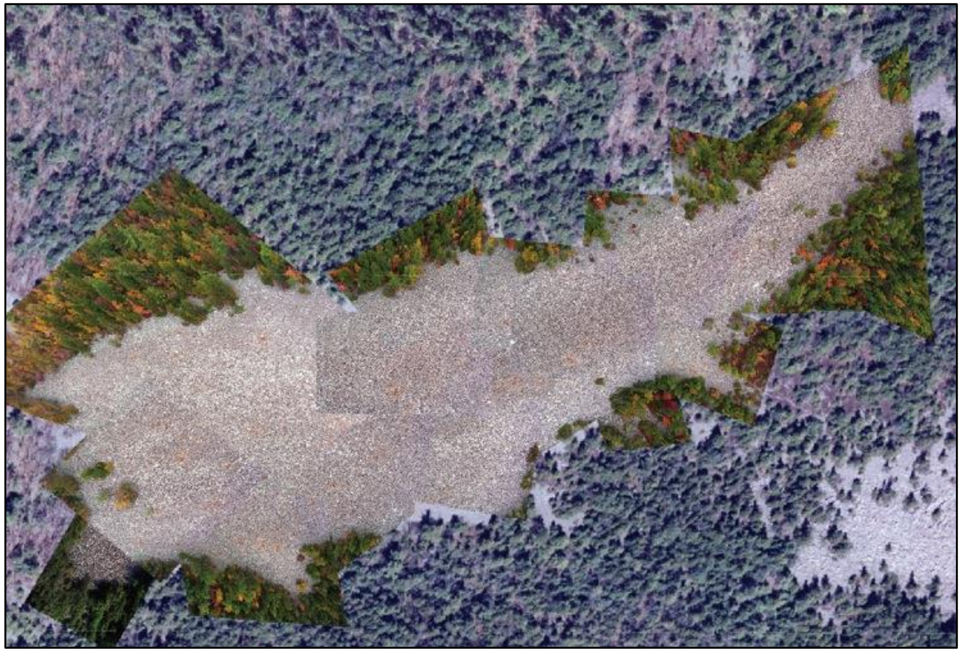
From rock to ^{10}Be…

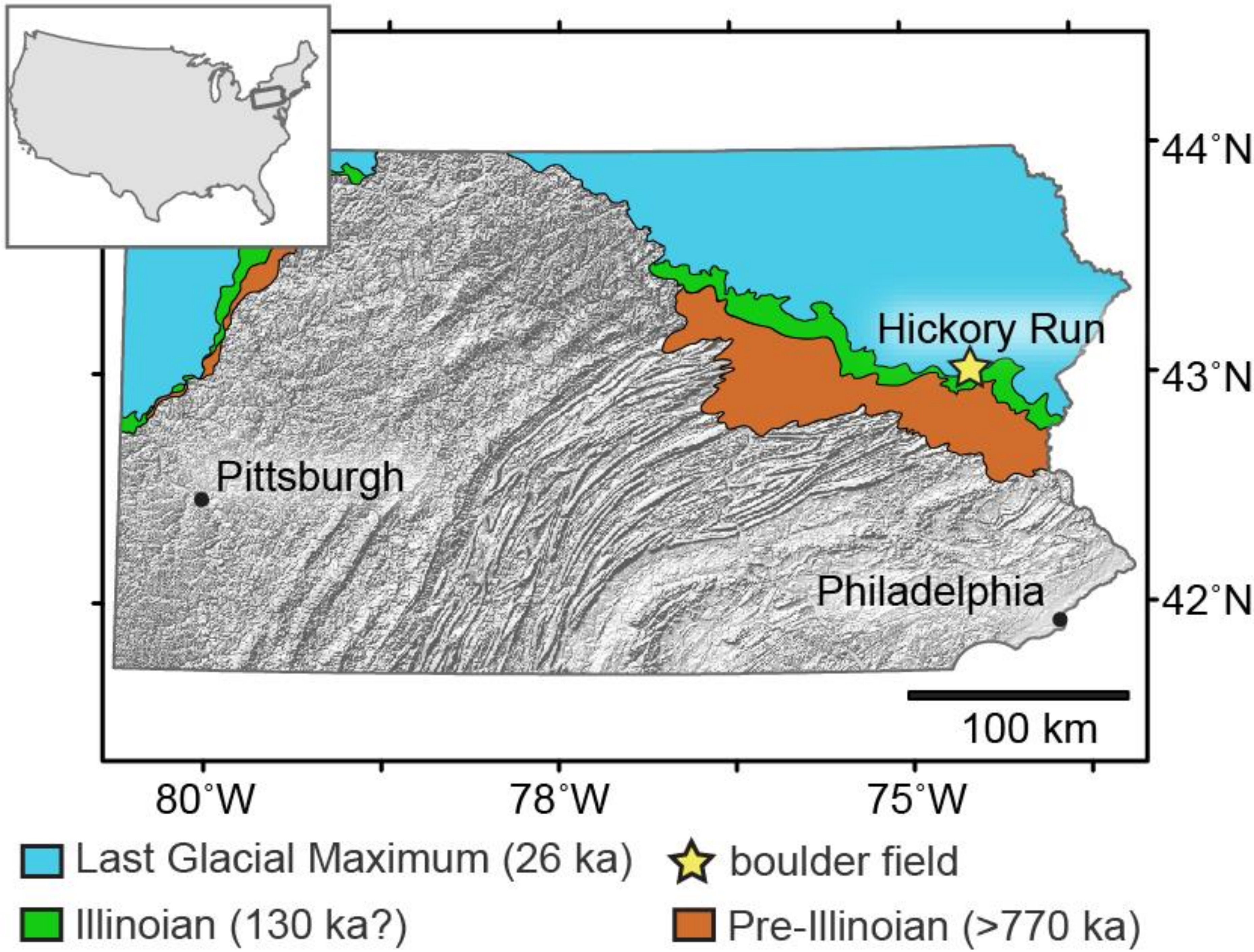
Find a sample, crush it, etch it, get it clean, dissolve it, get the gunk out, precipitate it, dry it, pack it, fly to CA, count atoms!

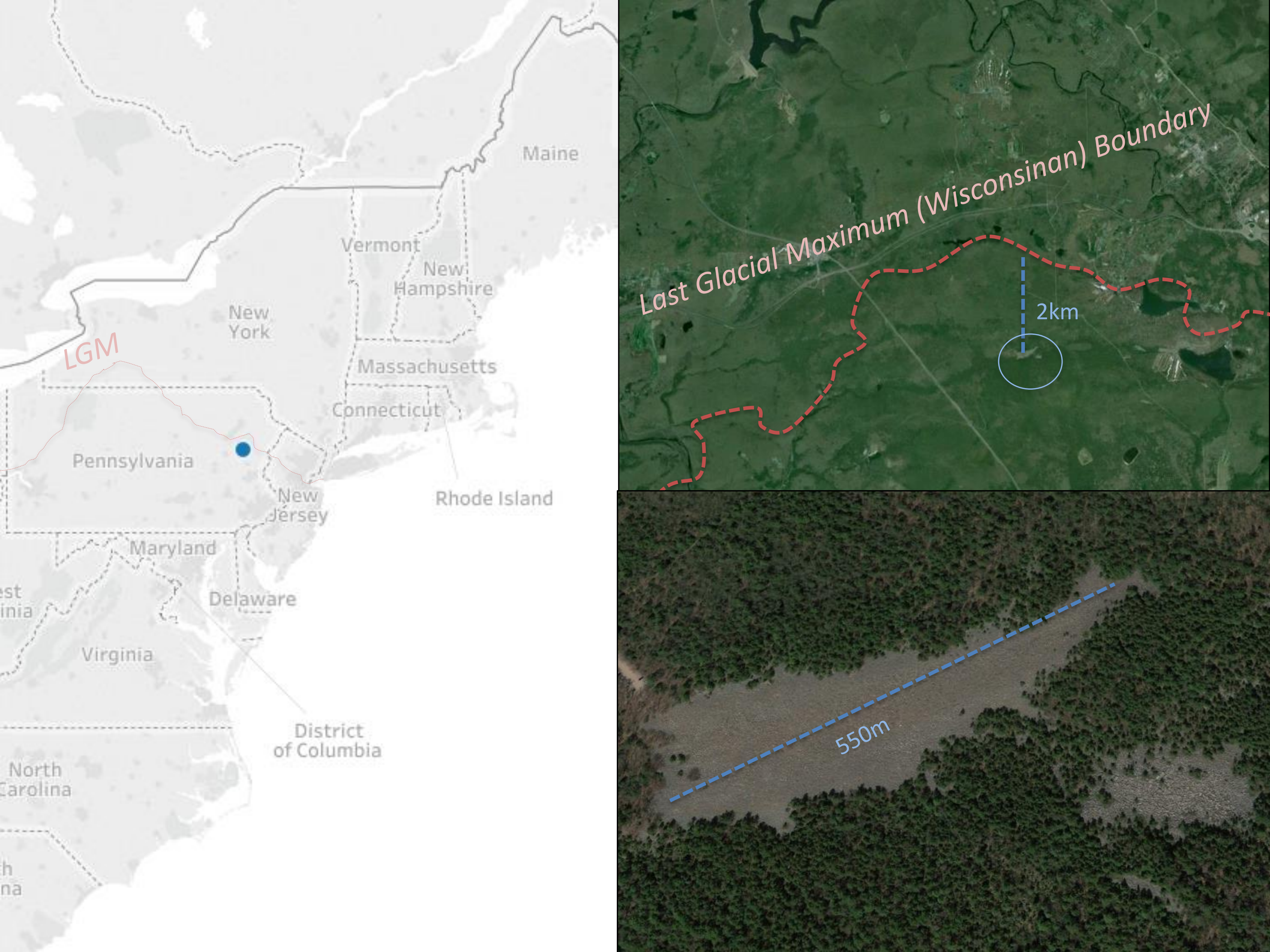




PROJECT 1: HICKORY RUN BOULDER FIELD




44°N
43°N
42°N
80°W
78°W
75°W
Hickory Run
Pittsburgh
Philadelphia
100 km
Last Glacial Maximum (26 ka)
Illinoian (130 ka?)
boulder field
Pre-Illinoian (>770 ka)


Maine
Vermont
New Hampshire
New York
Massachusetts
Connecticut
Rhode Island
LGM
Pennsylvania
New Jersey
Maryland
Delaware
Virginia
District of Columbia
North
Last Glacial Maximum (Wisconsinan) Boundary
2km
550m

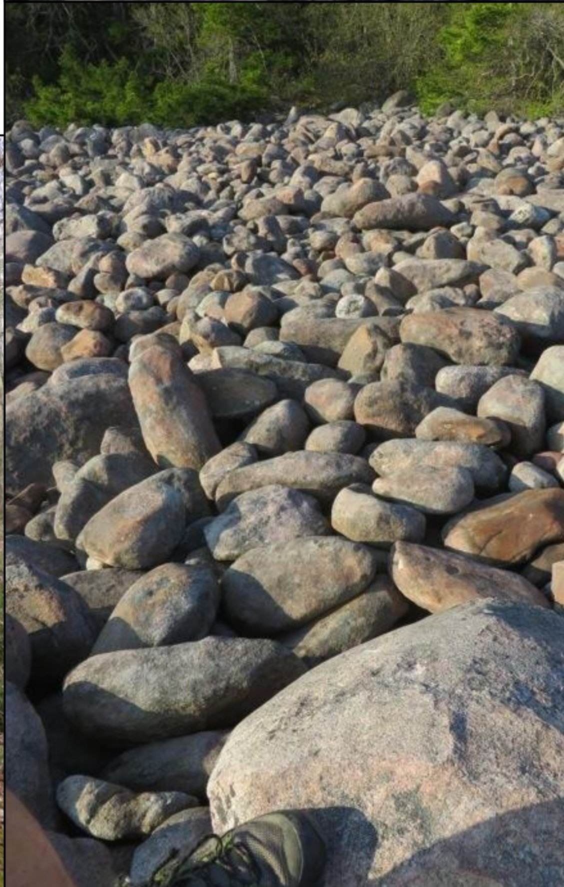
The Past

Boulder Field formed 20,000 years ago during last ice age. Ice a mile thick covered most of Canada and part of the United States. This ice sheet stopped less than one mile north of Boulder Field and greatly cooled the climate. Cave dwellers, woolly mammoths, and saber-tooth tigers roamed the world south of the ice sheet during the Wisconsin Glacial Period.

The yearly temperature was 20° to 25° F cooler and winter lasted for six months. The average annual temperature was below freezing, causing the ground to be frozen throughout the year. This is called permafrost.

