TRACKING EROSION WITH SEDIMENT ASSOCIATED ISOTOPES IN YUNNAN, CHINA

Thesis Defense Presentation

Thomas B. Neilson

Introduction

- **Humans** are one of the most effective geomorphic agents on the planet
  - Humans have been estimated to move more earth material annually than any other geomorphic or geologic process

- **Erosion** and sediment disturbance that results from human activity directly impacts fluvial systems as well as communities reliant on river resources

Introduction

- Long history of human influence on the landscape
  - First recorded in 11th century AD
  - Communism and subsequent opening and development severely impacted erosion
- Since the 1950's, China has maintained sediment yield monitoring stations throughout the country
- Data from these stations **do not show a systematic increase** in sediment yield as a result of land-use

Question

- **Have humans increased erosion over the long-term average through land-use change?**


N
00:01
US Dept of State Geographer
© 2009 GeoBasis-DE/BKG
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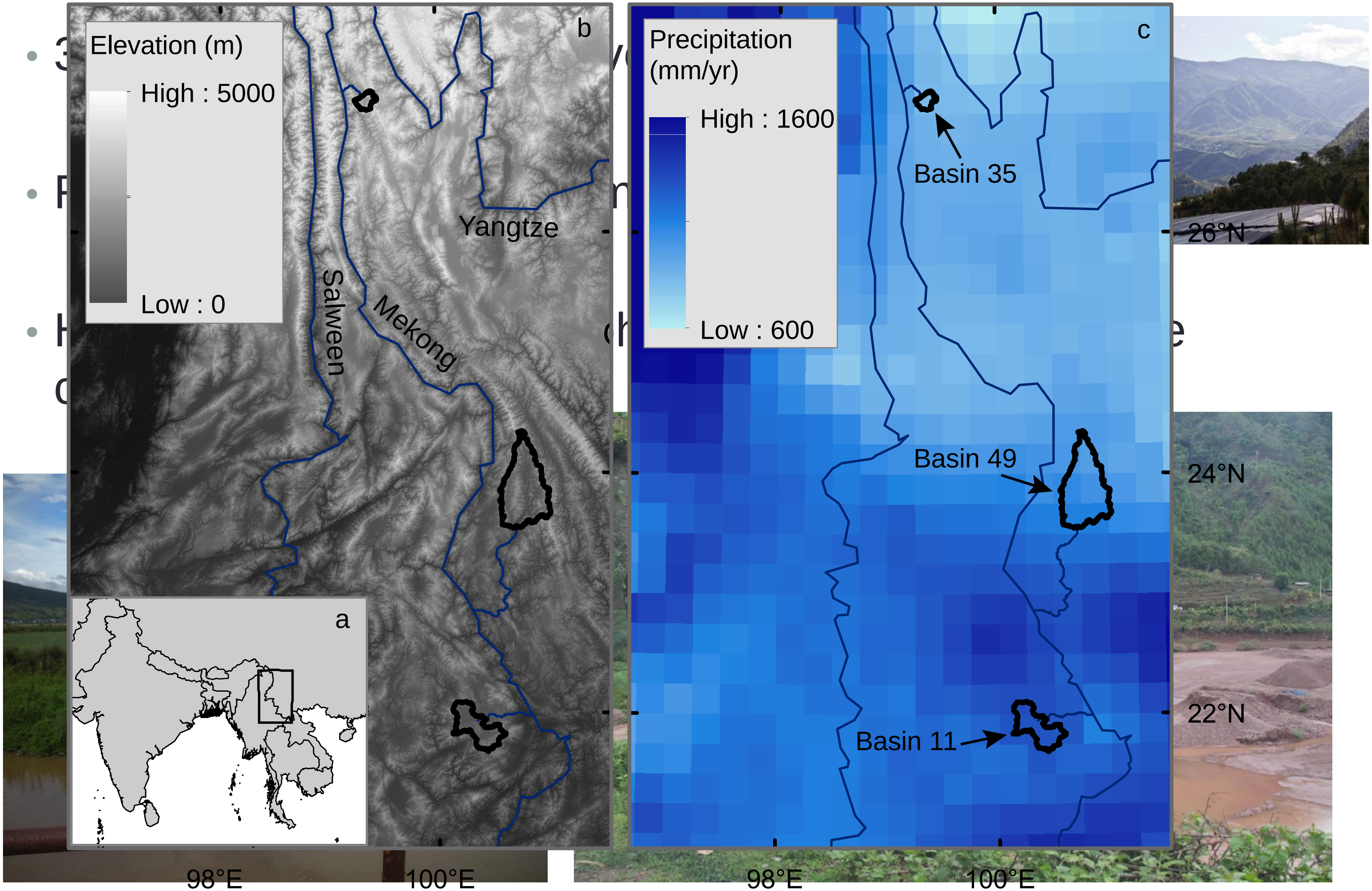
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Tour Guide
38°57'33.81" N 95°15'55.74" W eye alt 6838.52 mi

Field Sites



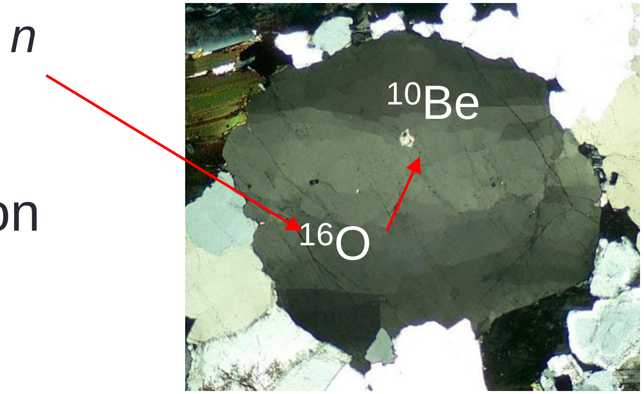
Elevation (m)
High : 5000
Low : 0
b
Yangtze
Salween
Mekong
a
98°E
100°E
Precipitation (mm/yr)
High : 1600
Low : 600
c
Basin 35
Basin 49
Basin 11
26°N
24°N
22°N
98°E
100°E

Experimental Approach

Goals		Tools
Determine long-term (~1,000 – 50,000 yr) average erosion rate	→	• In situ ^{10}Be • Meteoric ^{10}Be
Assess contemporary rates of erosion	→	• Excess ^{210}Pb • ^{137}Cs • Sediment Yield
Determine what factors drive erosion • Tectonic and lithologic controls • Slope, rainfall, channel steepness, etc. • Agriculture vs. Forest	→	• Topographic analysis of DEM's • Analysis of land-use data • Field observations

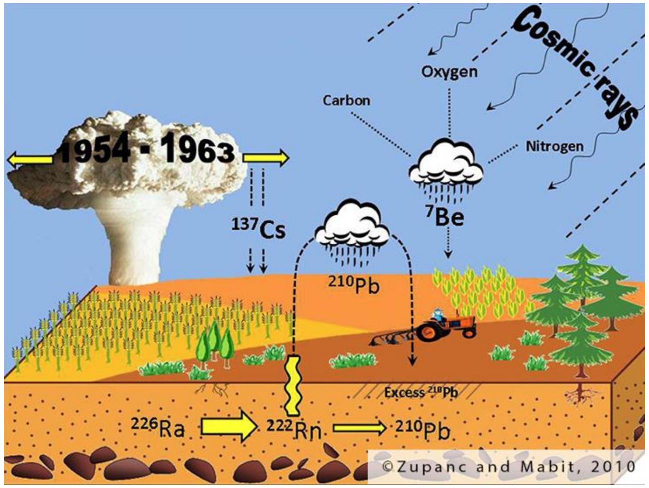
In situ-produced ^{10}Be

- $t_{1/2}$ = 1.39 myr
- Produced within quartz grains from interaction between cosmic rays and oxygen
- Permanently entrained in mineral grain
- ~290 atoms/cm^2 y^{-1} production rate
- Useful for estimating basin-wide rates of erosion when measured in fluvial sediment

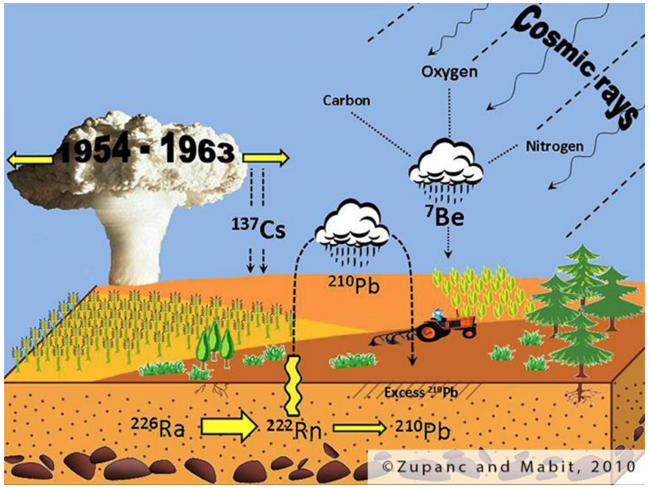


Fallout Radionuclides ($^{10}Be_m$, $^{210}Pb_{ex}$, ^{137}Cs)

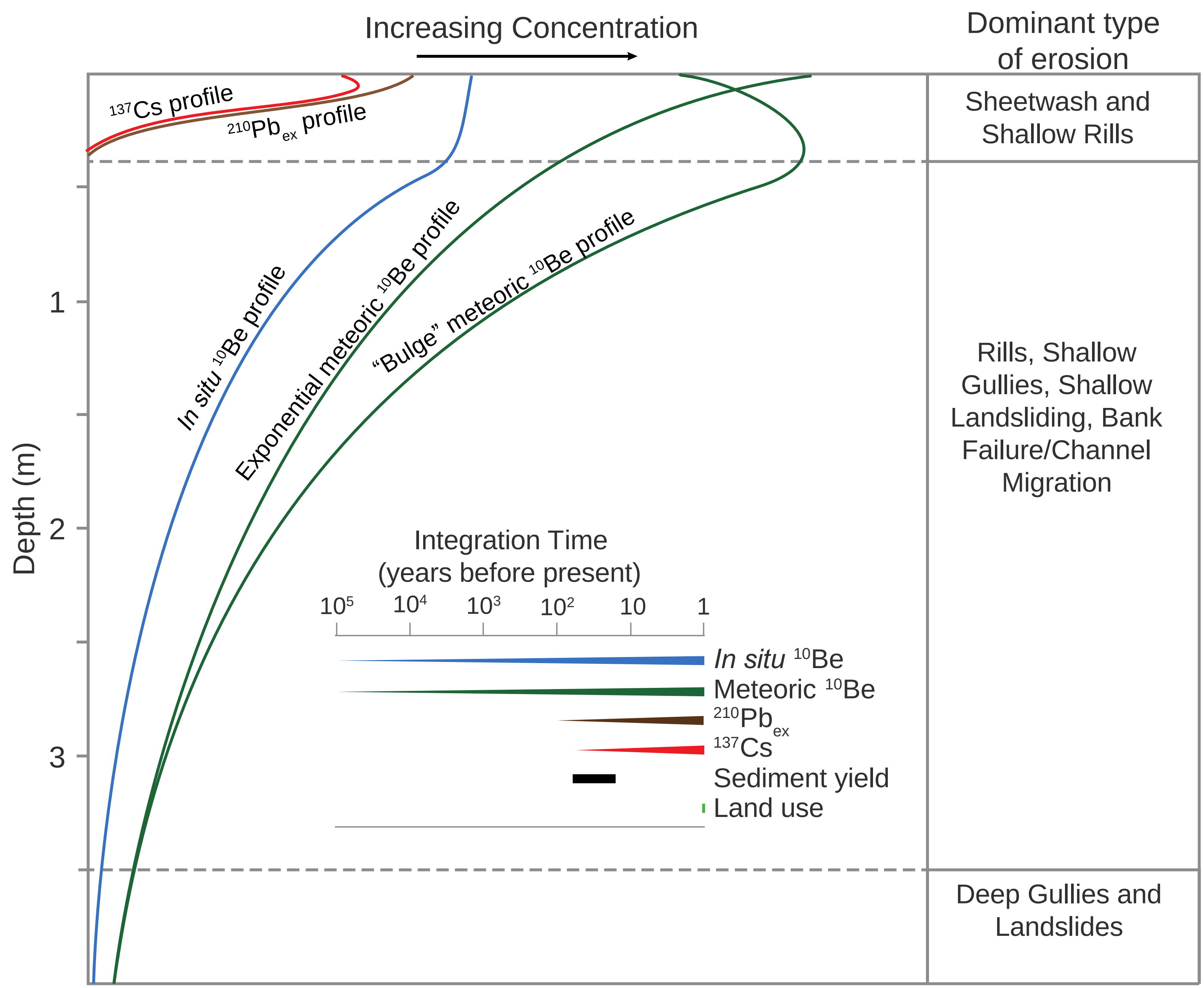
- Produced in the atmosphere
- Delivered to earth surface via precipitation and dust/dry-fall
- Can be mobilized in certain conditions (e.g. pedogenesis), but generally are assumed permanently sorbed to sediment
- Preferentially adsorb to finer sediment particles



Fallout Radionuclides ($^{10}Be_m$, $^{210}Pb_{ex}$, ^{137}Cs)