GUIDING QUESTIONS

1. How old is this thing really?!?
2. Spatial trends in ^{10}Be?
3. Glean some idea of process?



We sampled 52 boulders for in-situ ^{10}Be analysis, and 20 for ^{26}Al

TORS (NE OF MAIN FIELD)

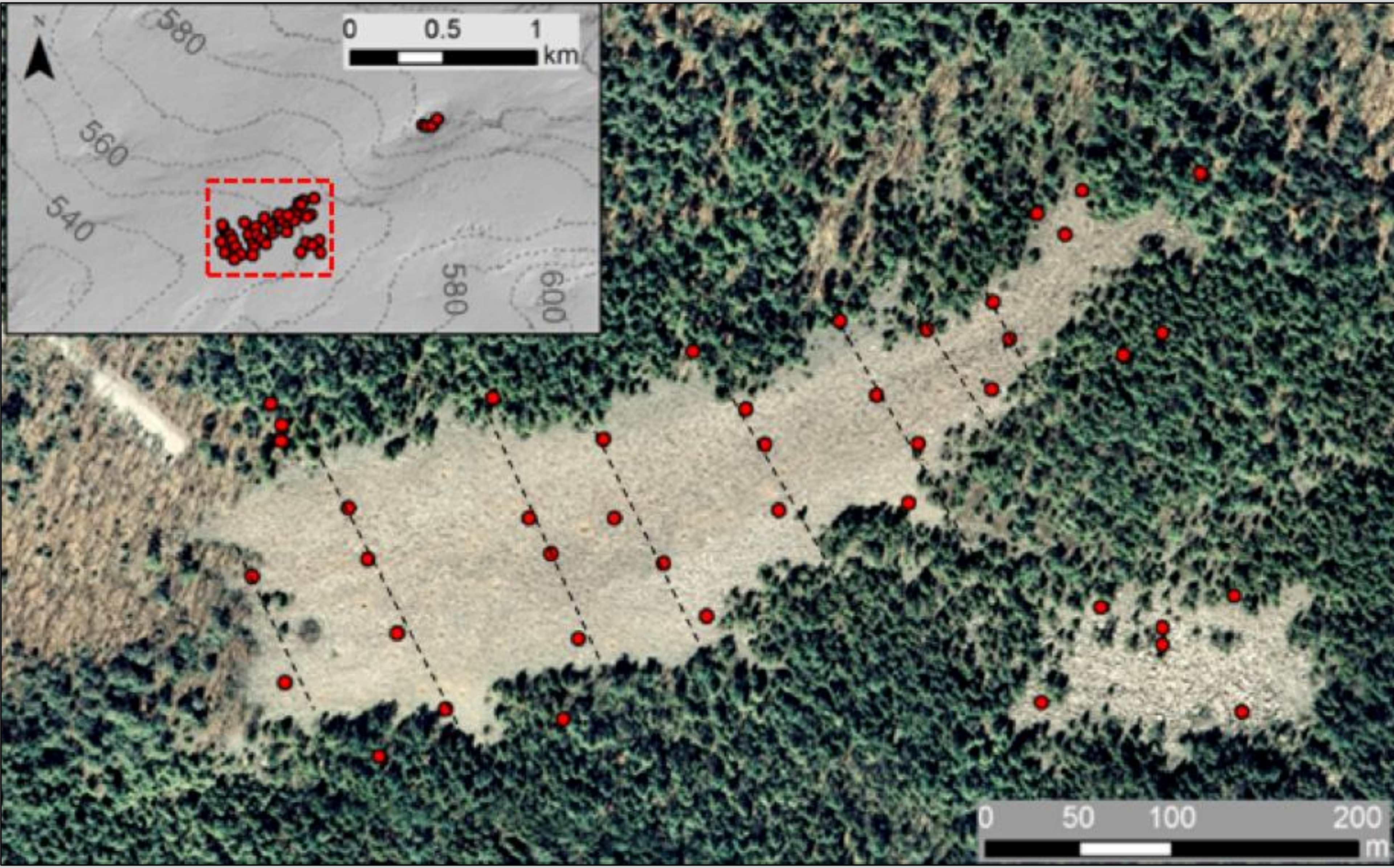
TOP OF FIELD (UPSLOPE)


BOTTOM OF FIELD (DOWNSLOPE)
HR 04
A
B
C
D
250 m

SUB-FIELD (SE OF MAIN FIELD)

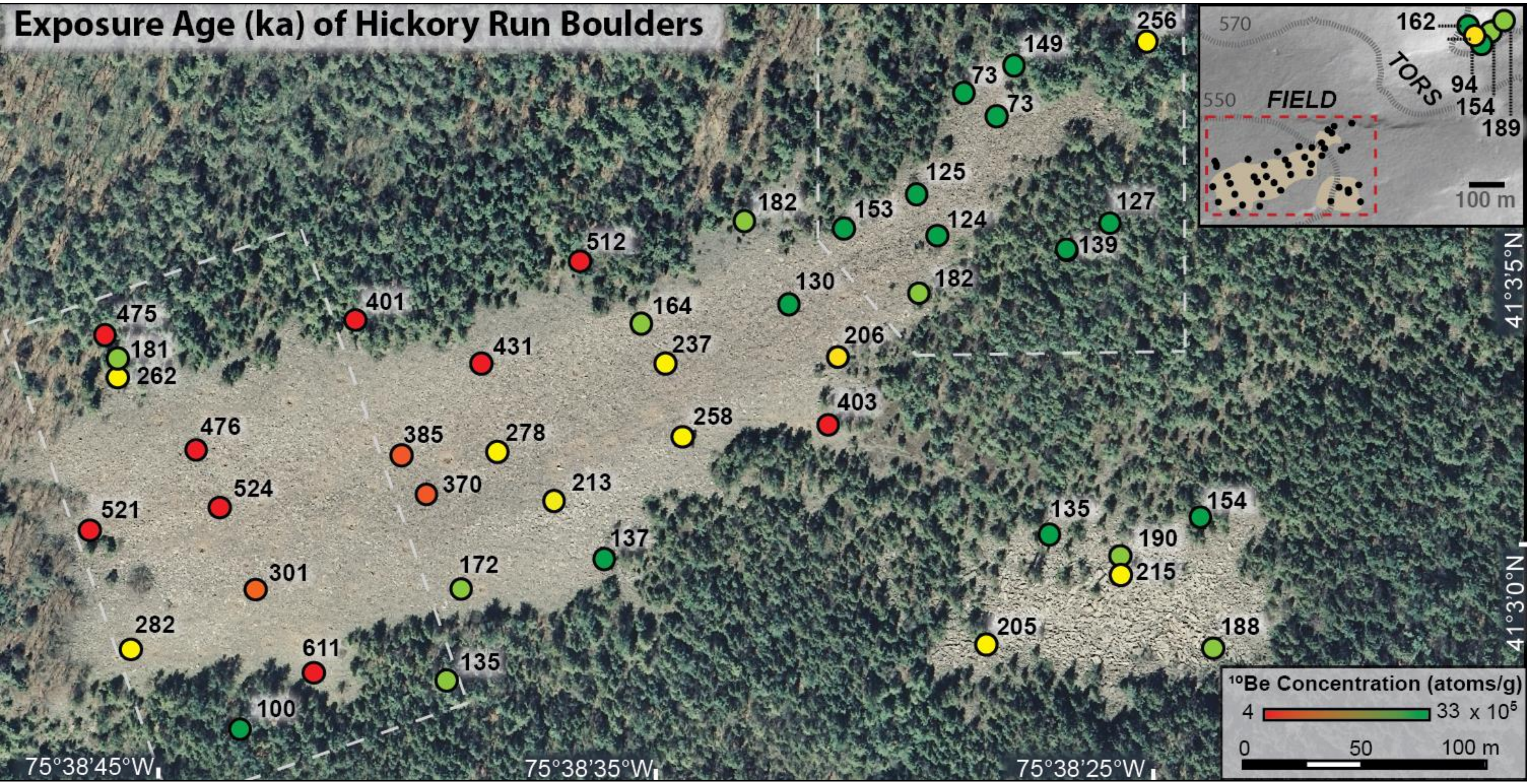
[Aerial View of Hickory Run]

SAMPLING STRATEGY

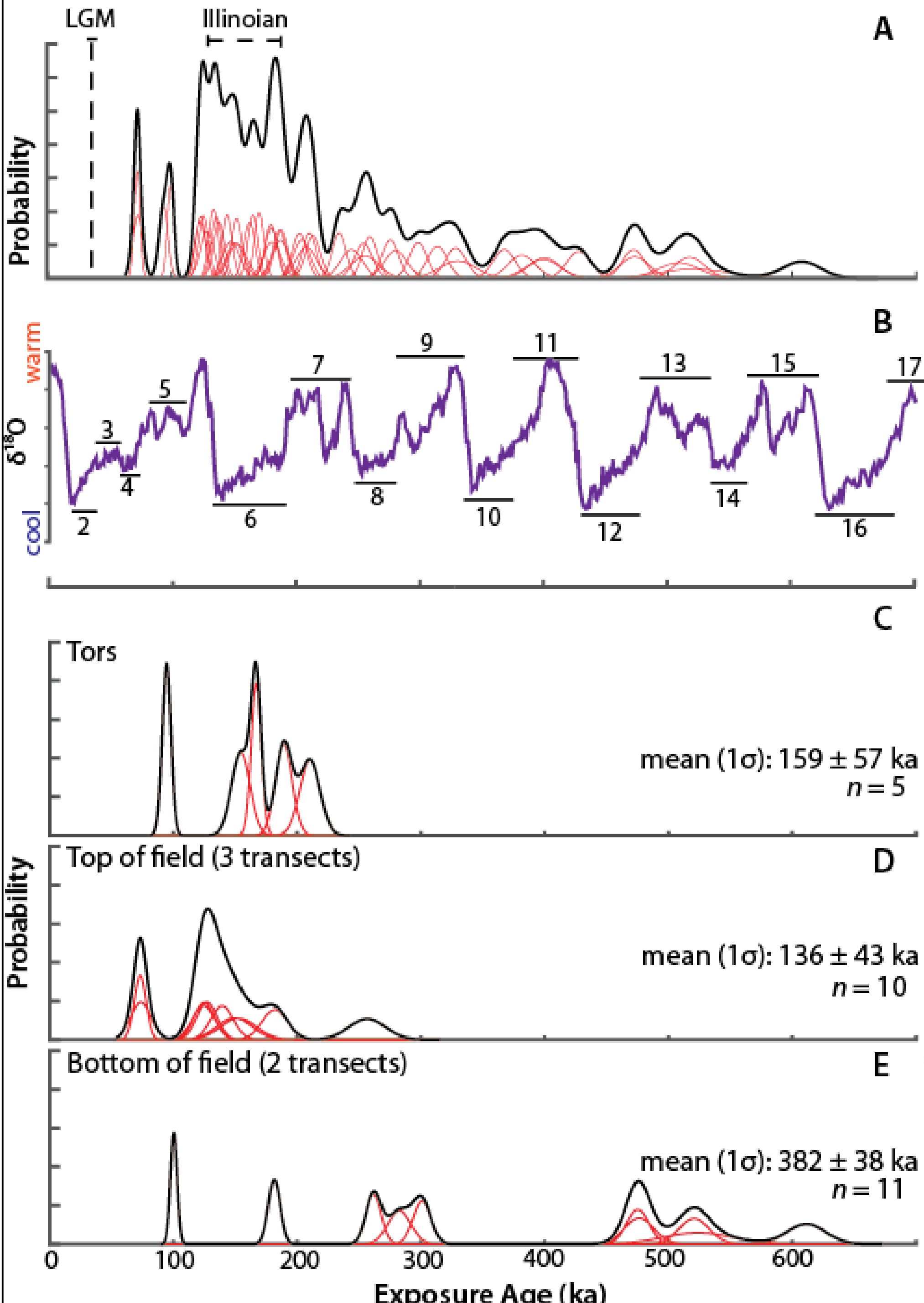


Remember this!

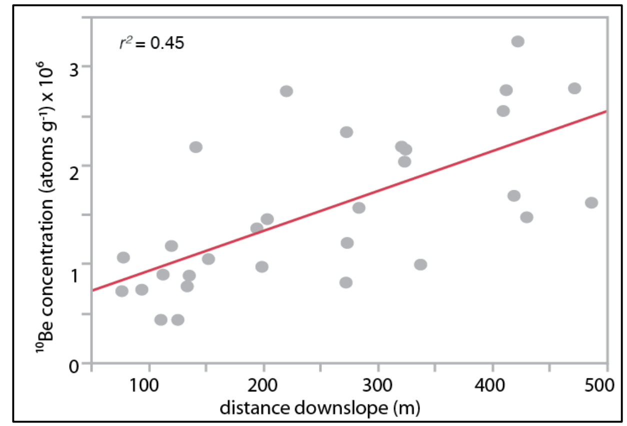
If I make many simplifying assumptions…

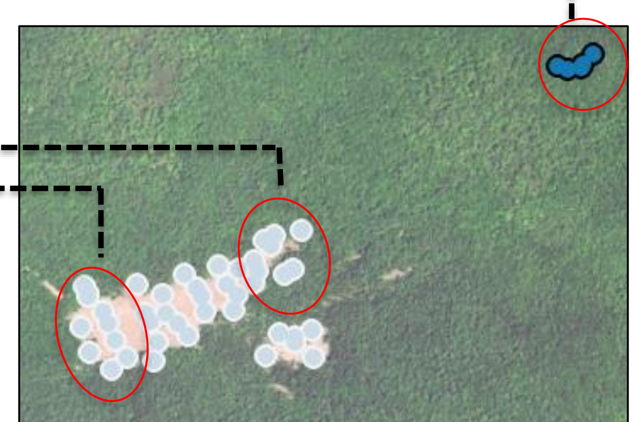


Minimum limiting ages of a half million years!



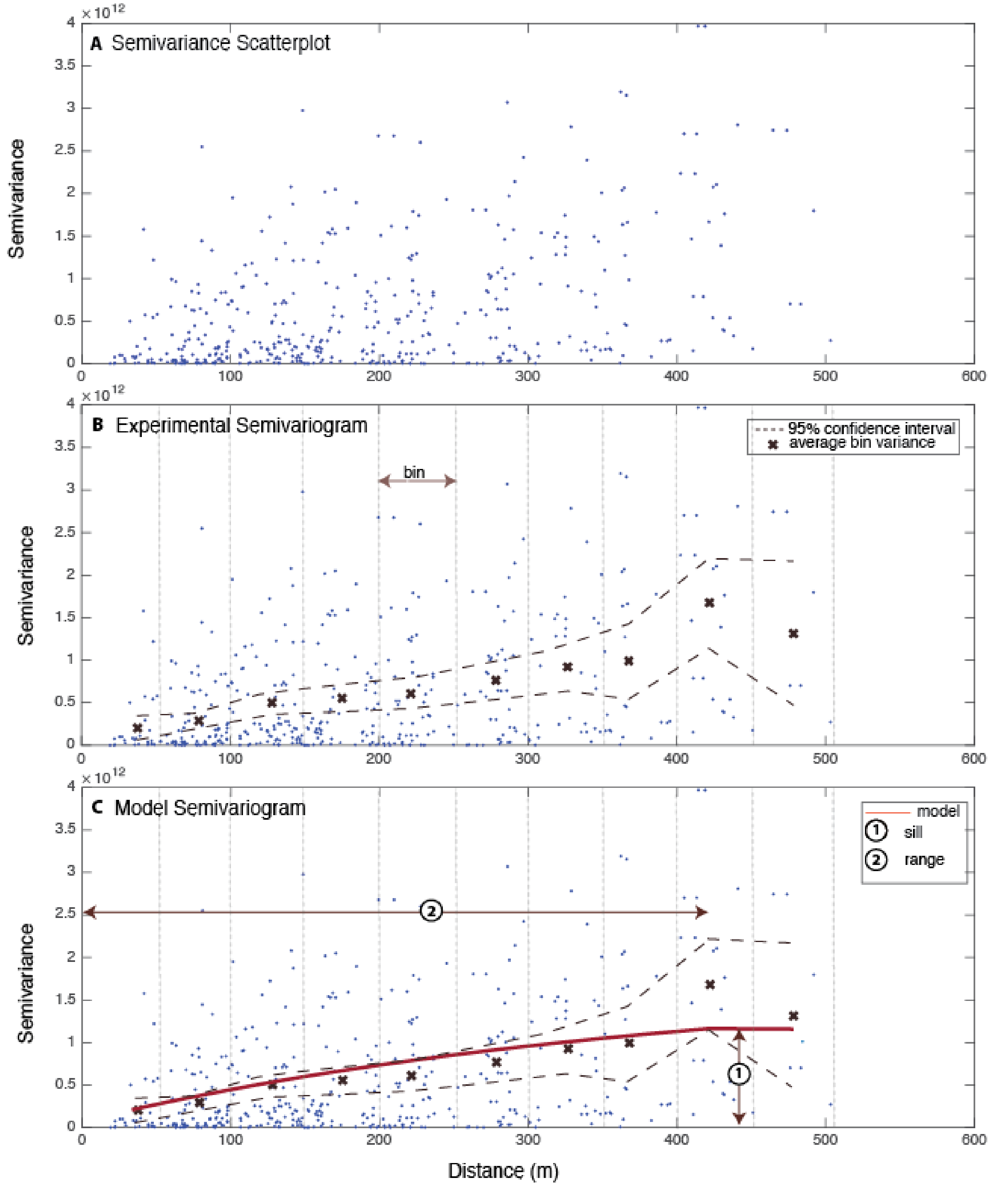
SPATIAL AND TEMPORAL TRENDS IN ^{10}Be



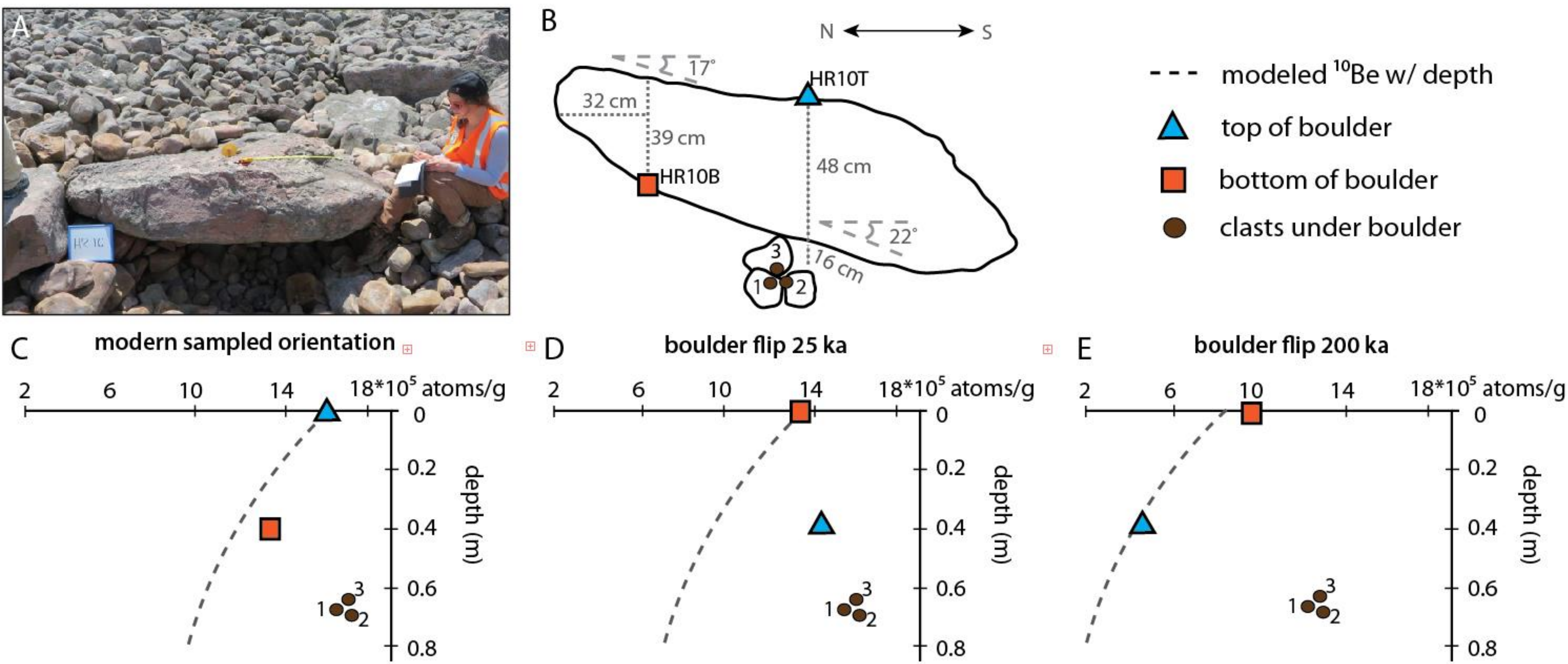


Semivariogram

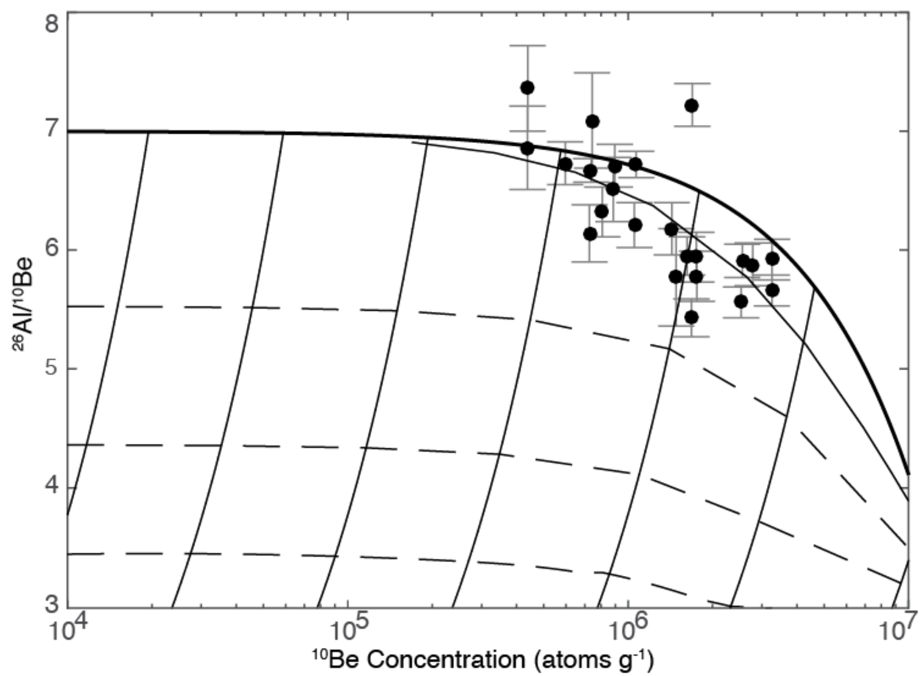
A second, perhaps more elegant, way to express spatial autocorrelation in boulder ages



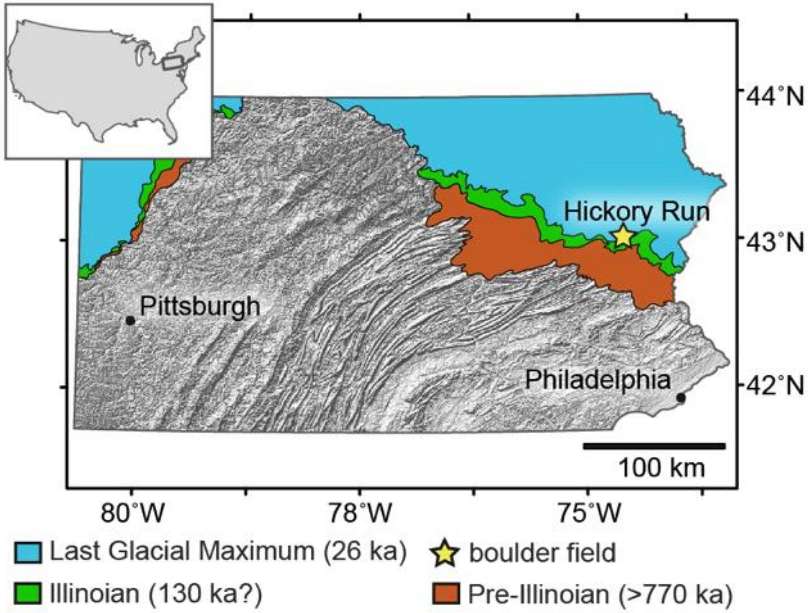
Hickory Run boulders are dynamic.
They flipping flip!



Two-isotope results: boulders are more or less indistinguishable from production ratio



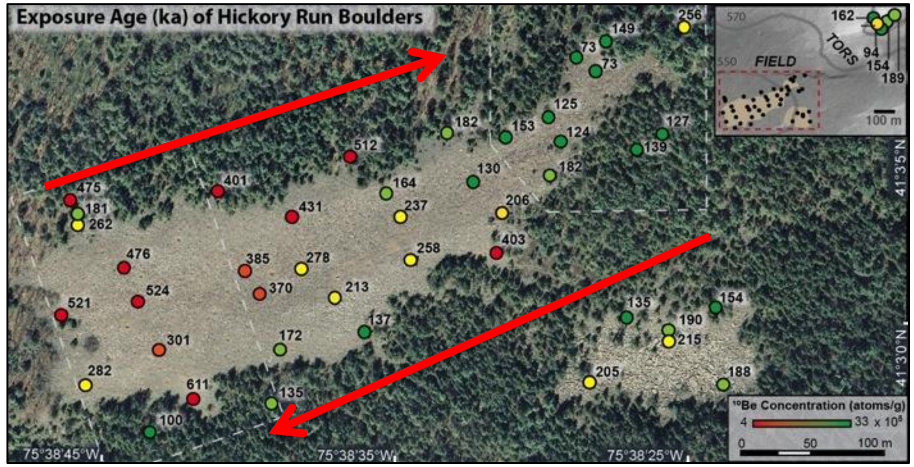
WAIT WHAT



But the field was under ice at 130 ka?
How can boulders be so old?!

1. *Glacial mapping is wrong?*
2. *Cold-based, non-erosive ice?*

HOLD UP



^{10}Be increases downslope… why?