- $^{10}Be_m$ ($t_{1/2}$ = 1.39 myr)
  - Atmospheric spallation reaction
  - ~1.3 million atoms/cm^2 y^{-1} delivery rate
  - Useful for assessing long-term erosion
- $^{210}Pb_{ex}$ ($t_{1/2}$ = 22.2 yr)
  - Naturally occurring as part of ^{238}U decay series
  - Fraction of total ^{210}Pb in soil derived from ^{222}Rn gas that leaves soil
  - Delivered back to soil through fallout
  - Integrates up to past ~100 years of erosion
- ^{137}Cs ($t_{1/2}$ = 30.2 yr)
  - Created from nuclear weapons testing in atmosphere
  - Delivered to soil through fallout
  - Only deposited globally from 1950's to 1970's
  - Useful for assess erosion over past 50-60 years

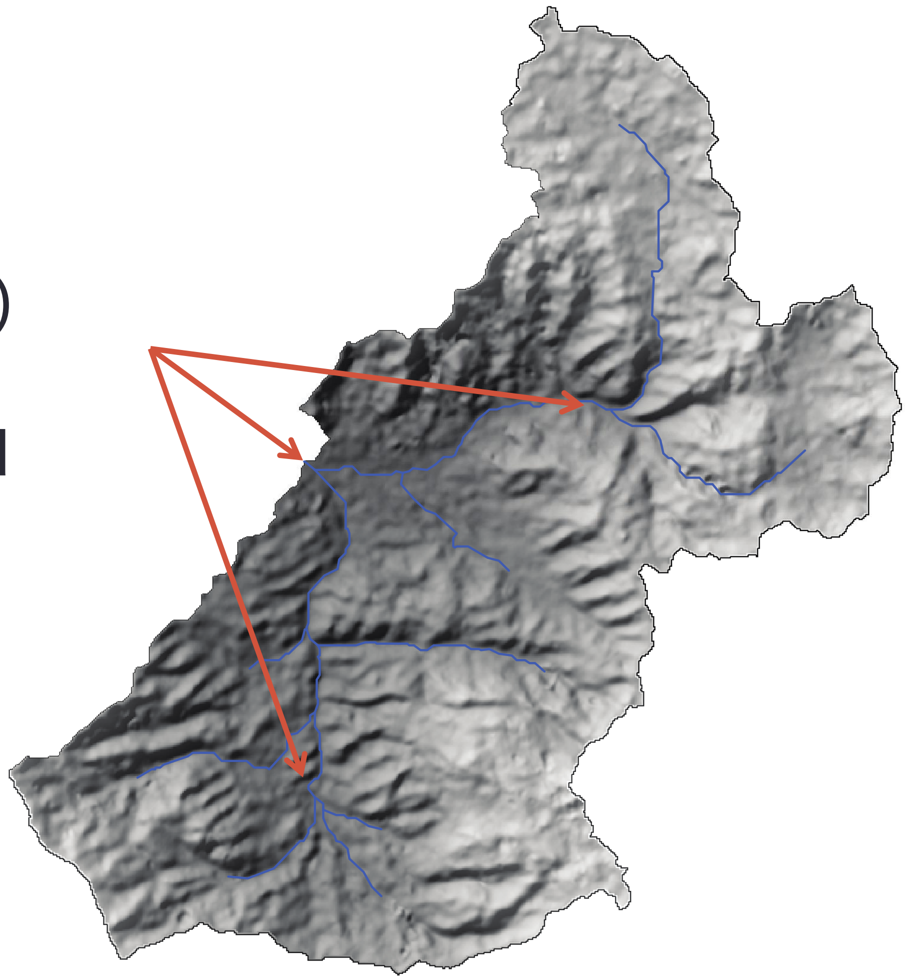


Increasing Concentration
Dominant type of erosion
Sheetwash and Shallow Rills
Rills, Shallow Gullies, Shallow Landsliding, Bank Failure/Channel Migration
Deep Gullies and Landslides
Depth (m)
1
2
3
137Cs profile
210Pbex profile
In situ 10Be profile
Exponential meteoric 10Be profile
"Bulge" meteoric 10Be profile
Integration Time
(years before present)
10^5
10^4
10^3
10^2
10
1
In situ 10Be
Meteoric 10Be
210Pbex
137Cs
Sediment yield
Land use

Going from ^{10}Be concentration to erosion rate (or index)

- River sediment is average of upstream area

- The production (or delivery) rate of ^{10}Be can be determined for the sampled watershed



Going from isotopic concentration to erosion rate (or index)

In situ ^{10}Be ($^{10}Be_i$):

- Isotopic concentration of the sediment is compared to the rate of production, and the difference is attributed to land surface lowering

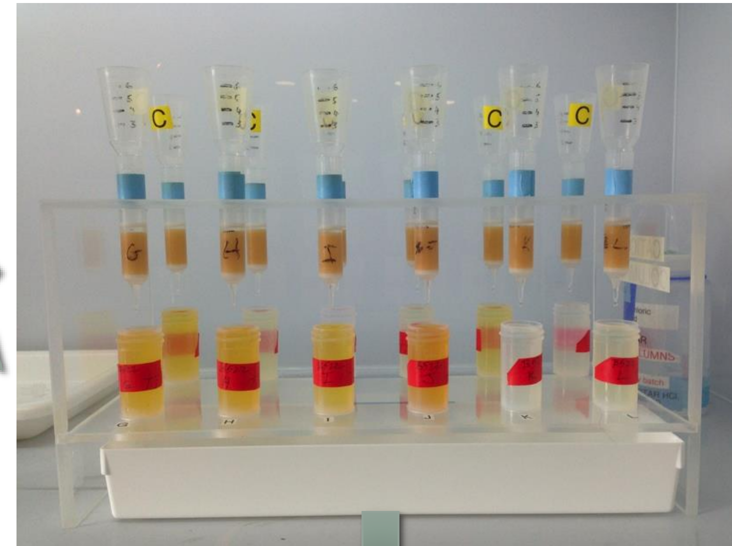
Meteoric ^{10}Be ($^{10}Be_m$):

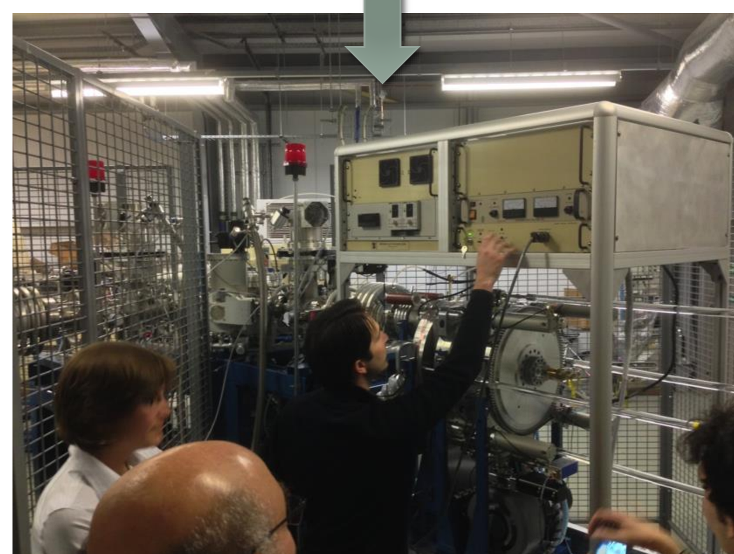
- The export rate of $^{10}Be_m$ on sediment is compared to the delivery rate, and a ratio is made
- >1 indicates more is leaving than being delivered
- <1 indicates more is being delivered than leaving

Sampling

- Collect active channel sediment from 54 locations throughout three watersheds
- Select sample sites to represent:
  - Basins that are primarily forested or agricultural
  - Natural range of representative slopes in watershed
  - Range of basin sizes
  - Sediment mixing above and below major junctions

Extracting and measuring Be



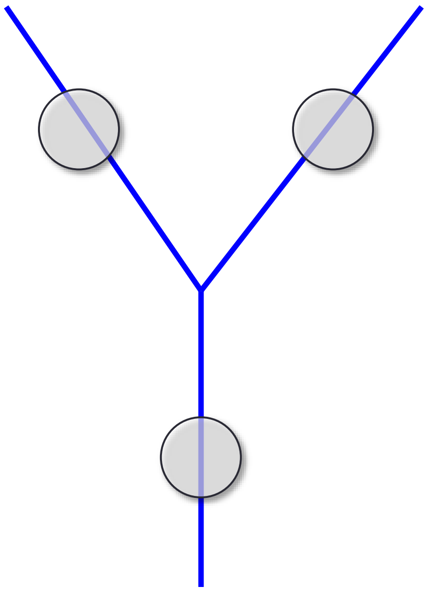


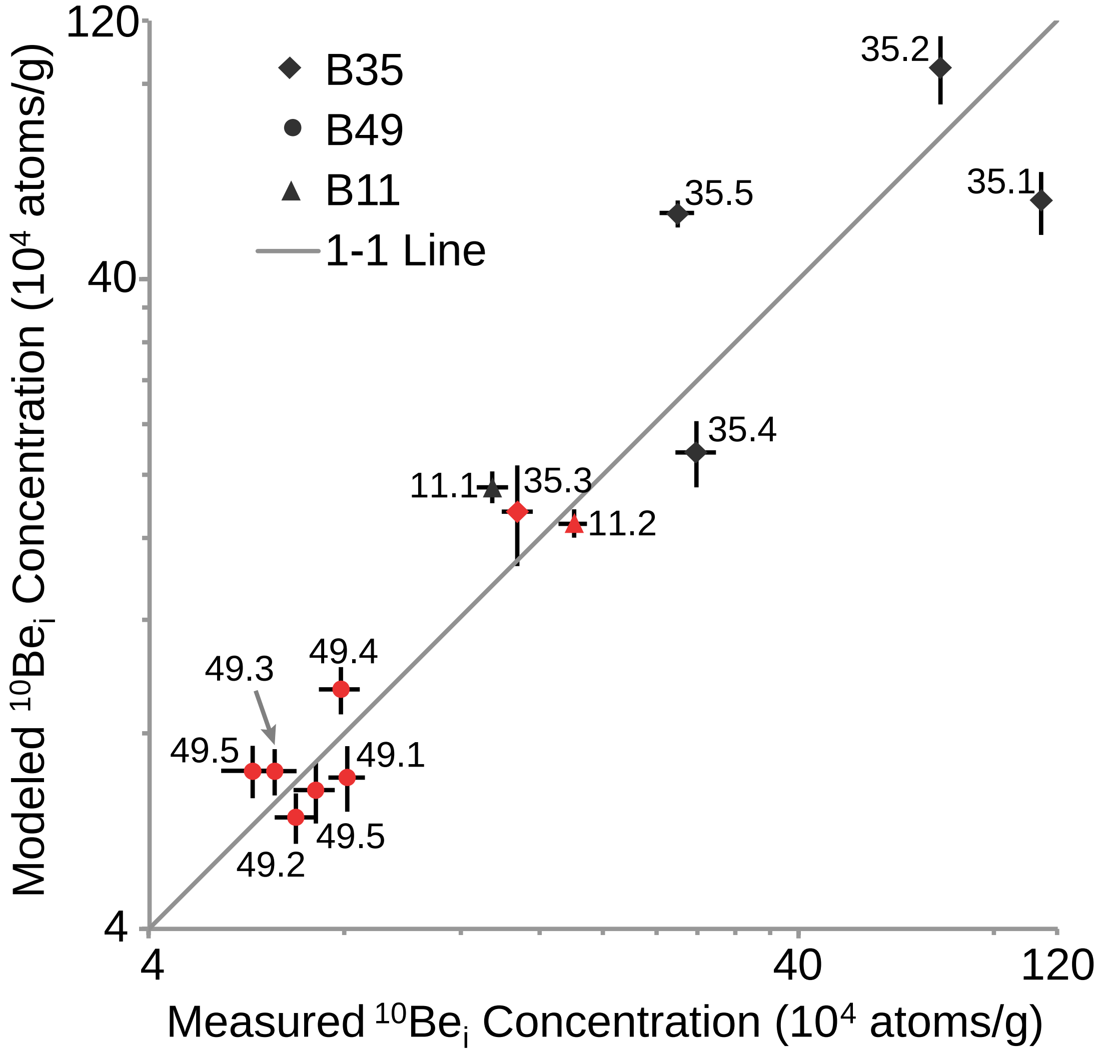
Measuring $^{210}Pb_{ex}$ and ^{137}Cs

- Measurement done with germanium detector

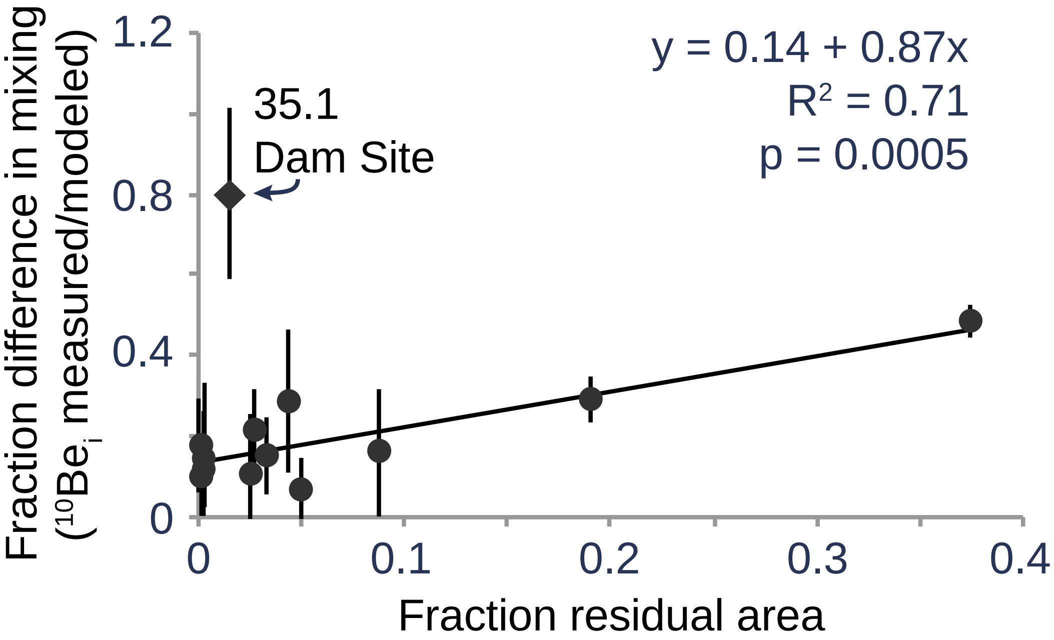
- Counts radioactive decay at given energy levels, which are converted to concentration