1. *Boulders moved downslope*
2. *Frost-driven scarp retreat*

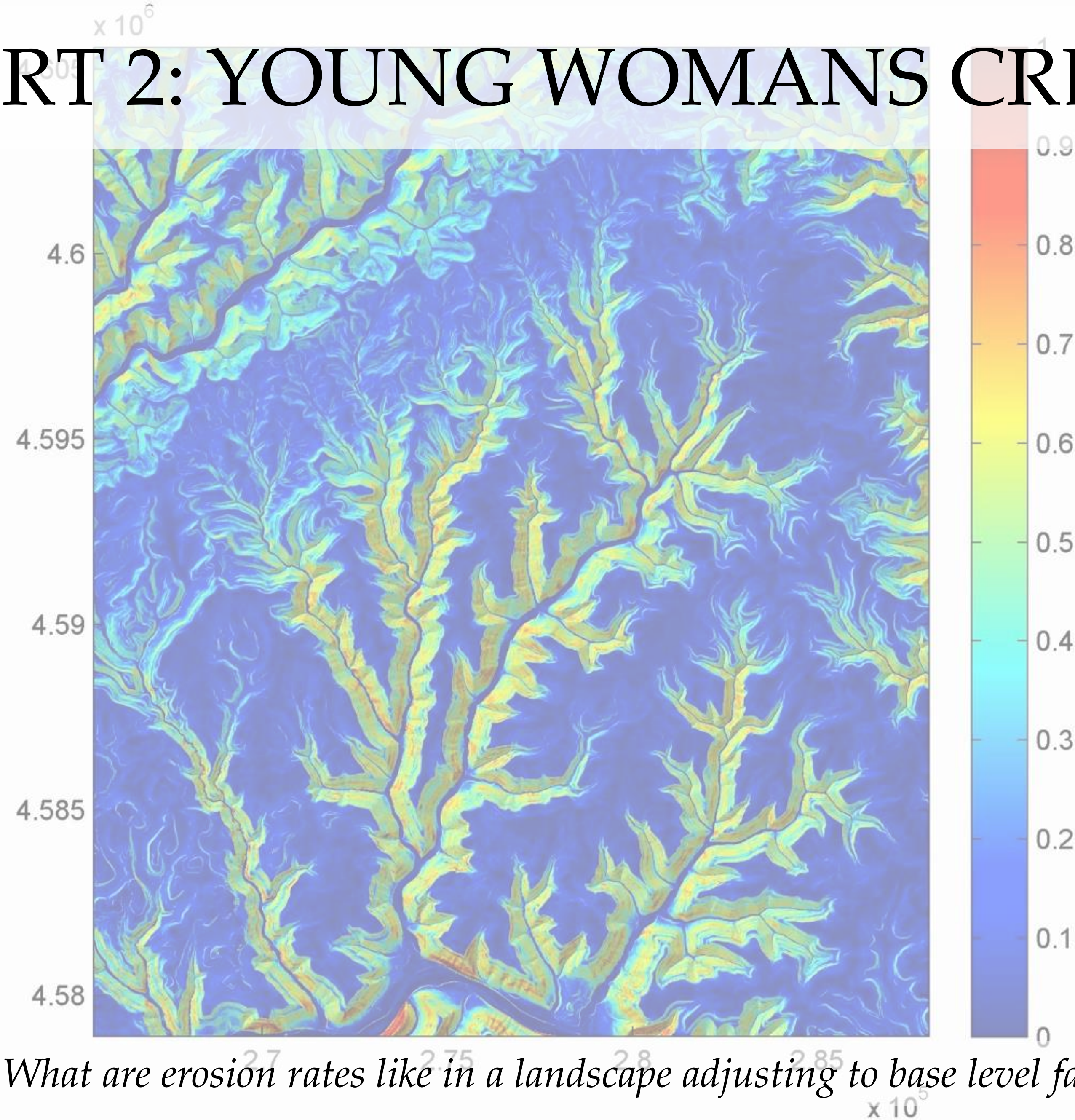
Main Takeaways…

- Periglacial boulder fields are ancient, dynamic, multigenerational features

- No LGM ages; mode is MIS 6

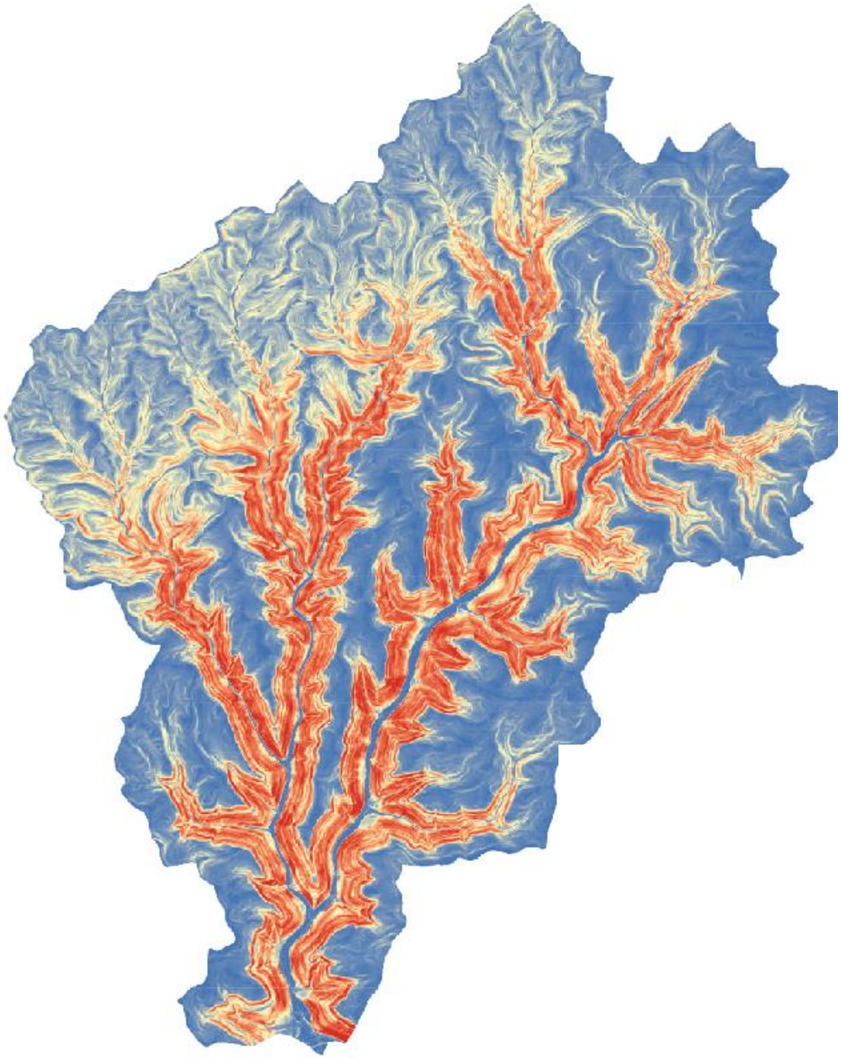
- Age of the ‘Illinoian’ in PA? Or cold-based (non-erosive) ice at 130 ka.

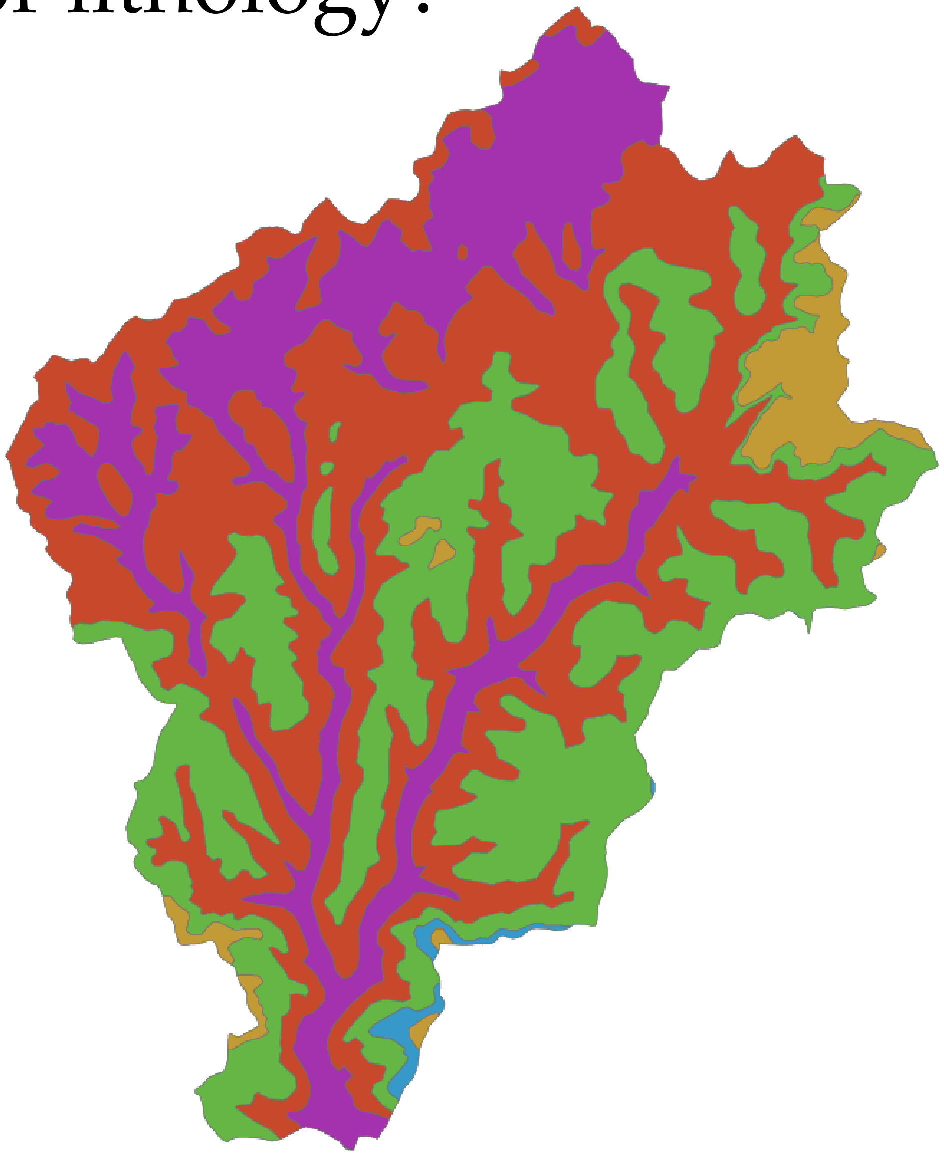
PART 2: YOUNG WOMANS CREEK



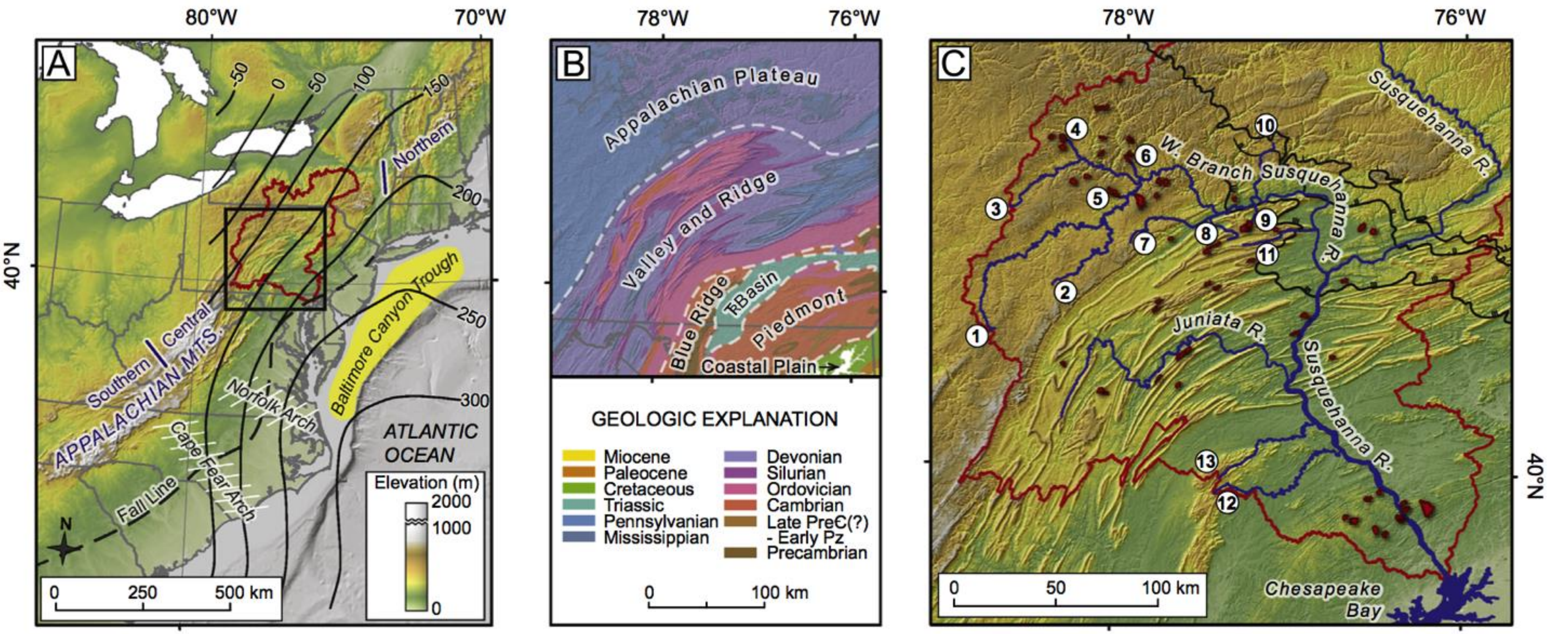
What are erosion rates like in a landscape adjusting to base level fall?