Sediment Mixing Results

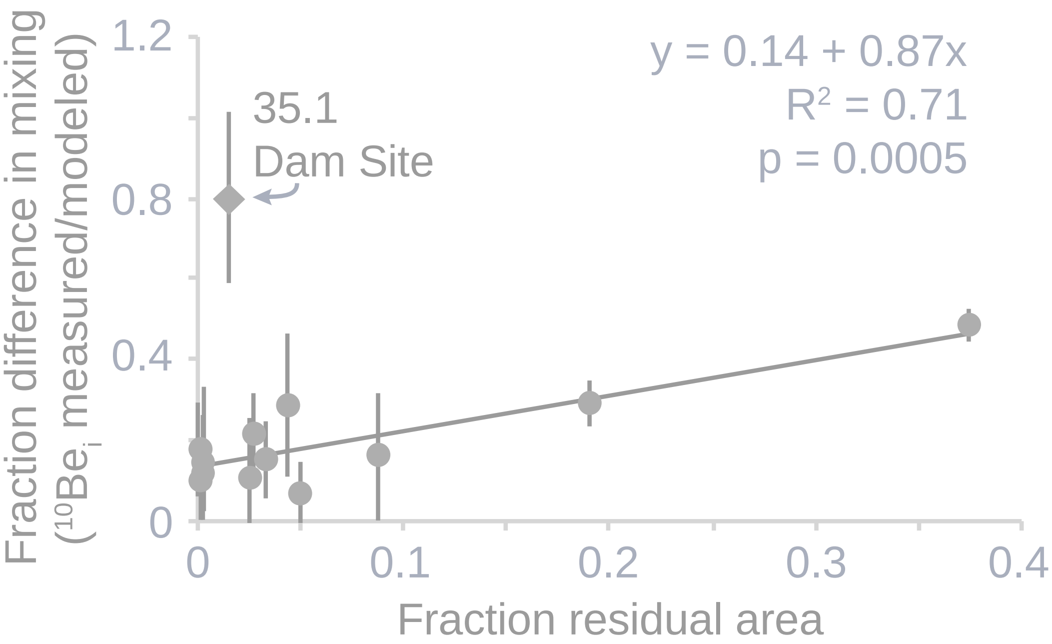


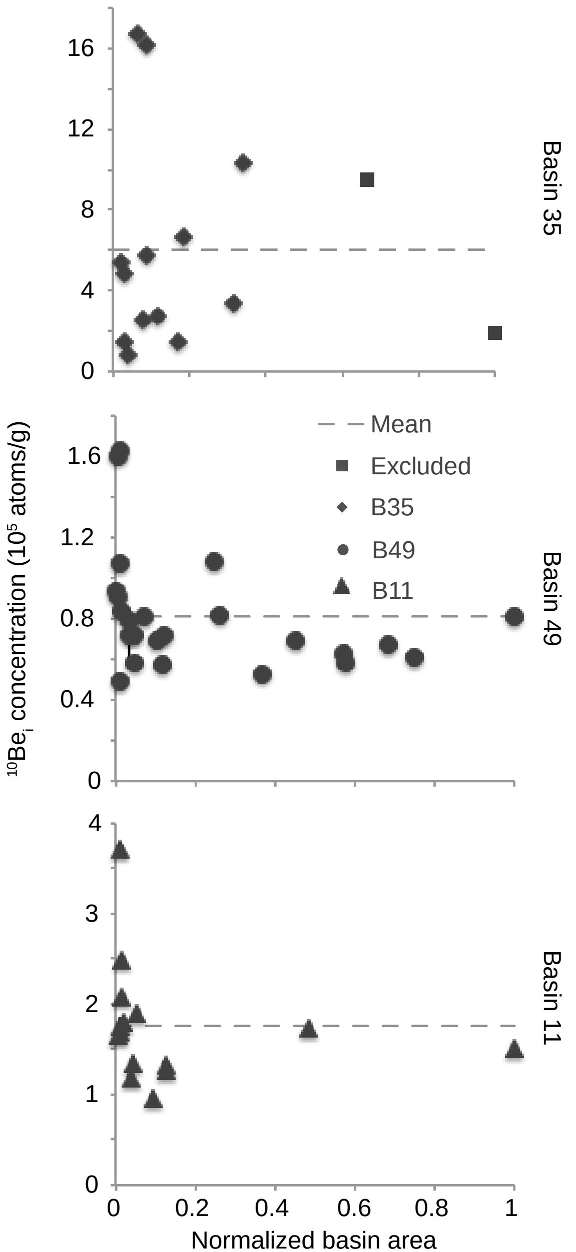


Sediment Mixing Results



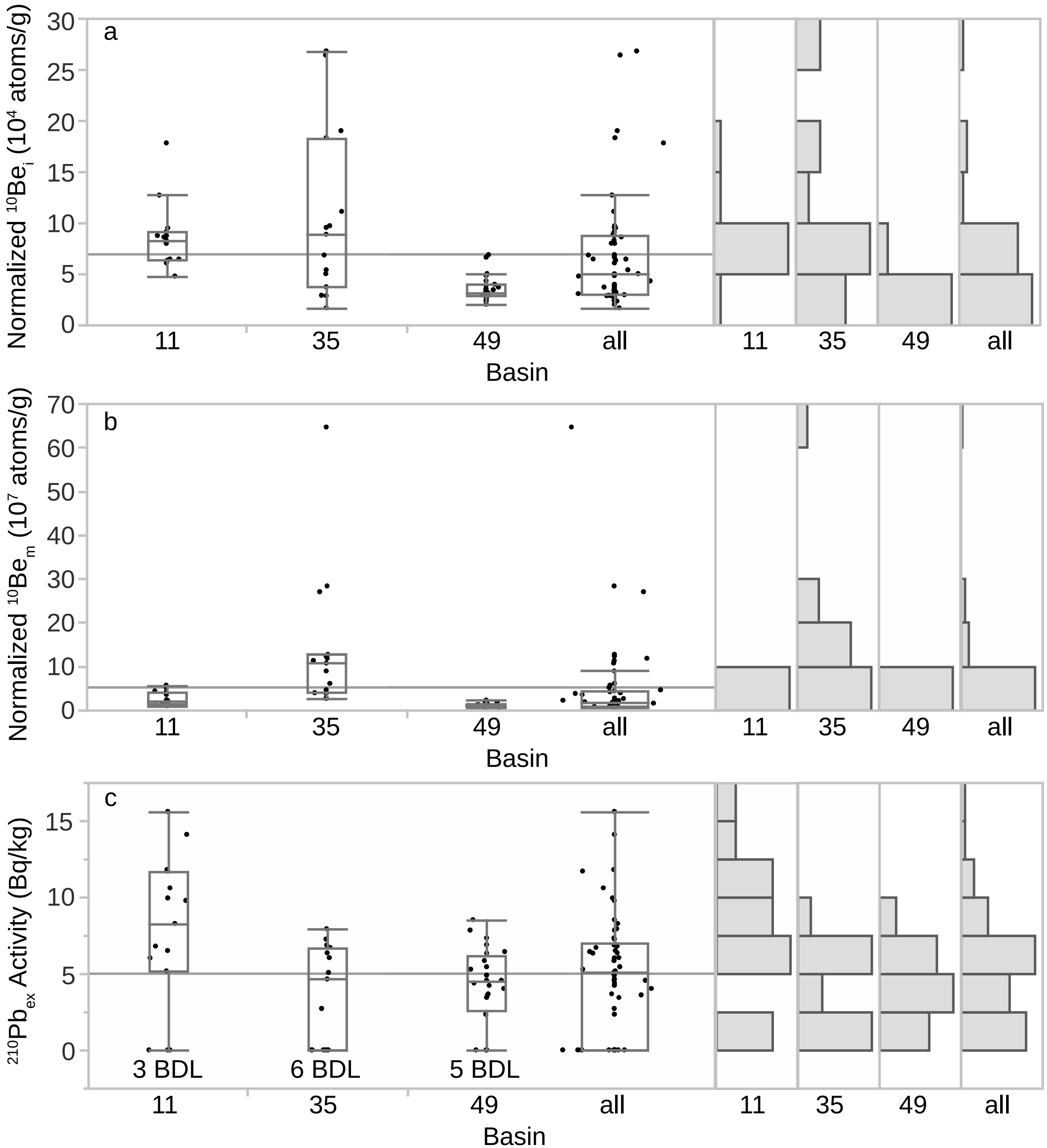
Sediment Mixing Results



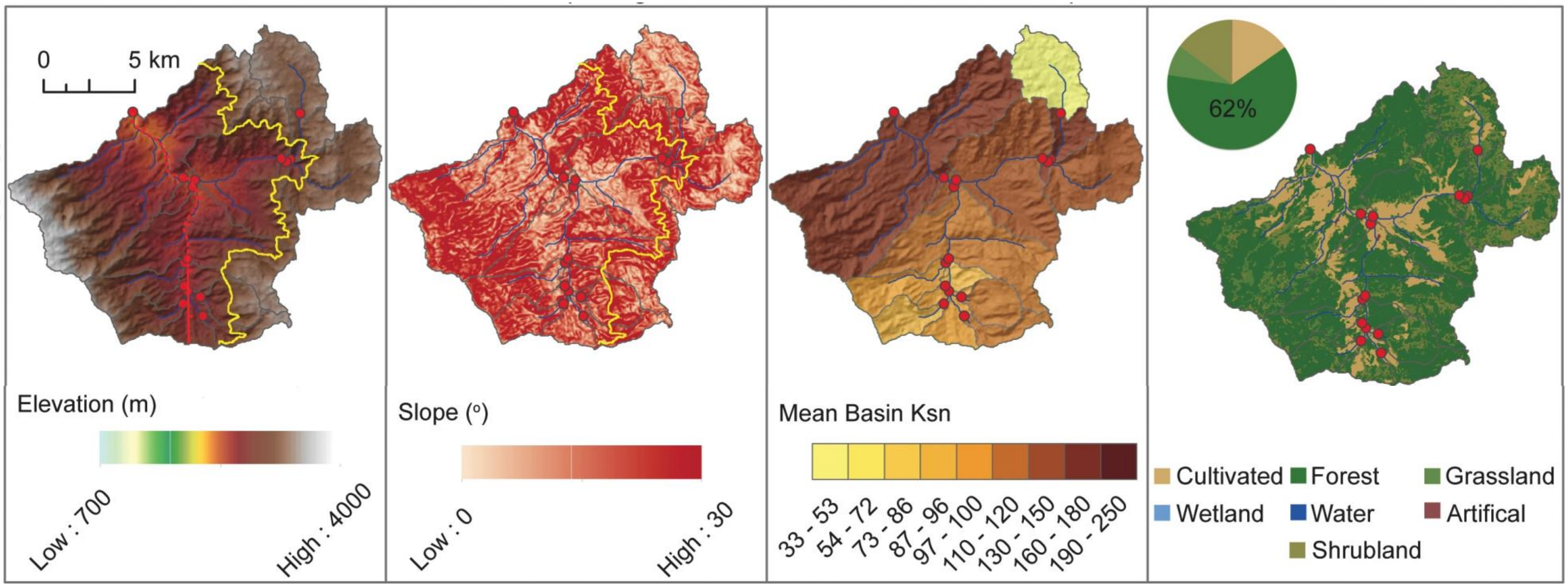


Isotopic Results

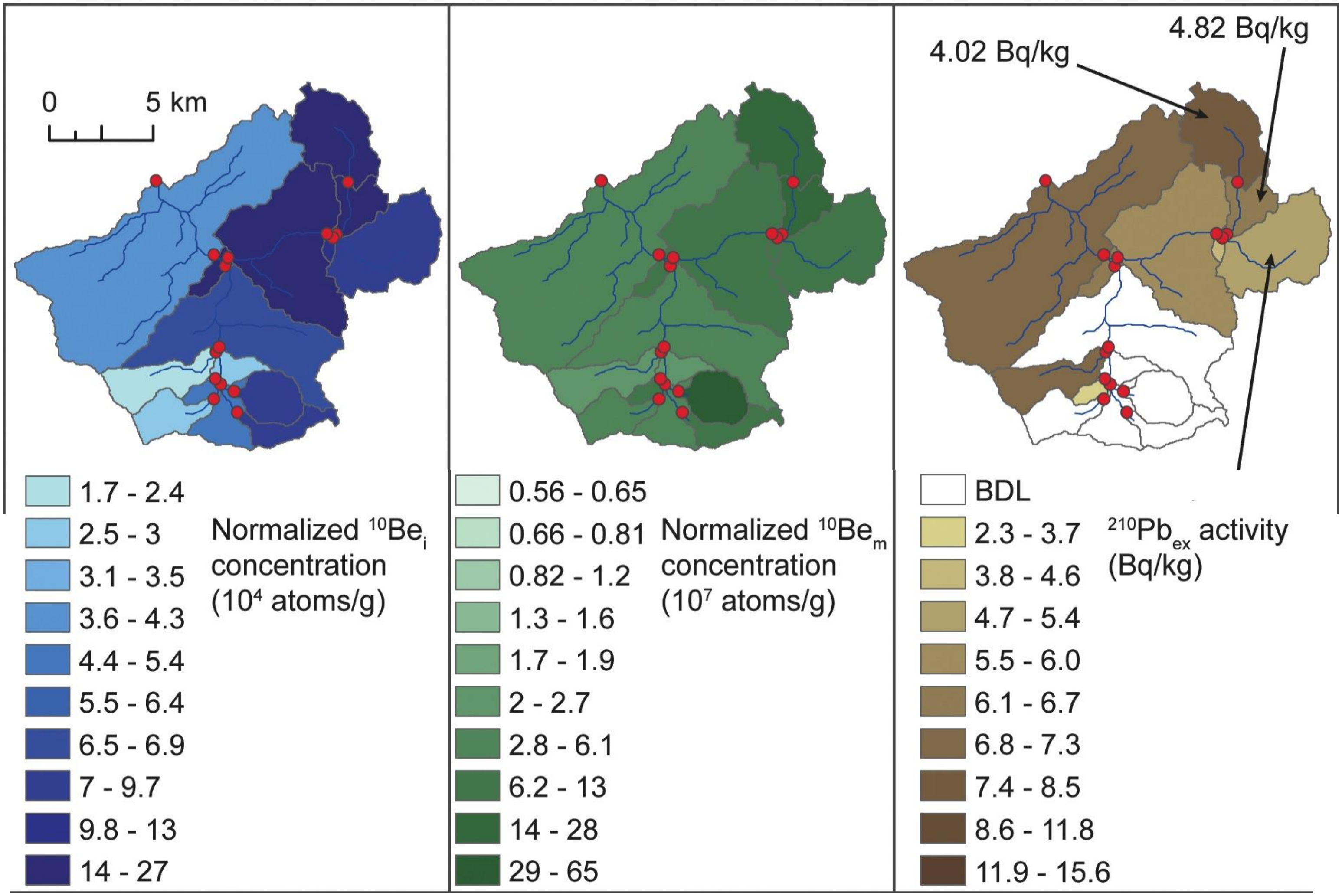
?



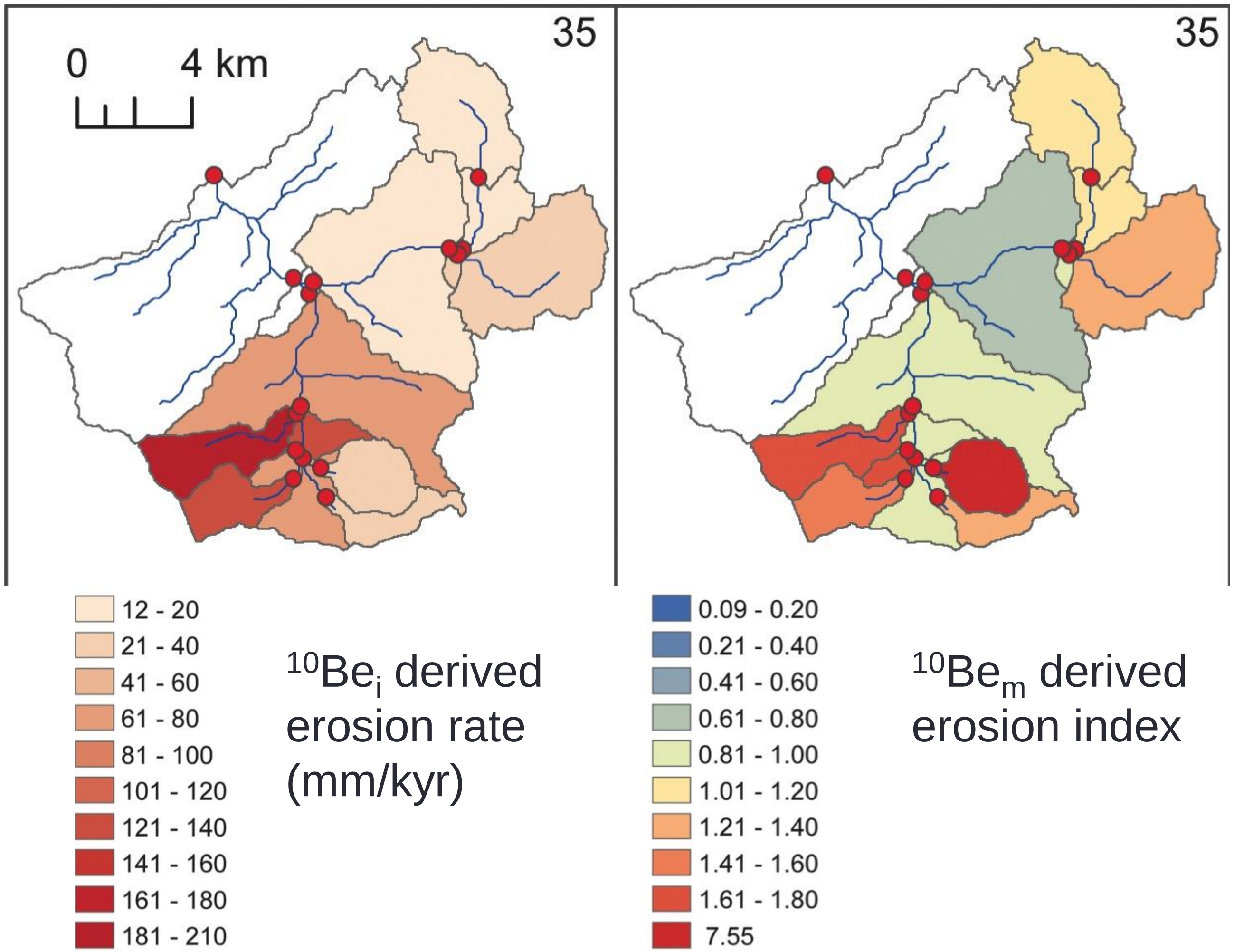
Basin 35: Physical properties



Basin 35: Isotopic Results



Basin 35: Long-term erosion

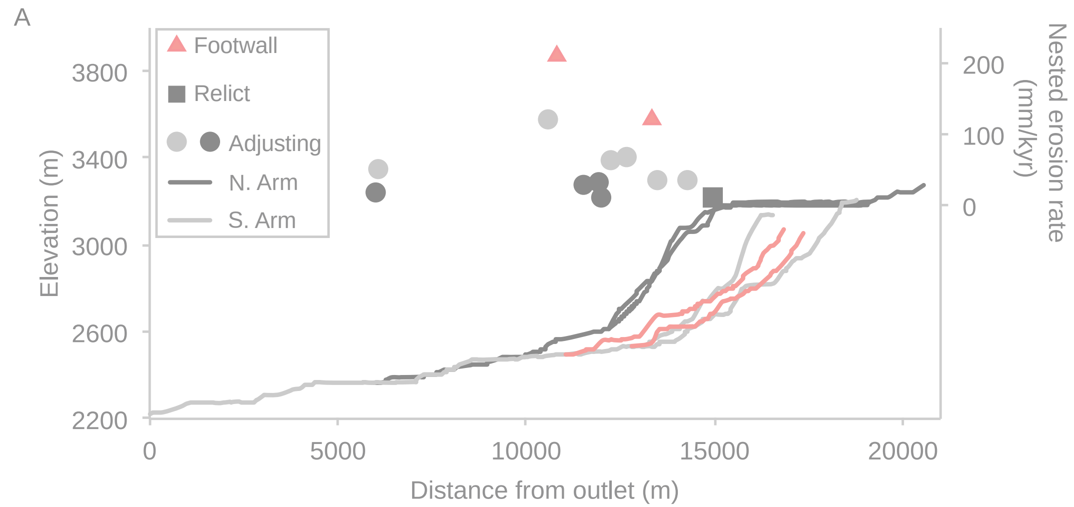