What exerts a stronger control on erosion: base level fall, or lithology?



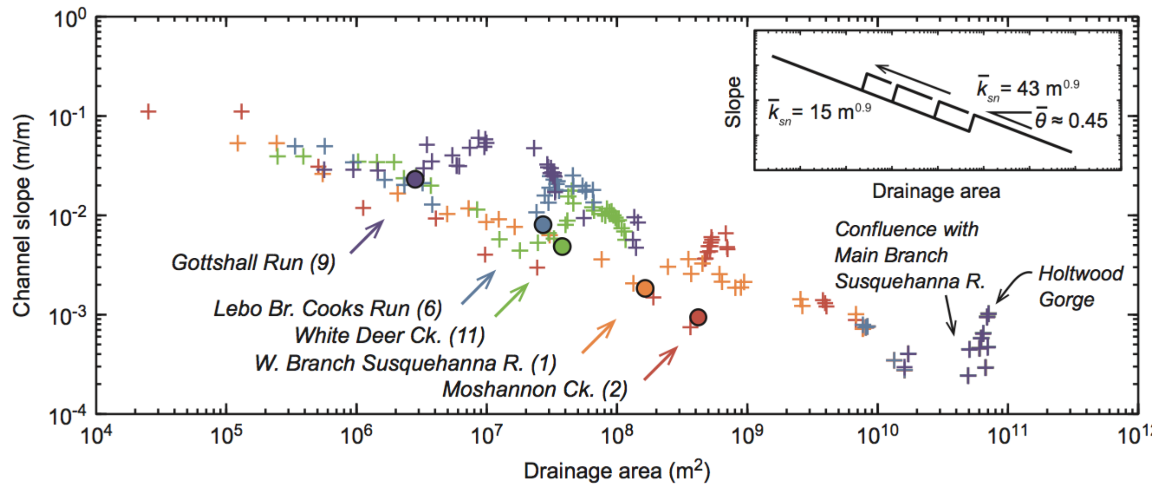


Context: Miller et al. 2013 in Susquehanna River Basin (SRB)



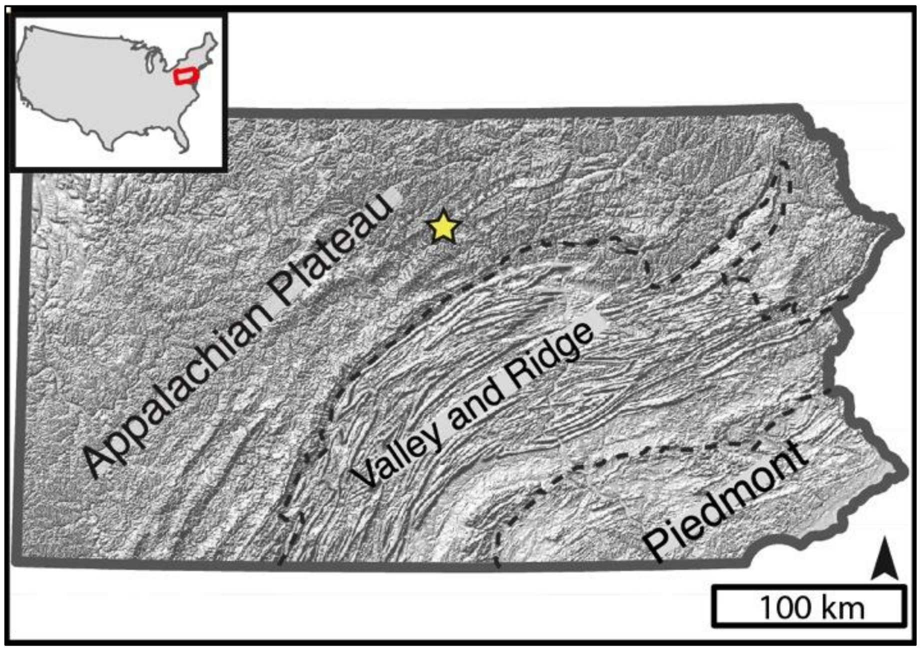
- Analyzed regional longitudinal profiles, compared them with previously measured cosmogenic erosion rates in the area
- Detected wave of knickzones propagating upstream in response to past base level fall in the Miocene

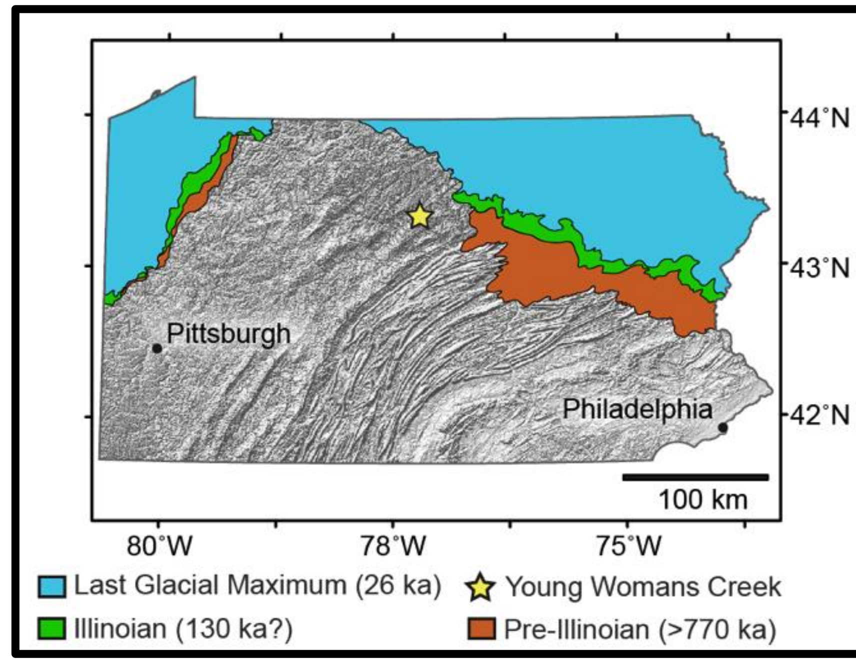
Context: Miller et al. 2013 in Susquehanna River Basin (SRB)



- Knickzones dictate erosion rates; higher erosion rates below knickzones regardless of lithology
- Appear as sudden breaks on log slope/log area plots
- We chose to intensively sample a watershed near Cooks Run (in purple)

Young Womans Creek Setting

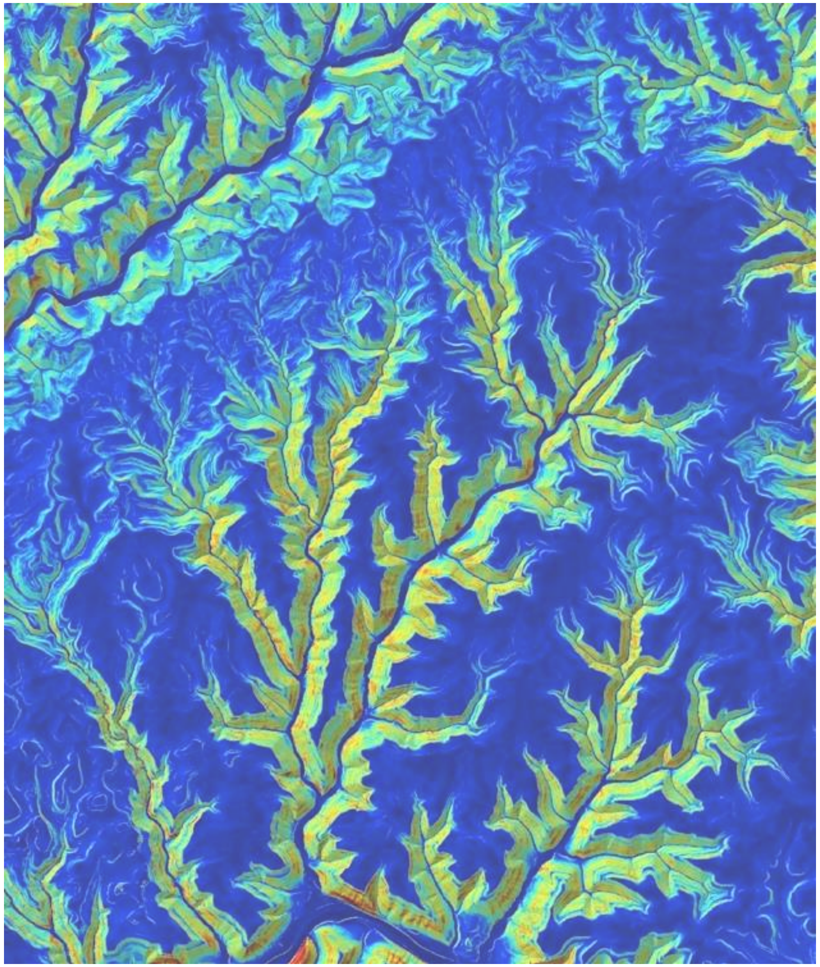




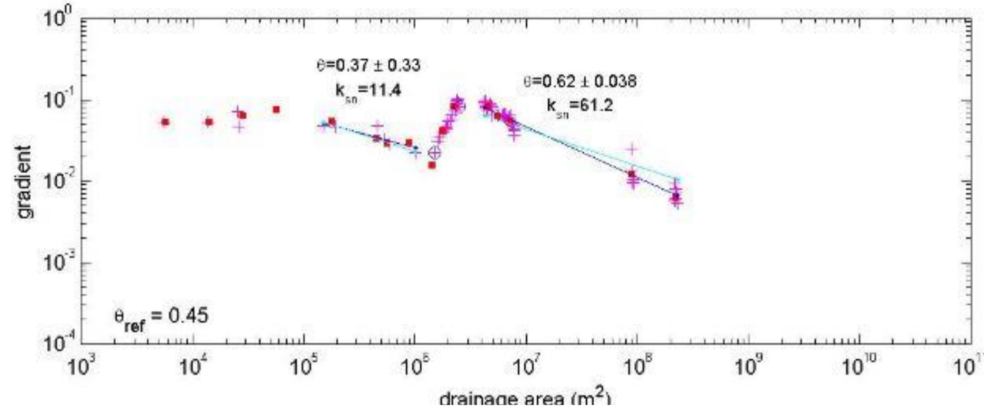
- Outside of glacial boundary
- Gently folded Paleozoic sandstones
- Supposed to be a lithologically ‘simple’, ‘uniform’ area

I took 17 fluvial sediment samples above and below stream junctions, across a range of subbasin slopes.

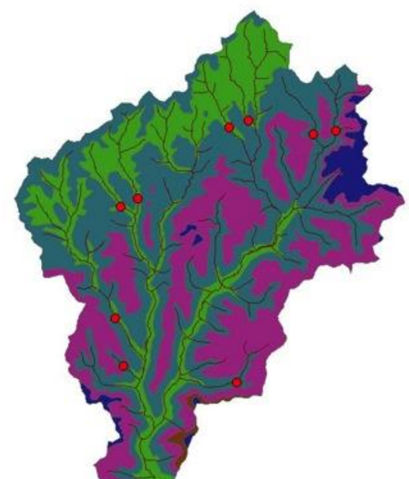
GIS/MATLAB ANALYSIS



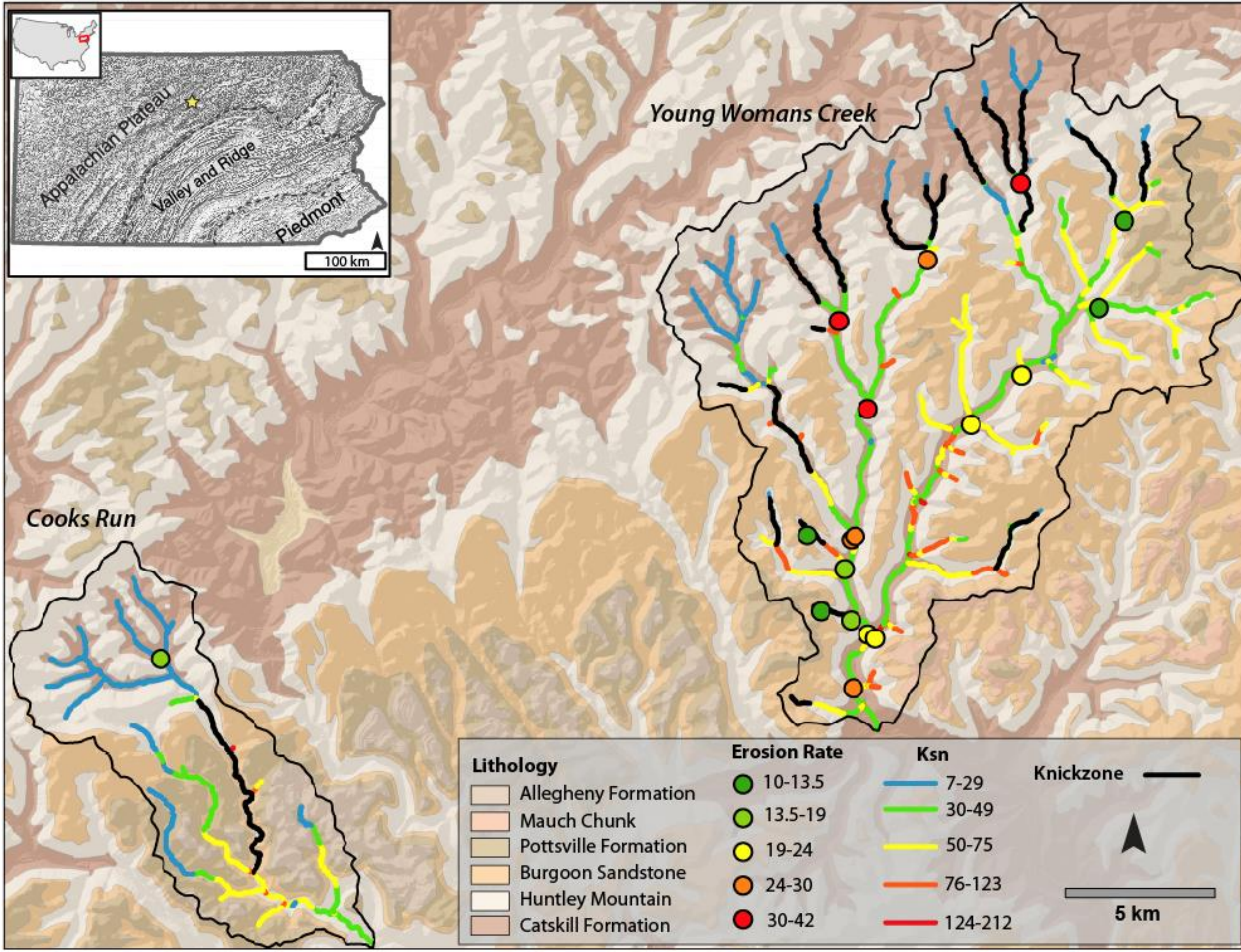
1. prepare elevation data



2. extract and analyze channels



3. identify zones of incision



Appalachian Plateau
Valley and Ridge
Piedmont
100 km
Young Womans Creek
Cooks Run
Lithology
Allegheny Formation
Mauch Chunk
Pottsville Formation
Burgoon Sandstone
Huntley Mountain
Catskill Formation
Erosion Rate
10-13.5
13.5-19
19-24
24-30
30-42
Ksn
7-29
30-49
50-75
76-123
124-212
Knickzone
5 km

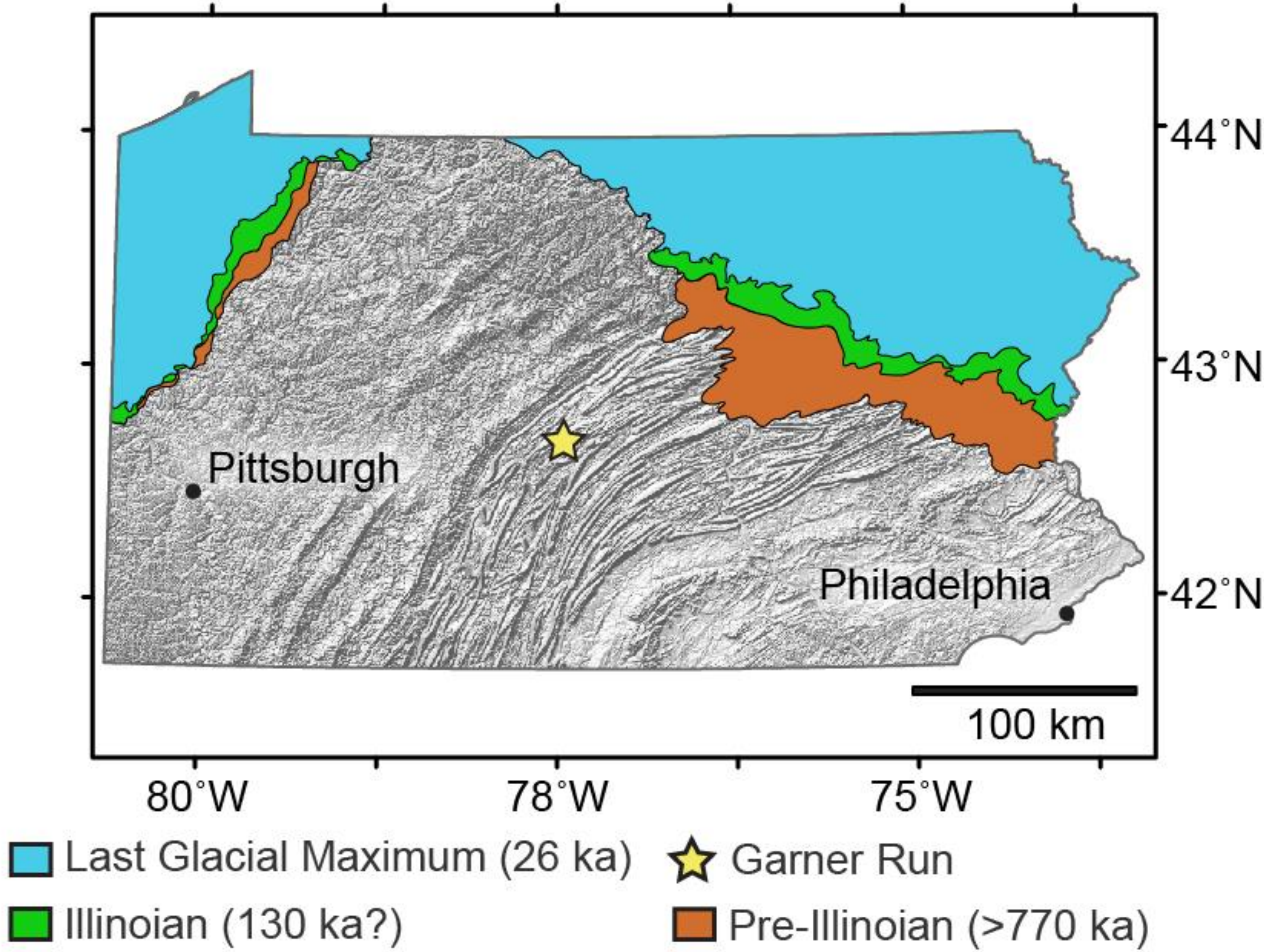
Young Womans Creek

- Base level and lithology difficult to disentangle
- Lithology exerts a control on erosion rate in small headwater catchments
- ‘Wave’ of incision stuck at top of watershed?
- Knickzones propogate differently in nearby areas; drainage area dependence?

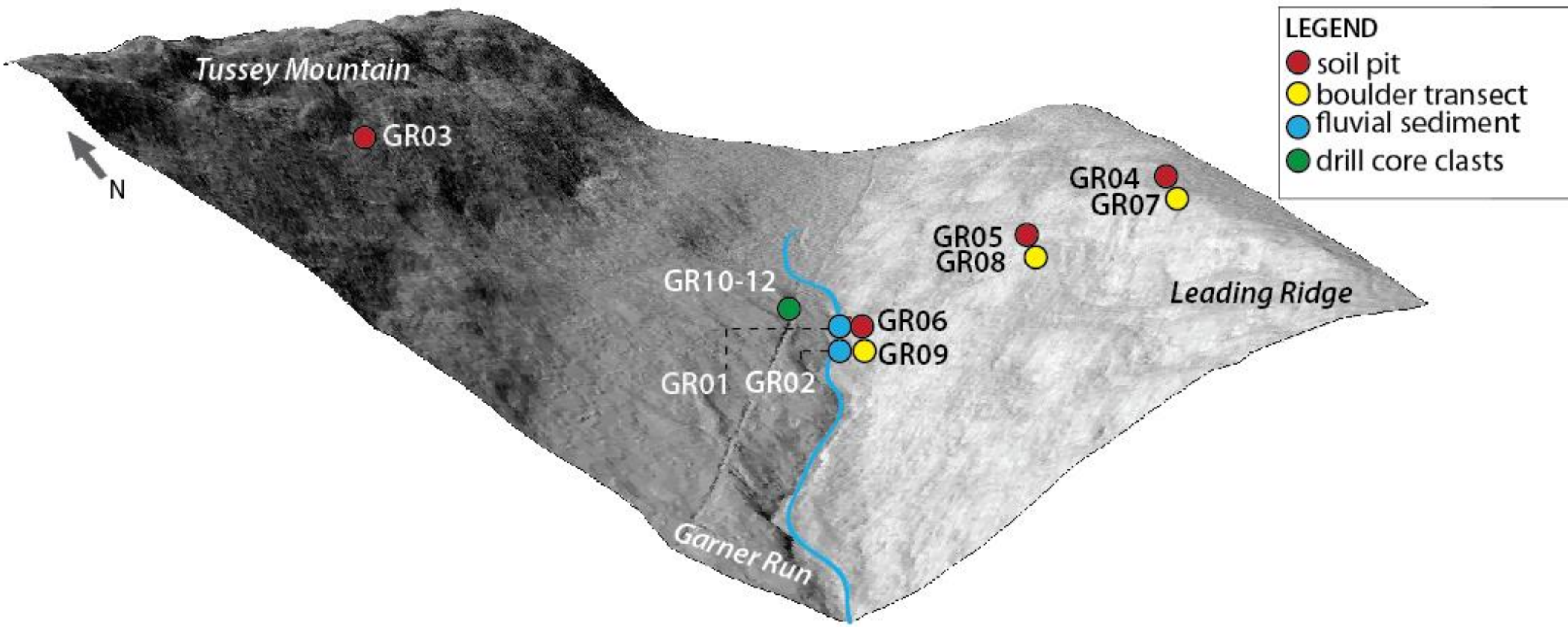
PART 3: GARNER RUN, SHALE HILLS CZO

PURPOSE OF GARNER RUN COSMO

- Sandstone ridgelines common features
- Does valley fill record history?
- To measure ^{10}Be concentrations in soil, rock, and fluvial sediment, and ^{26}Al in surface boulders and subsurface drill core samples.
- To use fluvial sediments to estimate basin-wide erosion rate.
- To estimate approximate residence time of regolith on Leading Ridge.


44°N
43°N
42°N
80°W
78°W
75°W
Pittsburgh
Philadelphia
100 km
Last Glacial Maximum (26 ka)
Garner Run
Illinoian (130 ka?)
Pre-Illinoian (>770 ka)