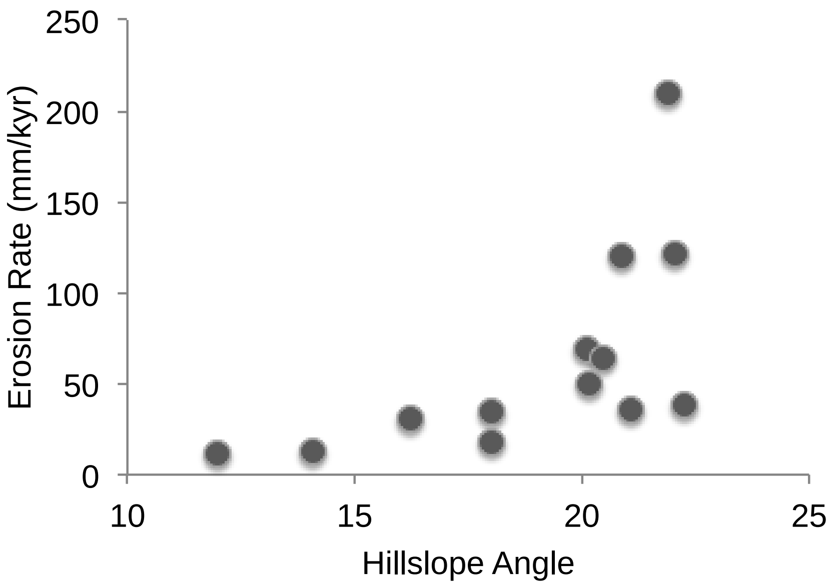
$^{10}Be_i$ derived erosion rate (mm/kyr)

$^{10}Be_m$ derived erosion index

Controls of erosion in basin 35

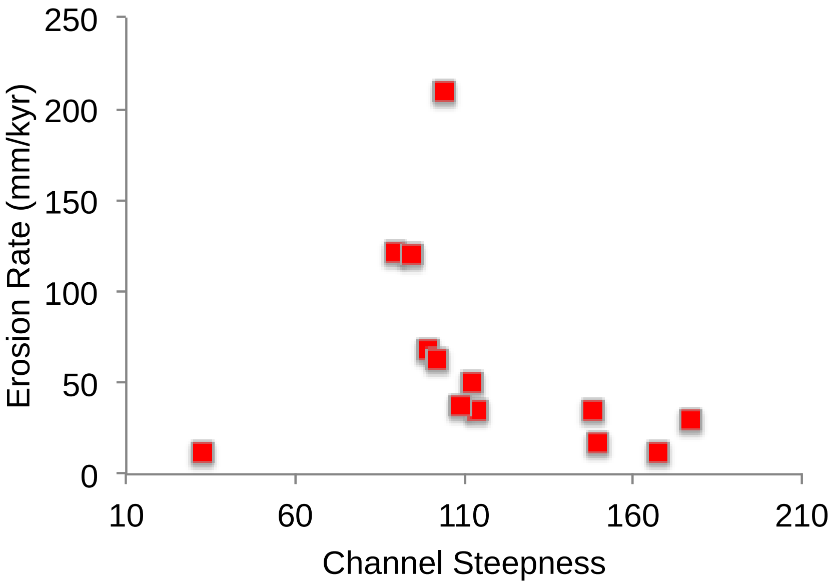
- Base level fall is primary control on long- and short-term erosion

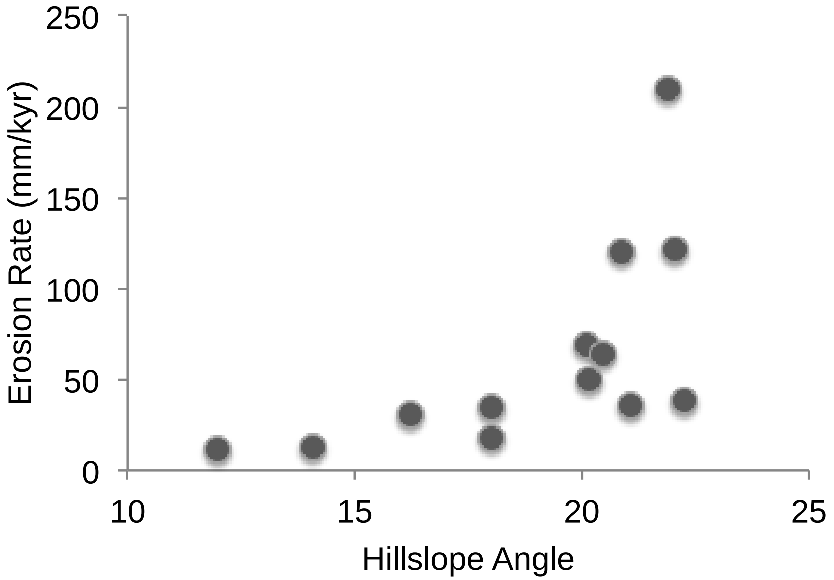




Controls of erosion in basin 35

- Base level fall is primary control on long- and short-term erosion
- Slope steepness determines long-term erosion rate



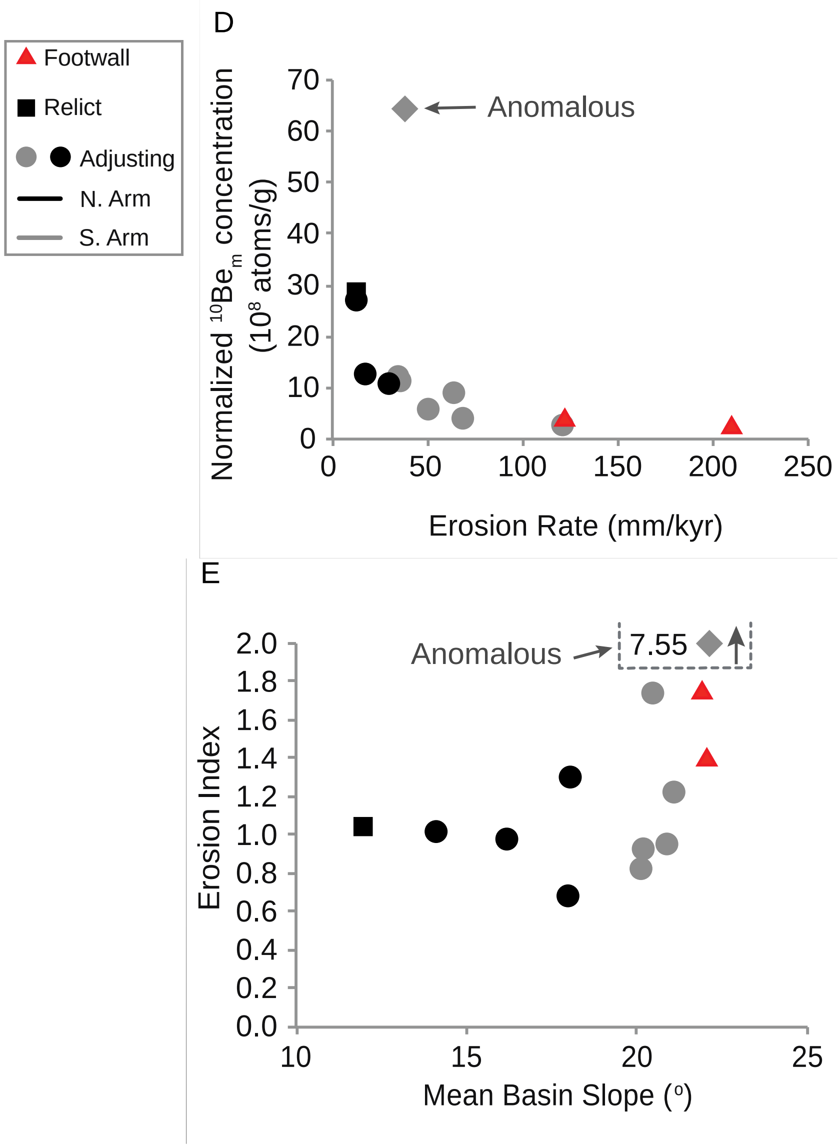


Controls of erosion in basin 35

- Base level fall is primary control on long- and short-term erosion

- Slope steepness determines long-term erosion rate

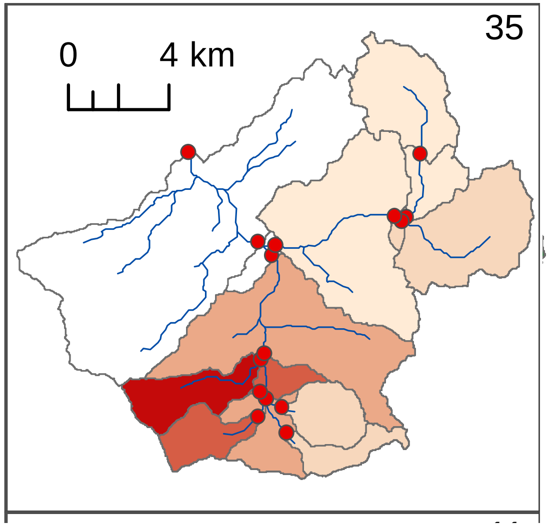
- Erosion rates increase after channels steepen and hillslopes respond



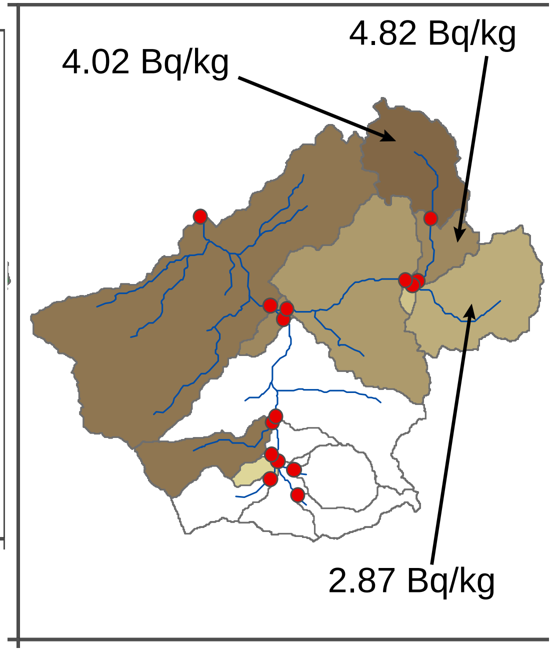
Controls of erosion in basin 35

- Base level fall is primary control on long- and short-term erosion
- Slope steepness determines long-term erosion rate
- Erosion rates increase after channels steepen and hillslopes respond
- Contemporary erosion appears to be controlled by un-measured variable(s)