GARNER RUN SAMPLING STRATEGY



amalgamated boulder transects

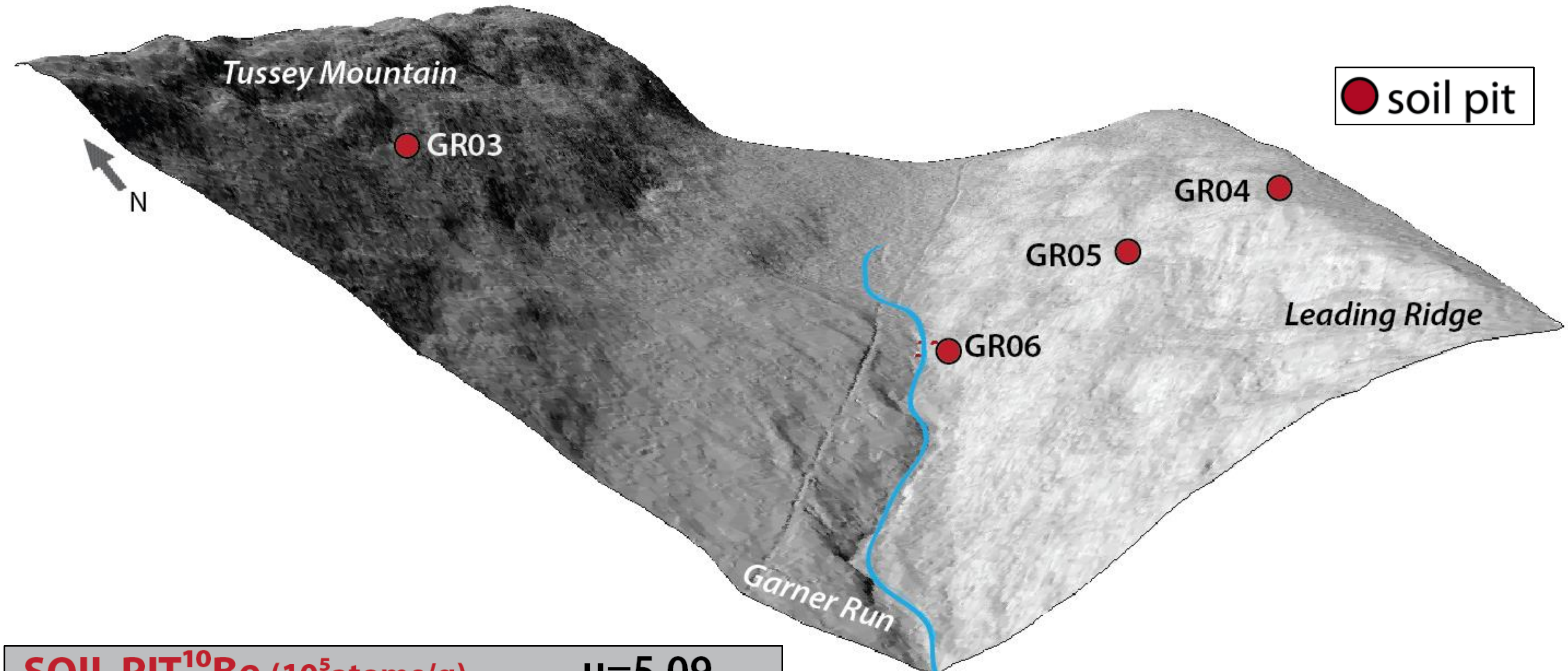
stream sediment collection

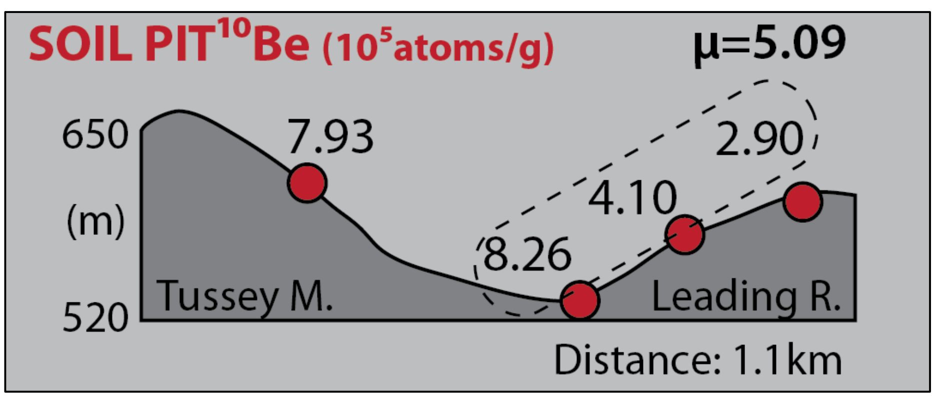
REMEMBER THOSE DATING ASSUMPTIONS

- No erosion after exposure
- No inheritance at initial exposure
- No intermittent shielding or complex exposure history (rolling, re-exposure, burial)

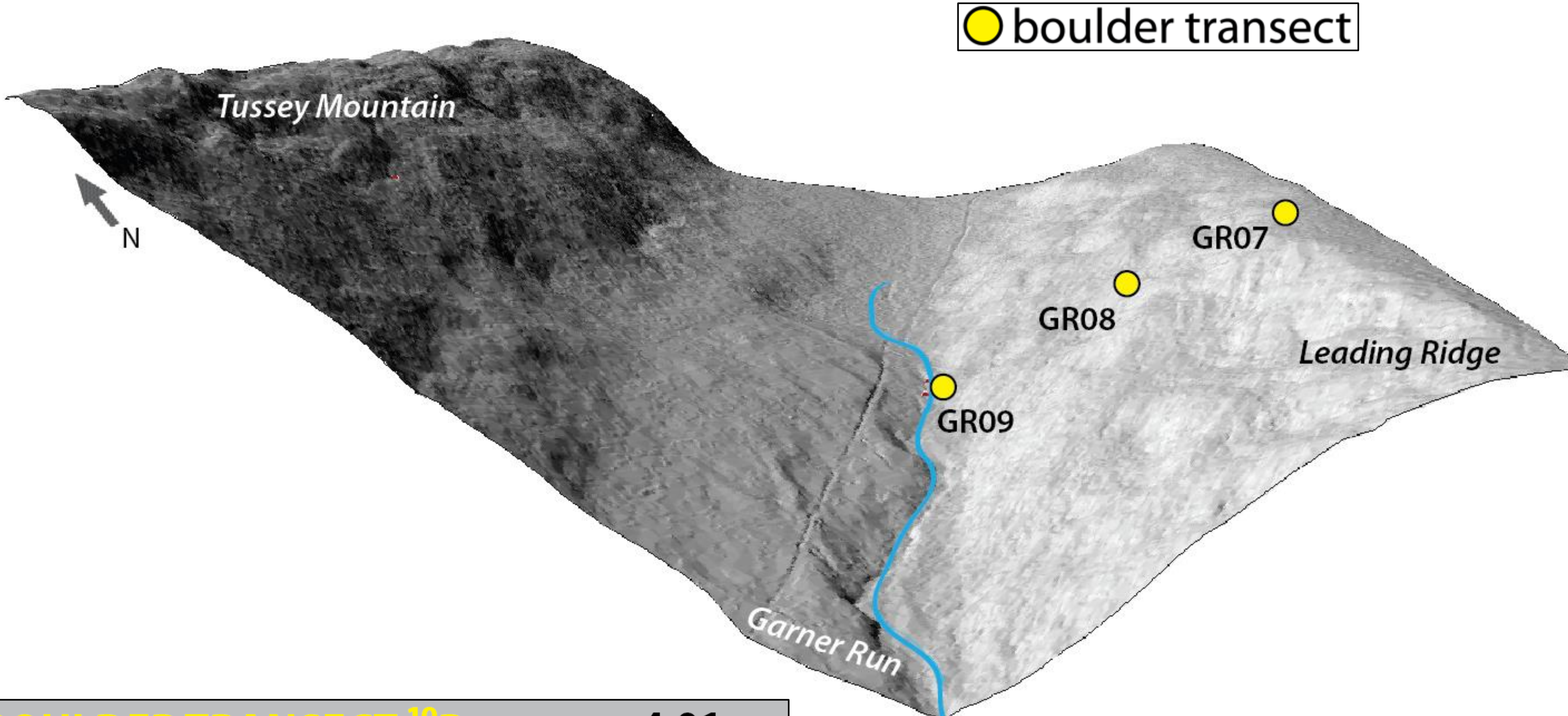
First, let's talk in terms of concentration…