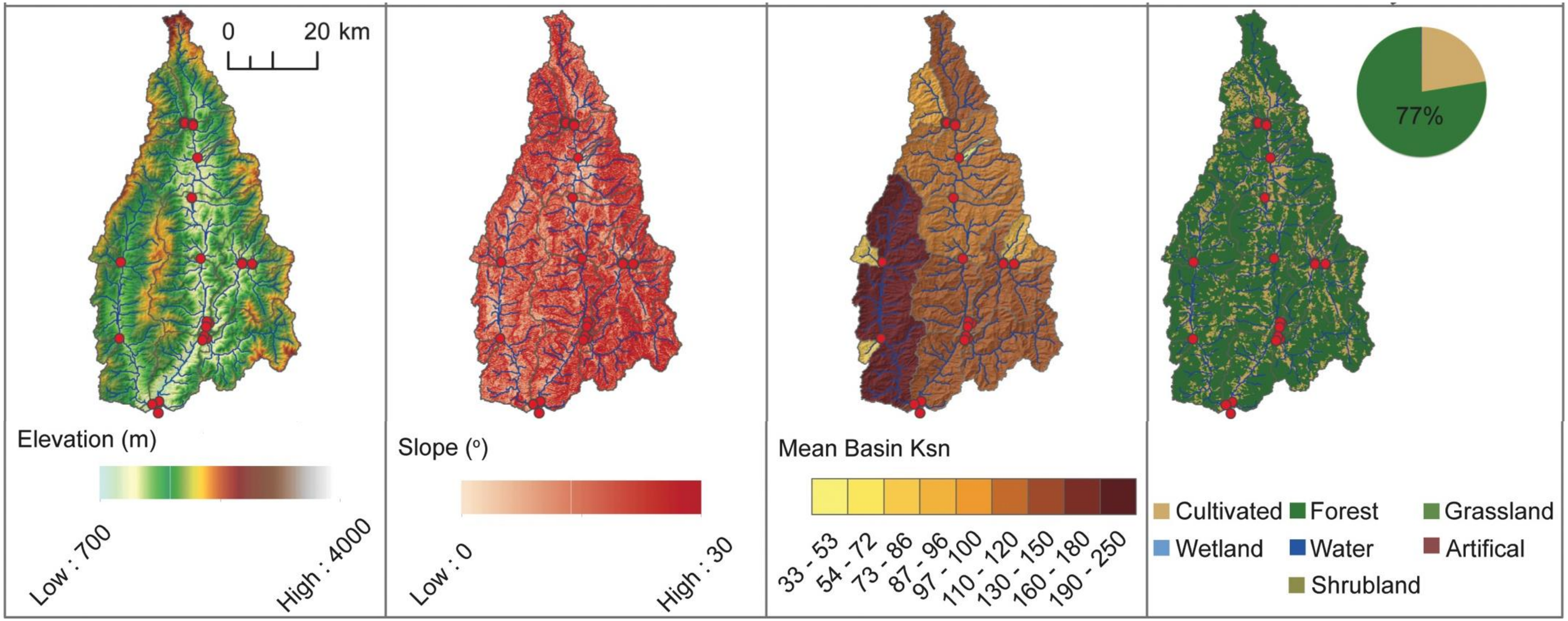
Erosion Rate



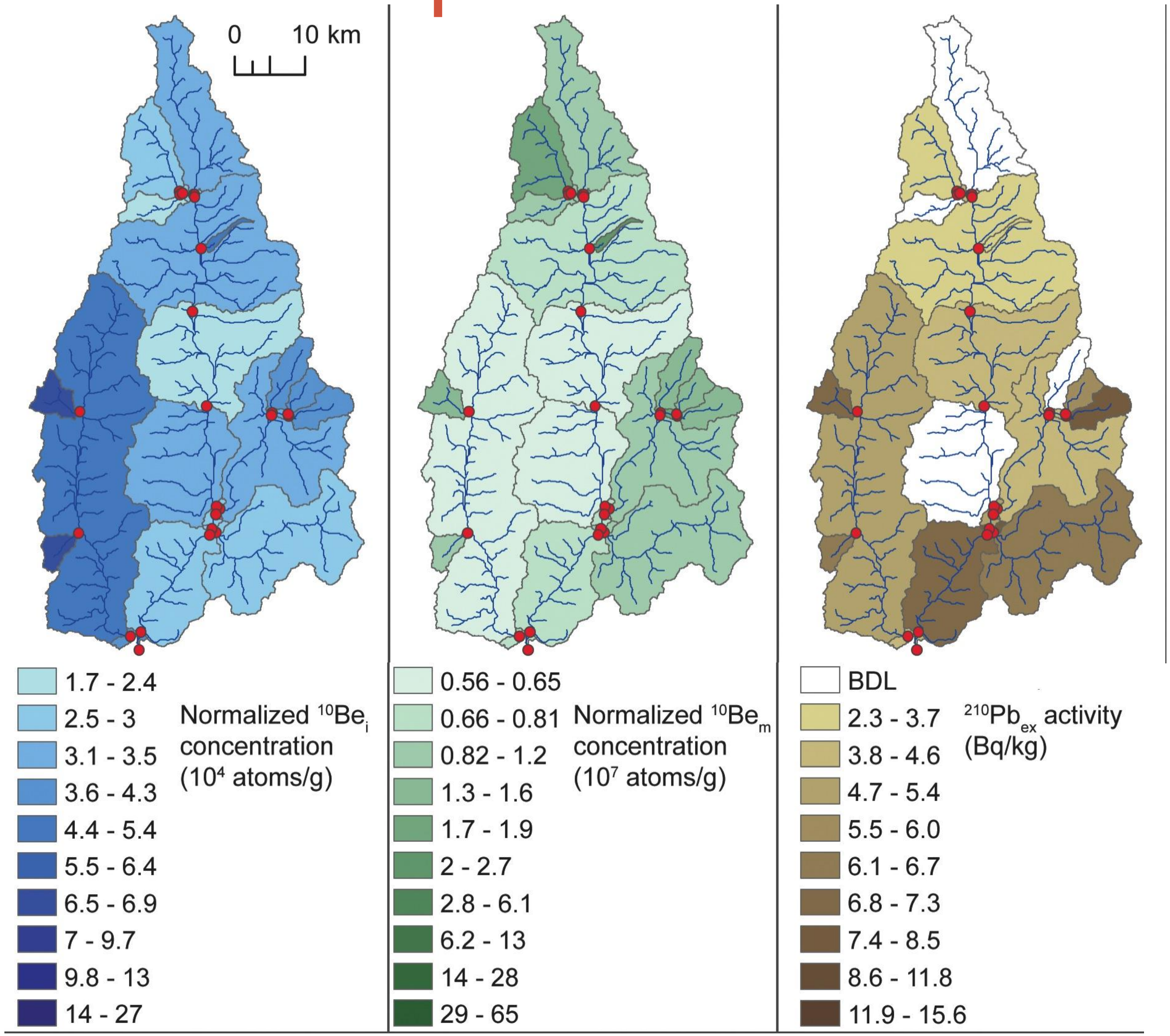
$^{210}Pb_{ex}$ Activity



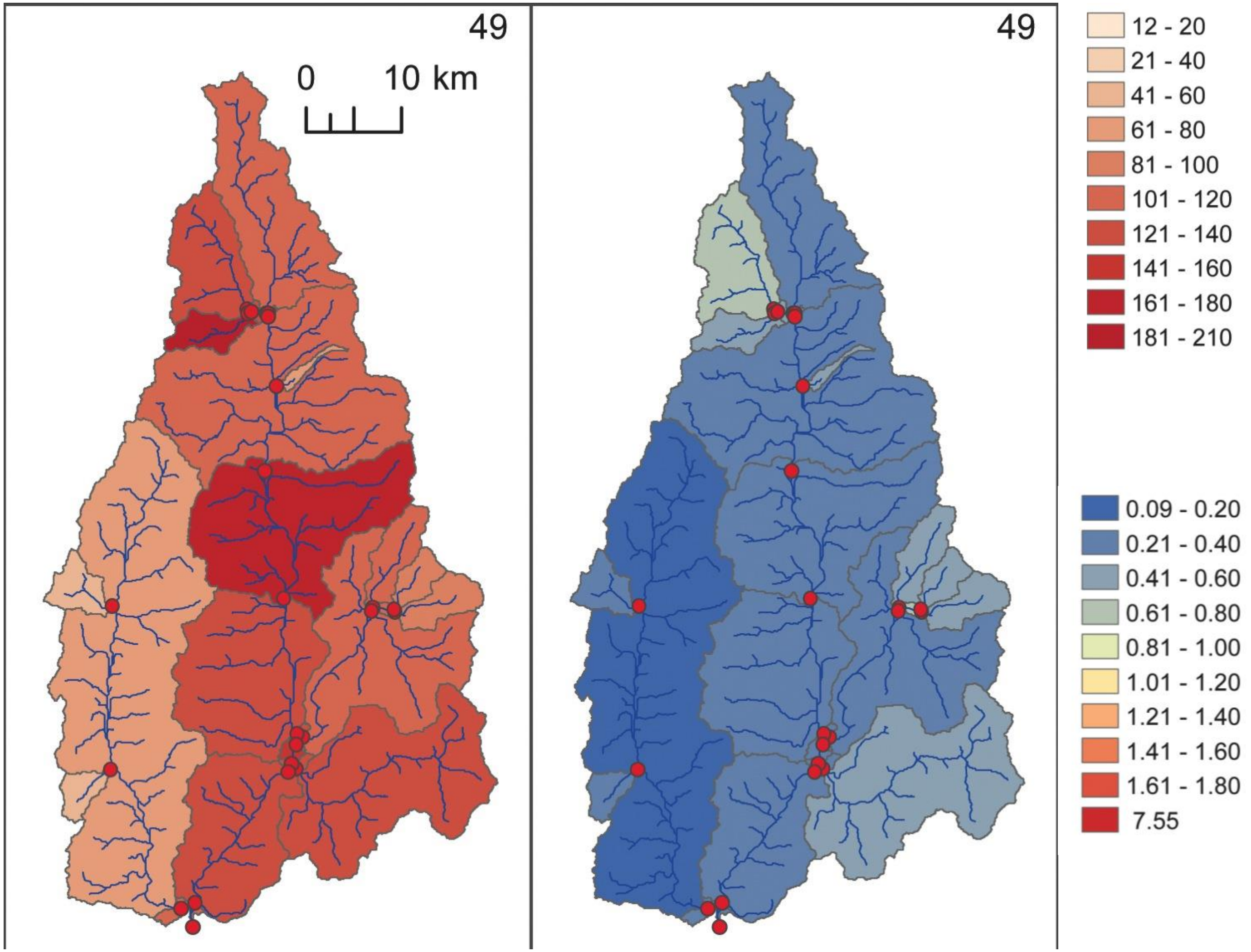
Basin 49: Physical properties



Basin 49: Isotopic Results



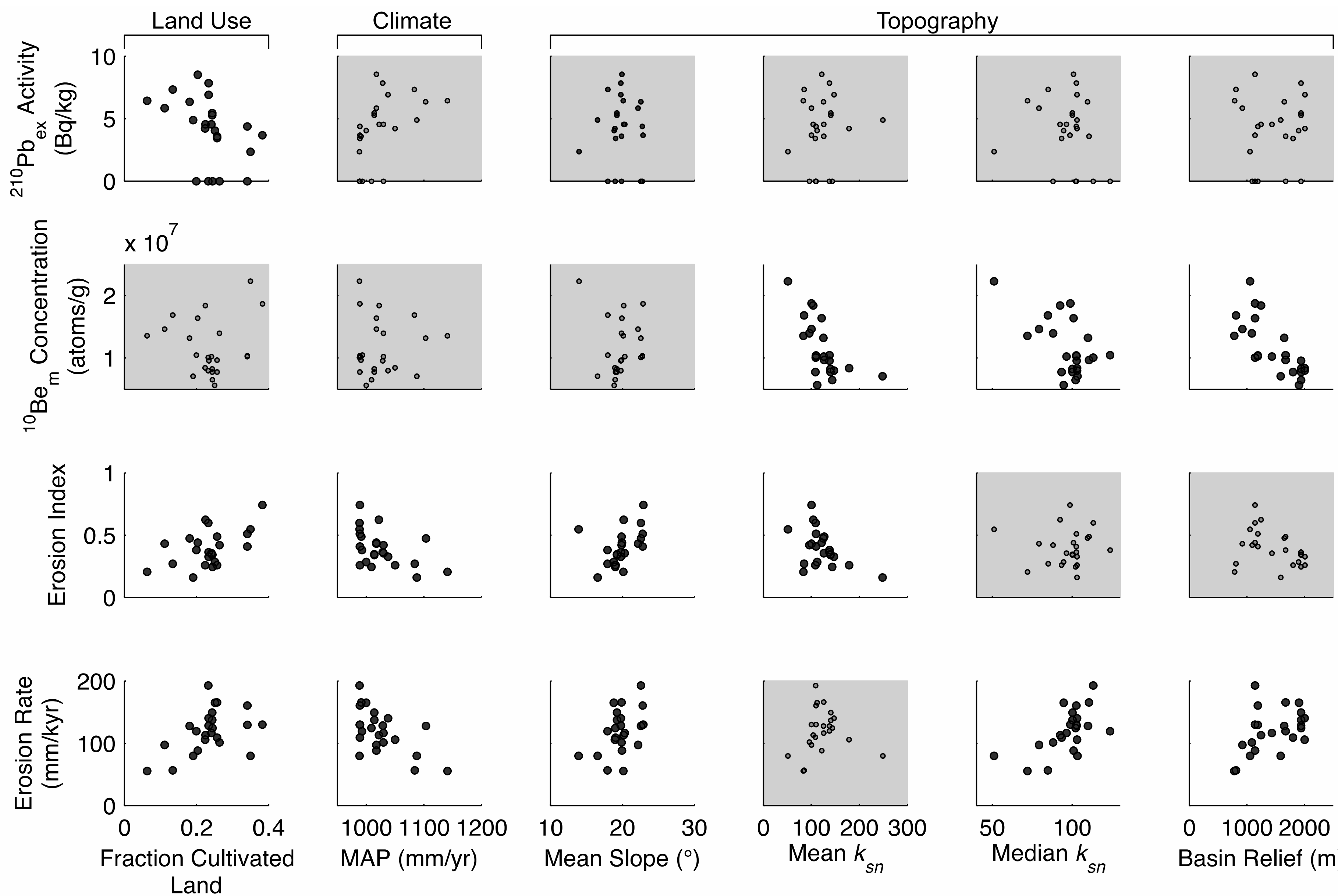
Basin 49: Long-term erosion



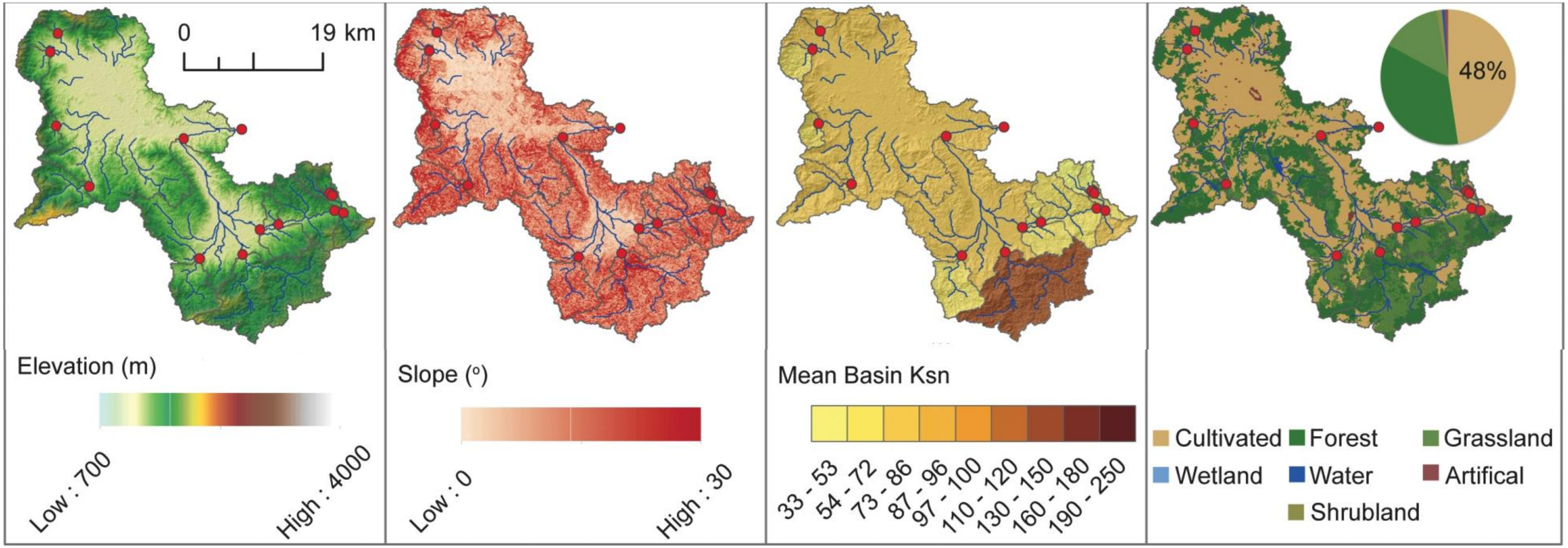
$^{10}Be_i$ derived erosion rate (mm/kyr)

$^{10}Be_m$ derived erosion index

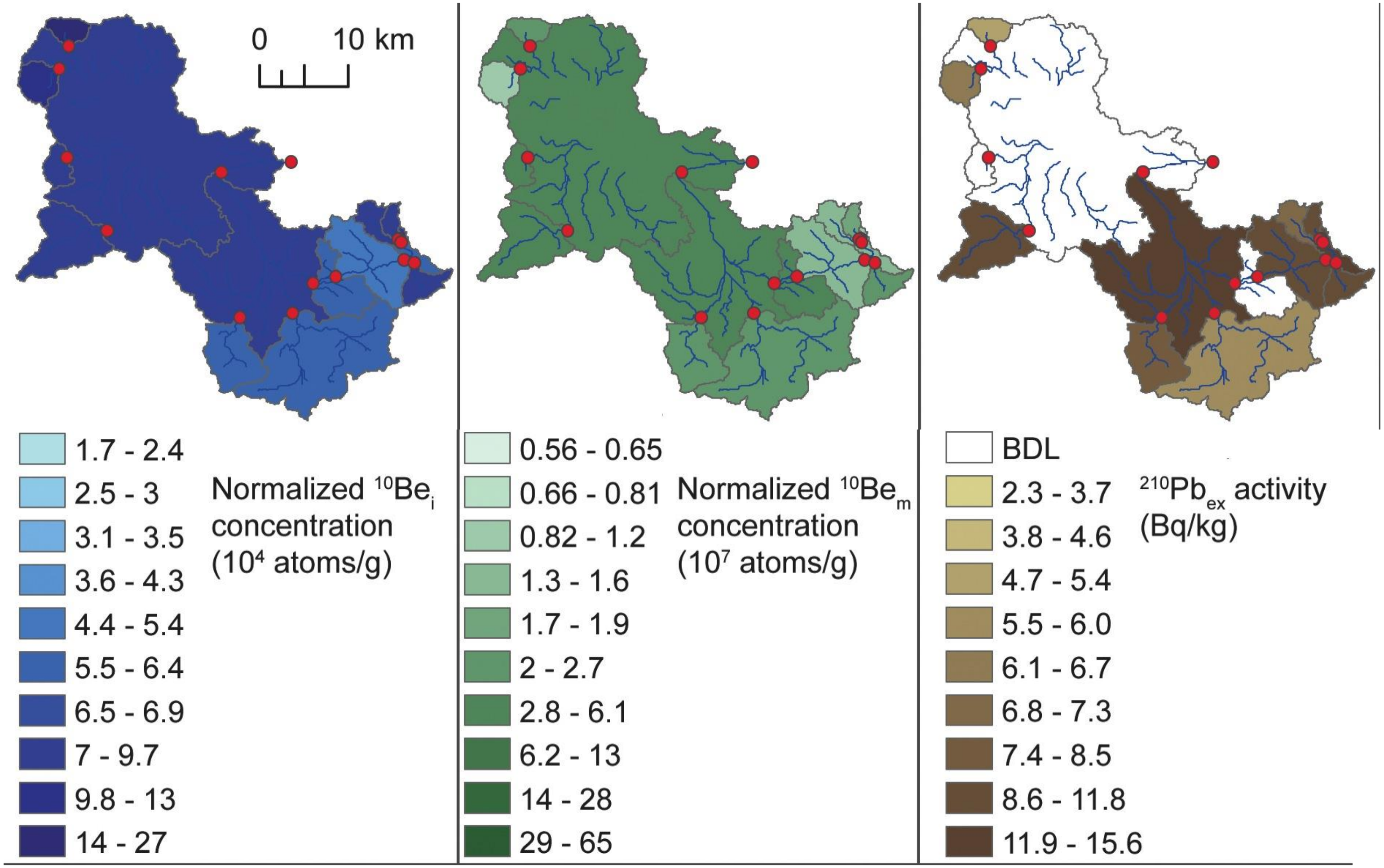
Controls of erosion in basin 49



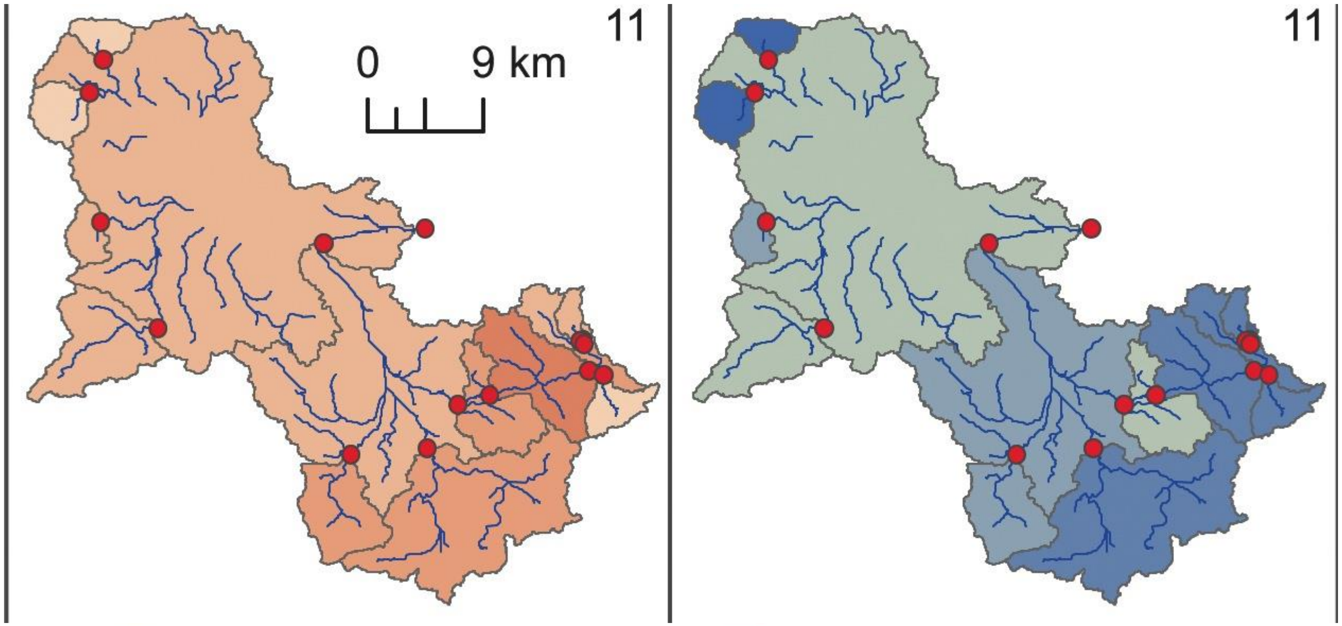
Basin 11: Physical properties



Basin 11: Isotopic Results



Basin 11: Long-term erosion



12 - 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 210

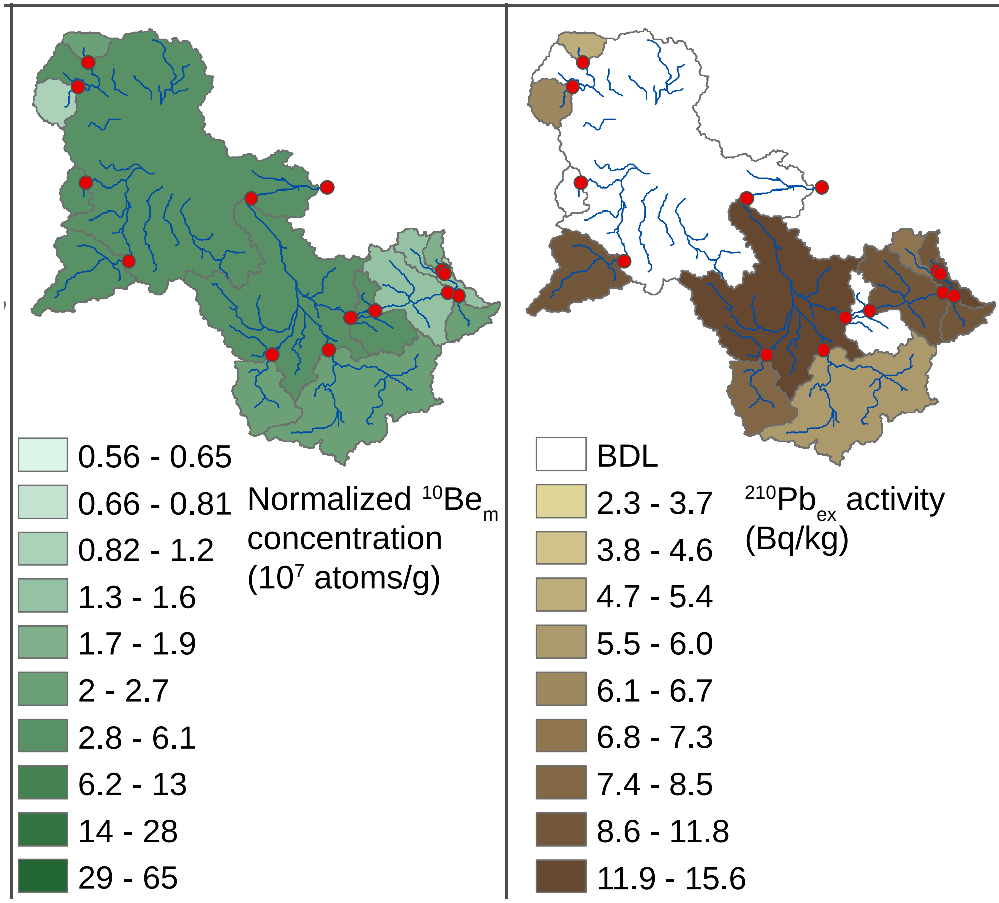
$^{10}Be_i$ derived erosion rate (mm/kyr)

0.09 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
1.01 - 1.20
1.21 - 1.40
1.41 - 1.60
1.61 - 1.80
7.55

$^{10}Be_m$ derived erosion index

Controls of erosion in basin 11

- No ^{137}Cs
- High $^{210}Pb_{ex}$, except at outlet where channel has been altered
- Contemporary sediment yield 50% lower than long-term average



Sediment transport path: working hypothesis

Explain erosion using a conceptual model that follows sediment grains from source to export from the basin.

Sediment transport path: working hypothesis

1. Begins on hillslope with low ^{137}Cs and $^{210}Pb_{ex}$ concentration
2. Enters agricultural terrace through irrigation diversion or direct transport
3. Sits near surface as it works through terrace network, from tread to riser to next terrace, accumulating $^{210}Pb_{ex}$ the entire time
4. Finally enters main river channel and is exported from basin with higher $^{210}Pb_{ex}$ concentration than it began with

Sediment transport path: working hypothesis

- Accounts for:
  - Absence of ^{137}Cs in sediment
  - High activity of $^{210}Pb_{ex}$
  - Low contemporary sediment yield

Primary Findings

- Basin 35: In transient landscape, knickpoint migration in response to base-level fall controls erosion
- Basin 49: In landscape that is adjusted to base-level, morphology controls long-term erosion while agriculture dominates contemporary erosion
- Basin 11: Diversion of water and sediment to terraces complicates interpretations of erosion

Conclusions: What do we learn about the effects Chinese land-use policy?

Change in pace of erosion coincides with extensive deforestation in 1950's – 1980's and top-down forest conservation policy from the 90's to present

Conclusions: Does this method work?

- Measuring four isotopes on the same samples means better temporal resolution of erosion
  - Can address drivers of contemporary and long-term erosion in one study

- Not all of the isotopes provide useful information in all settings

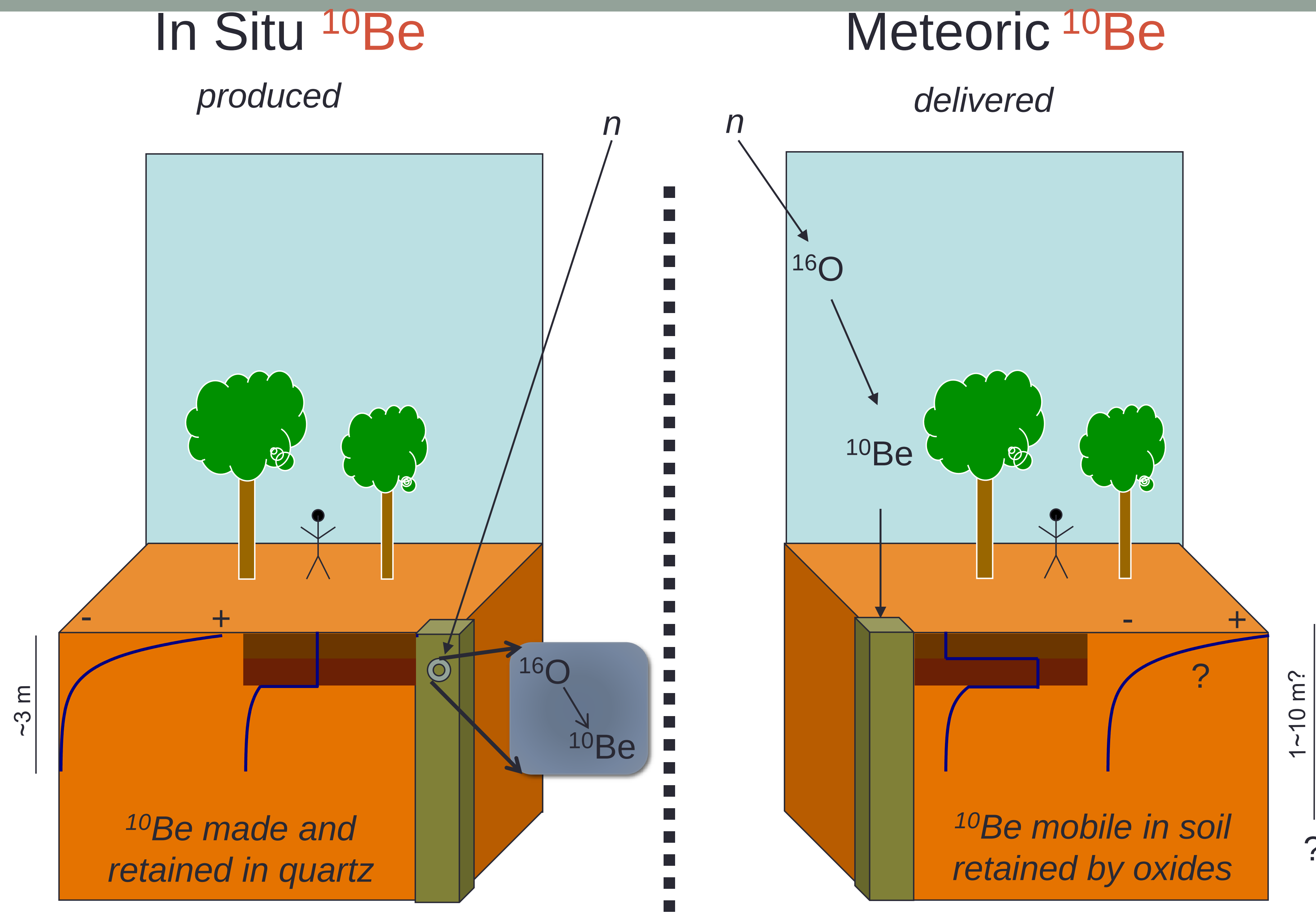
- Here, *in situ* ^{10}Be and $^{210}Pb_{ex}$ are most useful, followed by ^{137}Cs
  - $^{10}Be_{m}$ is difficult to interpret and does not greatly improve our understanding of erosion

Acknowledgements

Special thanks to:

- Paul Bierman
- Amanda Schmidt
- Donna Rizzo
- Andrea Lini
- Veronica Sosa-Gonzalez
- Dylan Rood
- The UVM Geology Department
- National Science Foundation
- And many more…


Questions?

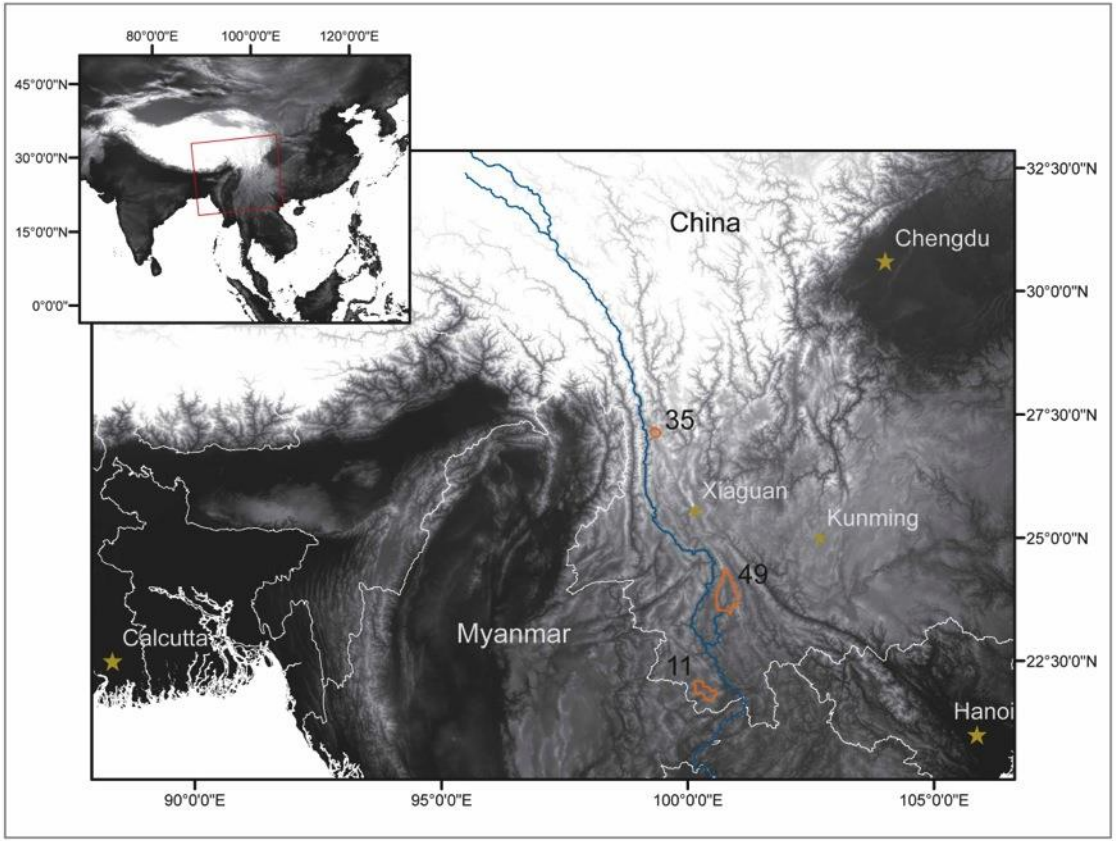


Production = 2.9 *10^2 atoms cm^{-2} y^{-1}

Delivery = 1.3 x 10^6 atoms cm^{-2} y^{-1}

Field area

- Three river basins in the Mekong watershed, Yunnan Provence, China
- Basins range from 200-2000 km^2
- Moderate to high relief (Up to ~1800 m)
- Intensive land use, primarily agriculture and forestry