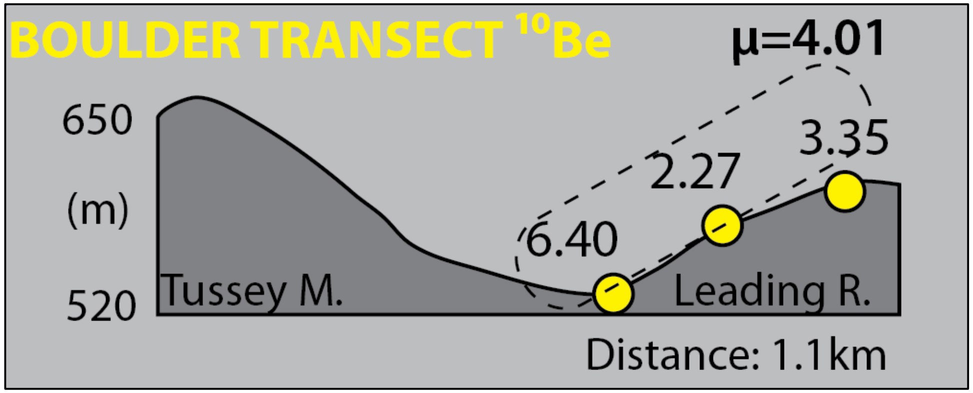
SOIL SAMPLES



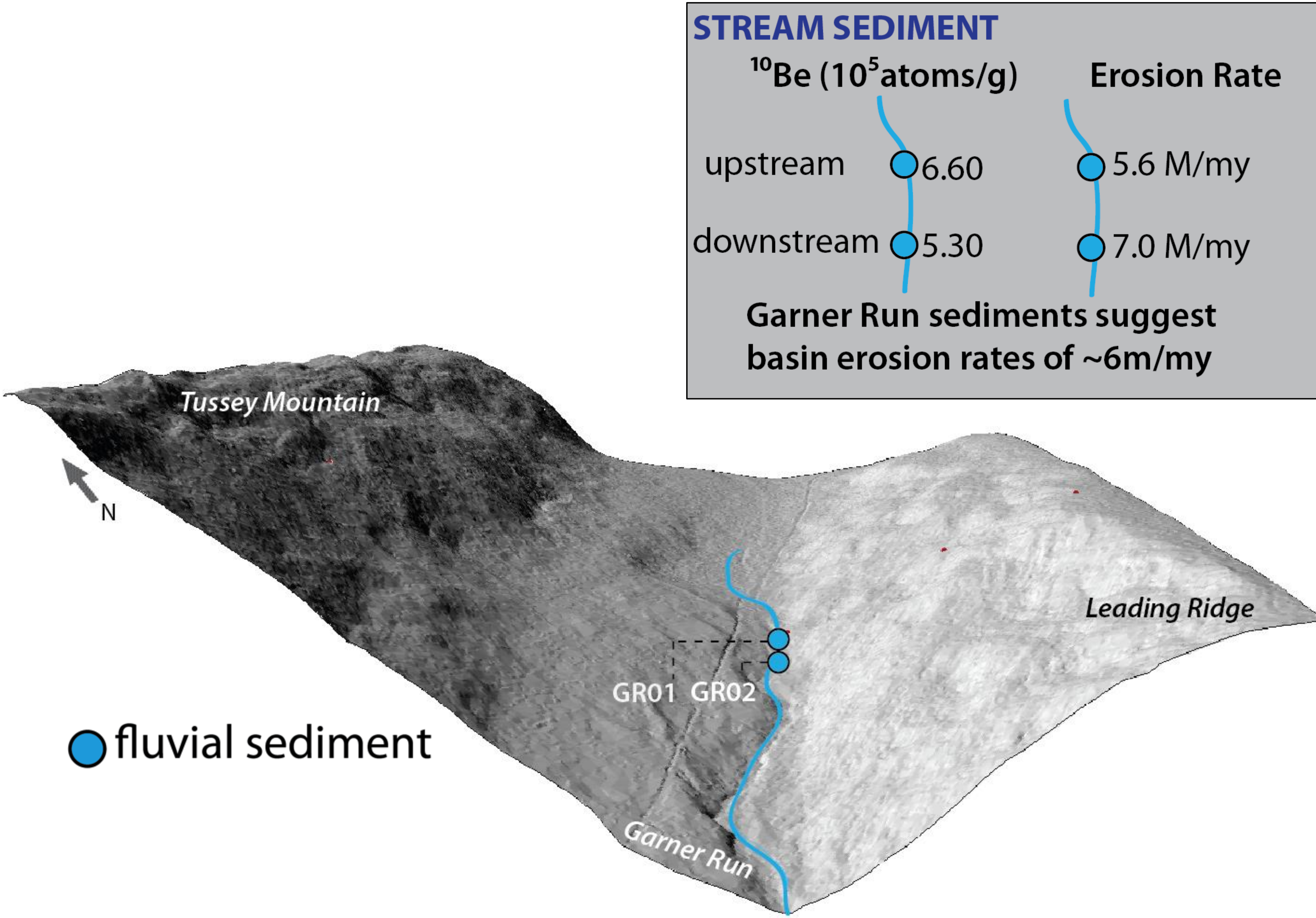


BOULDER TRANSECTS

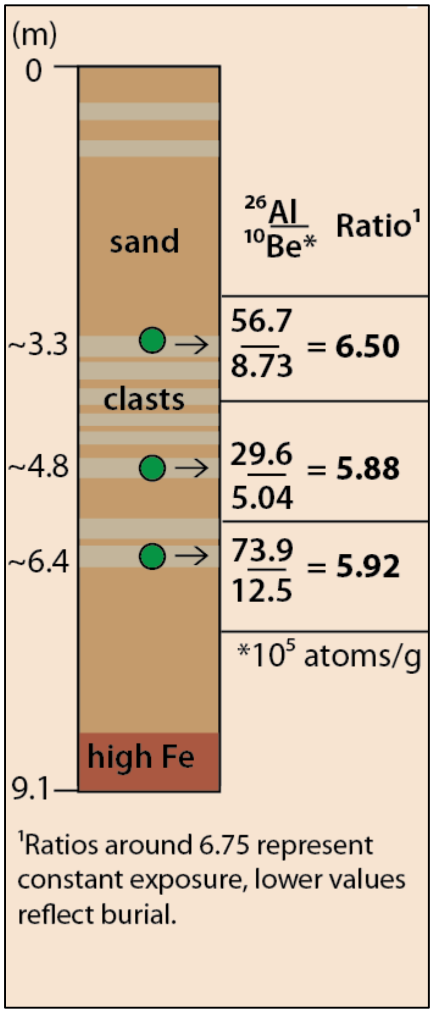


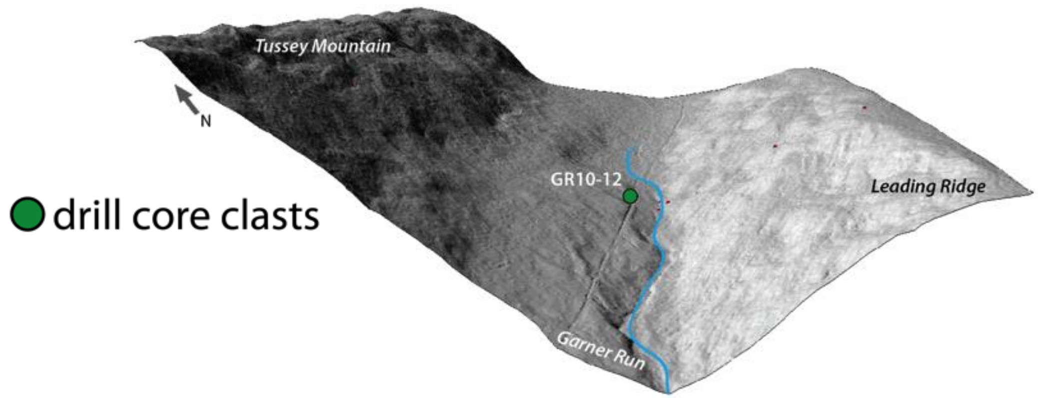


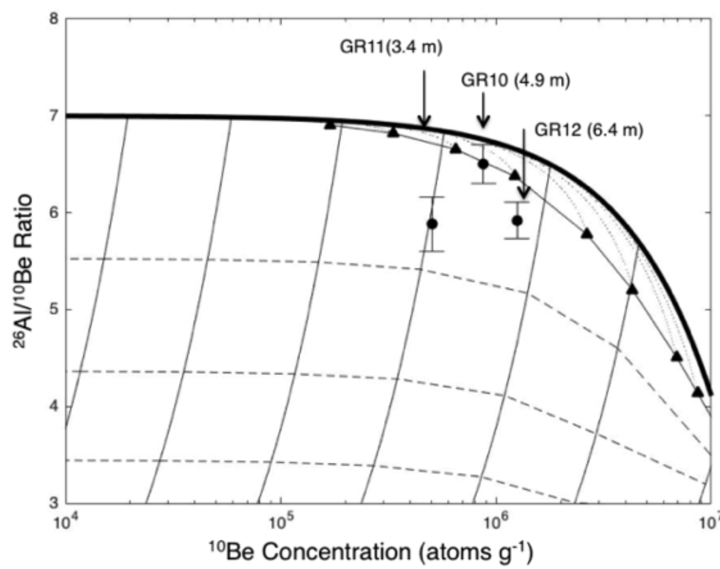
STREAM SEDIMENTS



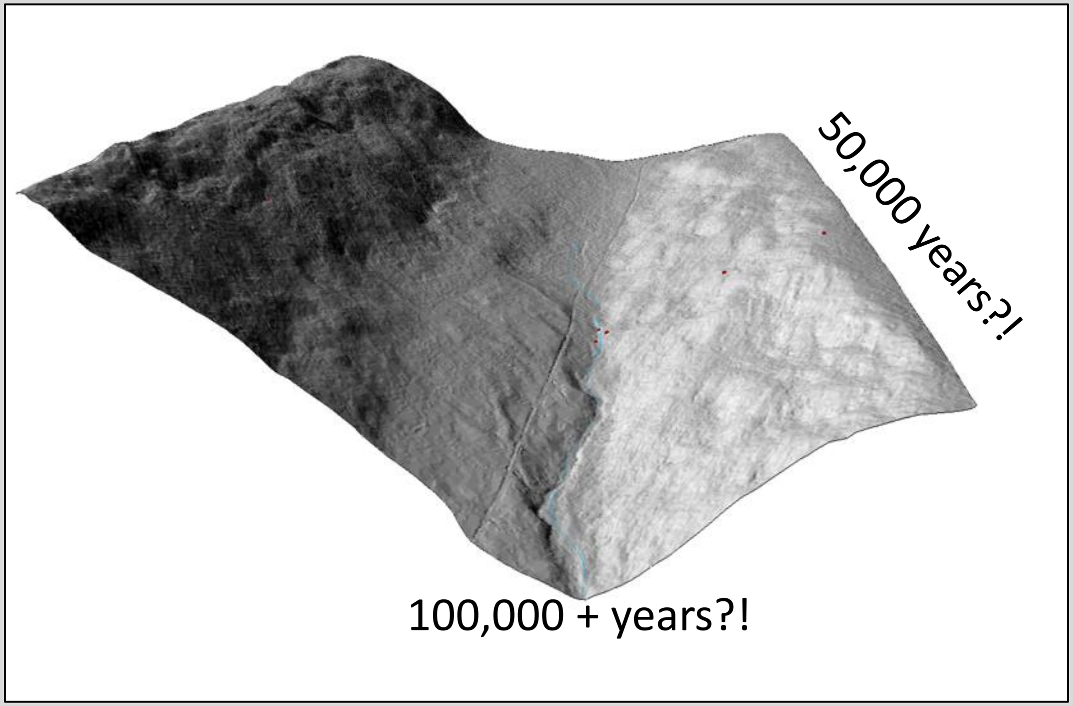
DRILL CORE WORK







IF WE MAKE A BUNCH OF ASSUMPTIONS THAT AREN'T NECESSARILY TRUE…



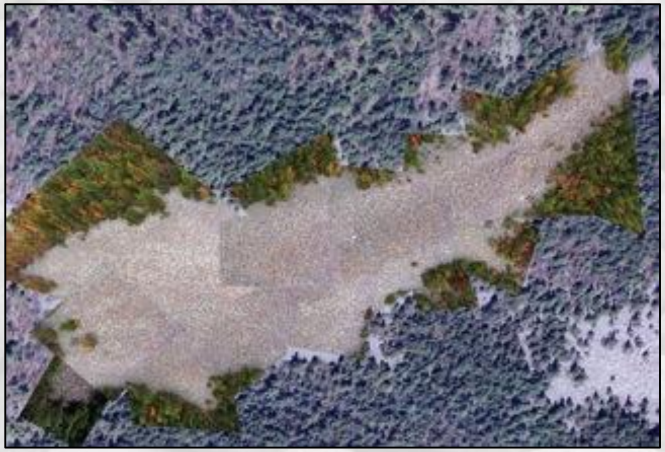
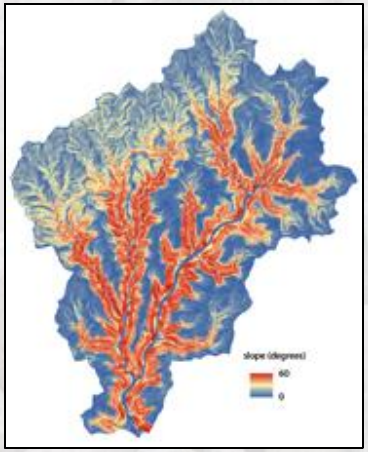
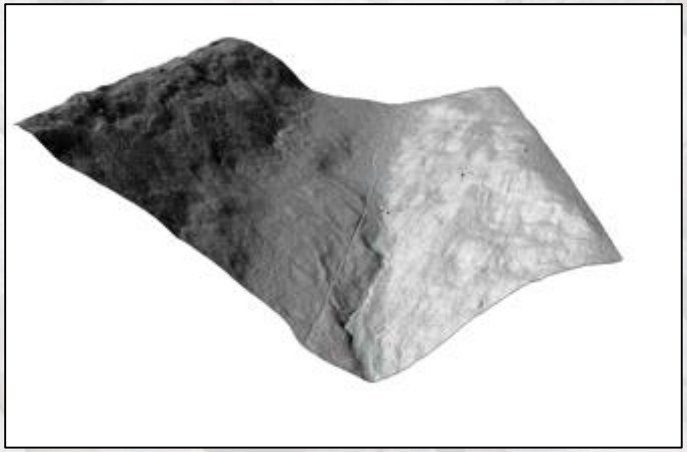
Then ^{10}Be concentrations represent effective exposure ages of ~50,000 years on LR and ~100,000+ on the valley floor

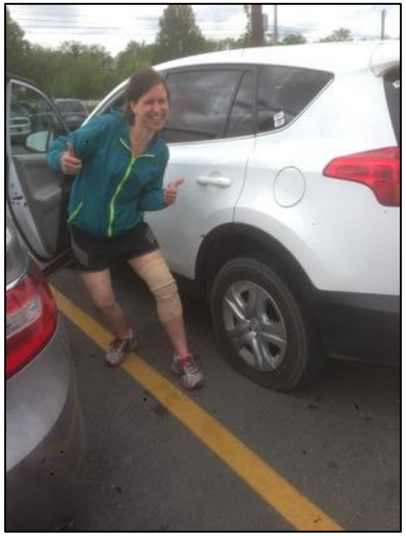
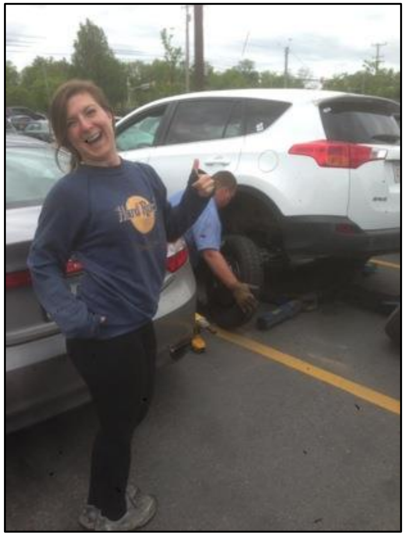
WHAT WE UNDERSTAND FROM GARNER RUN COSMO WORK

- Garner run soils, stream seds, and rock have similar ^{10}Be concentrations
- Catchment erosion rate of ~7m/My
- No LGM signal on ridgeline
- This stuff has been kicking around for at least 100 ka!

Main takeaways:

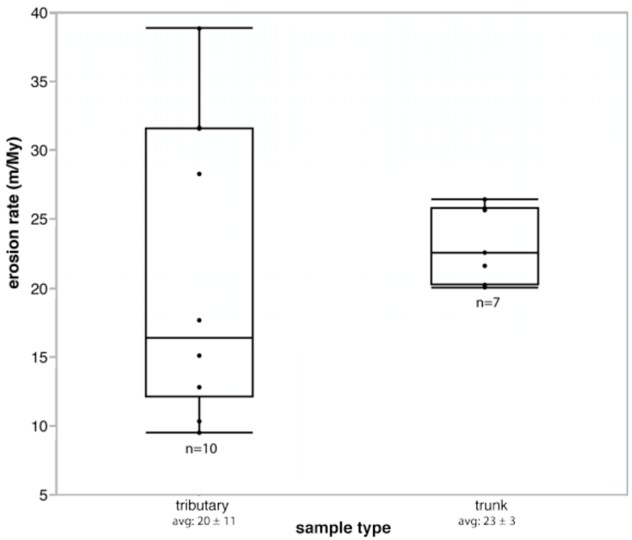
- Hickory Run is ancient despite LGM proximity
- Garner Run and Hickory Run record 100,000+ years of exposure: preservation of landscapes through glacial cycles
- No LGM signal anywhere?! Most dates 100-200 ka range
- Erosion rates tend to be quite high (YWC) or low (HR, GR). Bimodal tendency…

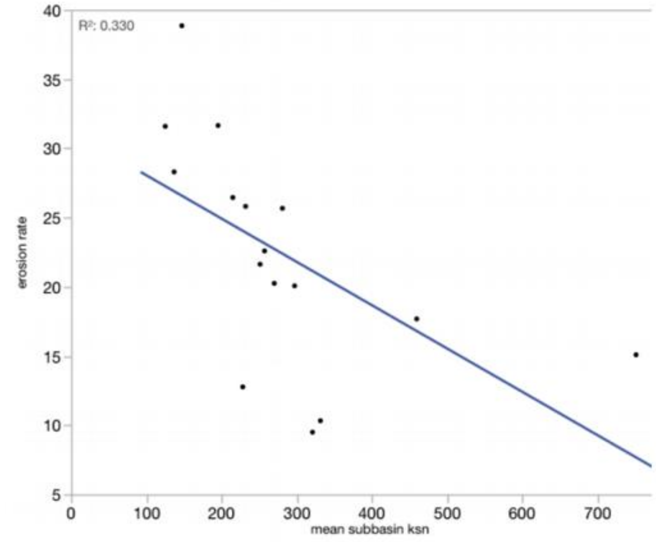




Thanks!

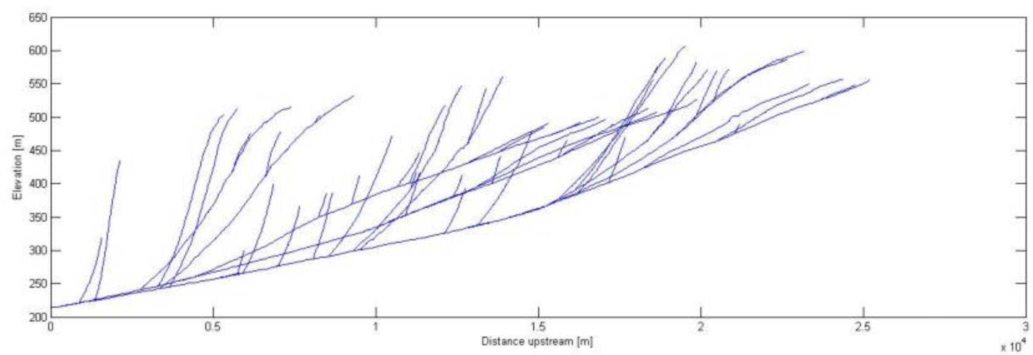

Young Womans Creek Results



Erosion rates in trunks are representative of upstream



This plot is completely counterintuitive



Transition between 'relict' and 'adjusted' landscapes