Methods

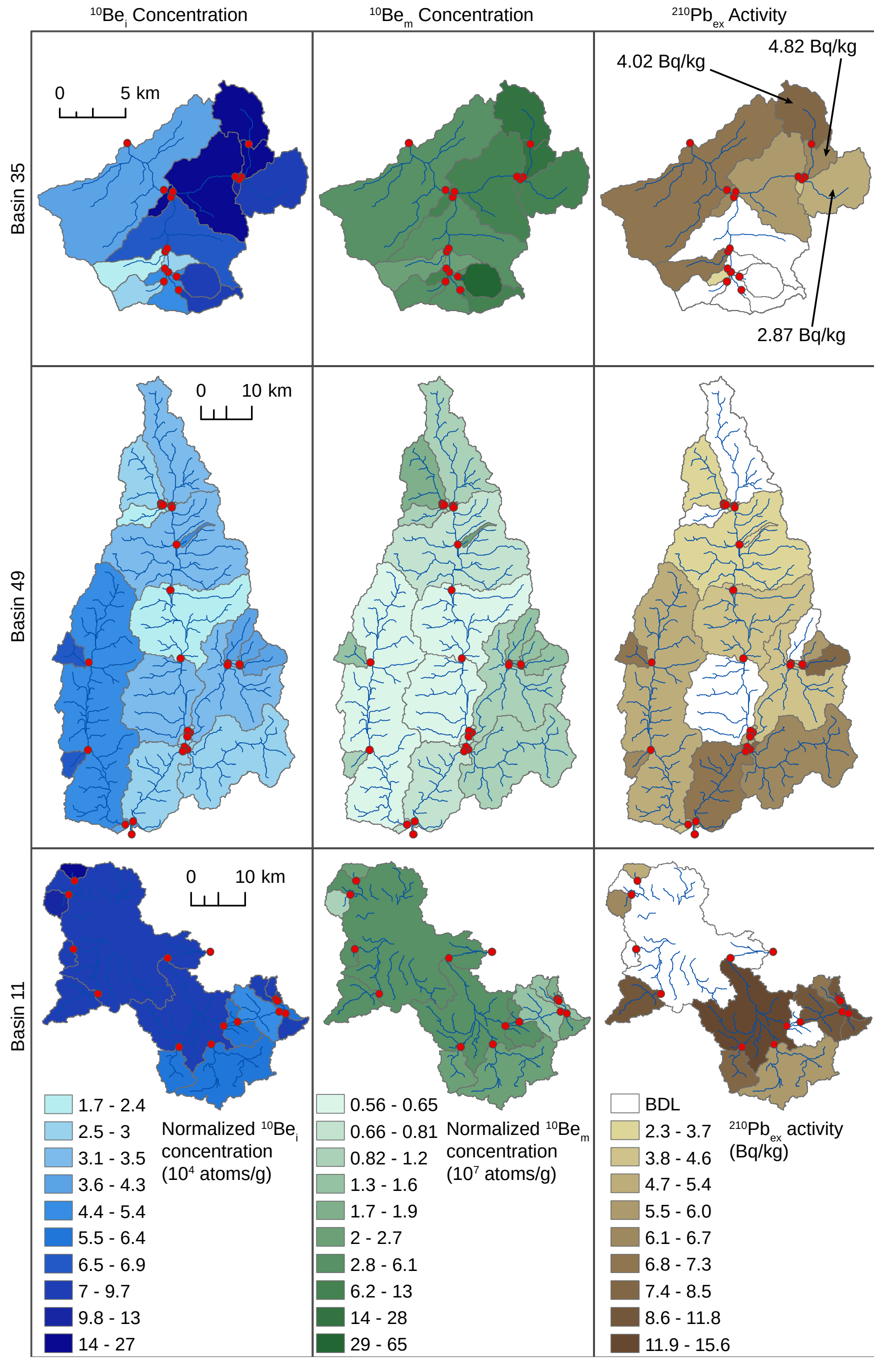
- Four sediment associated isotopic systems
  - Cosmogenic
    - Meteoric ^{10}Be
    - *In situ* ^{10}Be
  - Short-lived
    - Unsupported ^{210}Pb
    - ^{137}Cs

- ^{14}C to date terraces and “paleo” *in situ* ^{10}Be erosion rates

- Daily sediment yield data from Chinese Government hydrology stations (18-23 years)

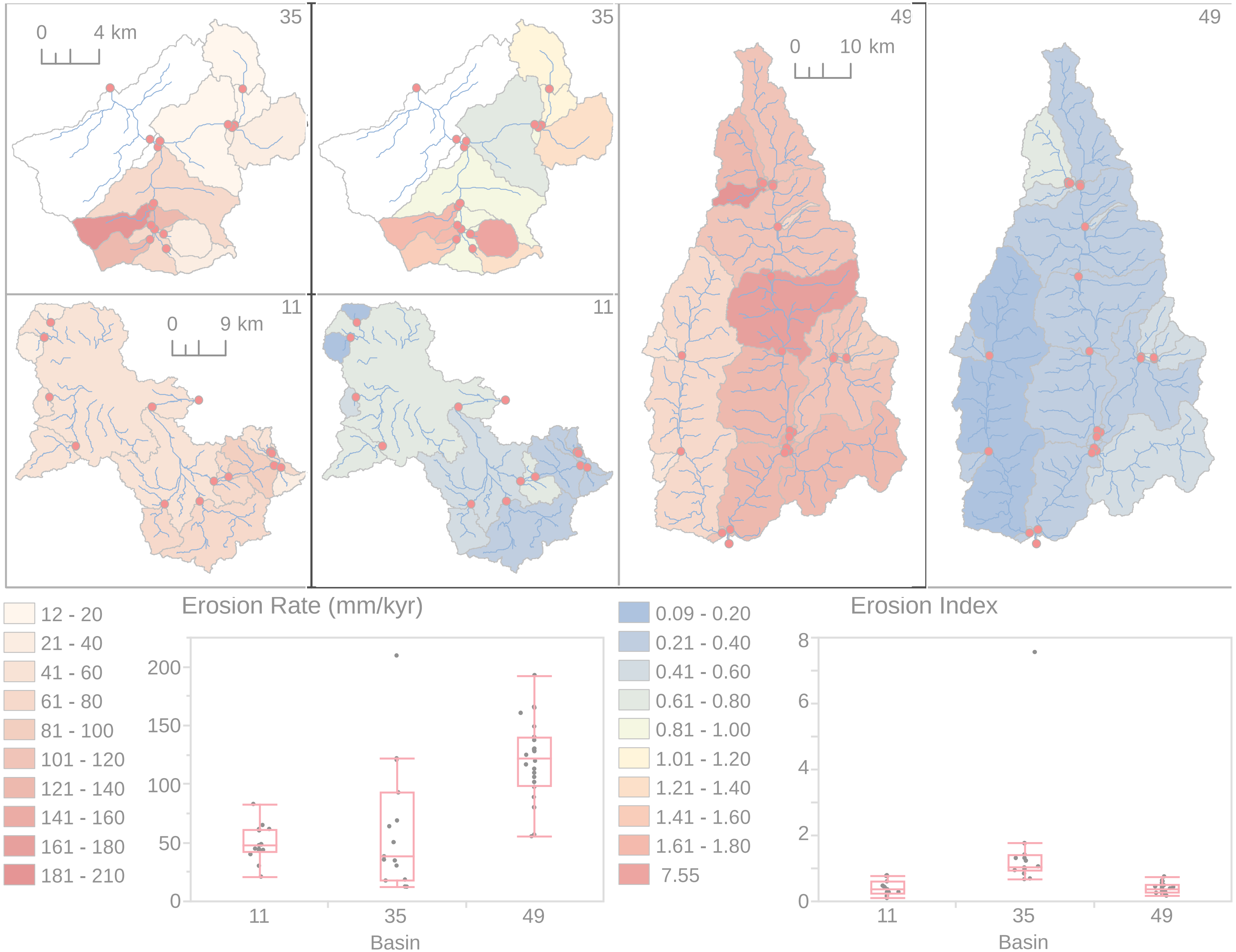
- Remotely sensed land-use classification

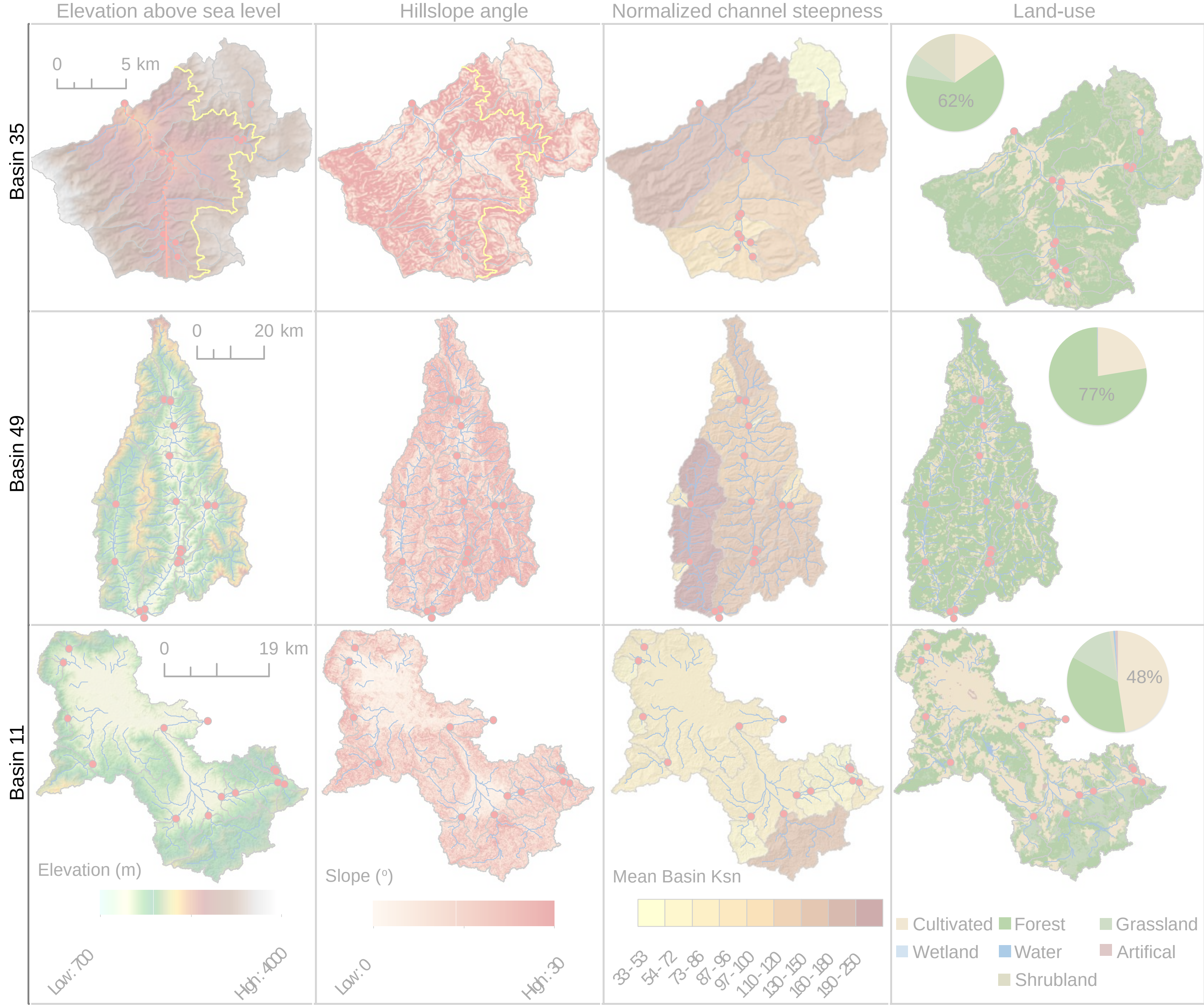
Results



$^{10}Be_i$ Concentration
$^{10}Be_m$ Concentration
$^{210}Pb_{ex}$ Activity
Basin 35
Basin 49
Basin 11
0 5 km
0 10 km
0 10 km
4.02 Bq/kg
4.82 Bq/kg
2.87 Bq/kg
1.7 - 2.4
2.5 - 3
3.1 - 3.5
3.6 - 4.3
4.4 - 5.4
5.5 - 6.4
6.5 - 6.9
7 - 9.7
9.8 - 13
14 - 27
Normalized $^{10}Be_i$ concentration (10^4 atoms/g)
0.56 - 0.65
0.66 - 0.81
0.82 - 1.2
1.3 - 1.6
1.7 - 1.9
2 - 2.7
2.8 - 6.1
6.2 - 13
14 - 28
29 - 65
Normalized $^{10}Be_m$ concentration (10^7 atoms/g)
BDL
2.3 - 3.7
3.8 - 4.6
4.7 - 5.4
5.5 - 6.0
6.1 - 6.7
6.8 - 7.3
7.4 - 8.5
8.6 - 11.8
11.9 - 15.6
$^{210}Pb_{ex}$ activity (Bq/kg)

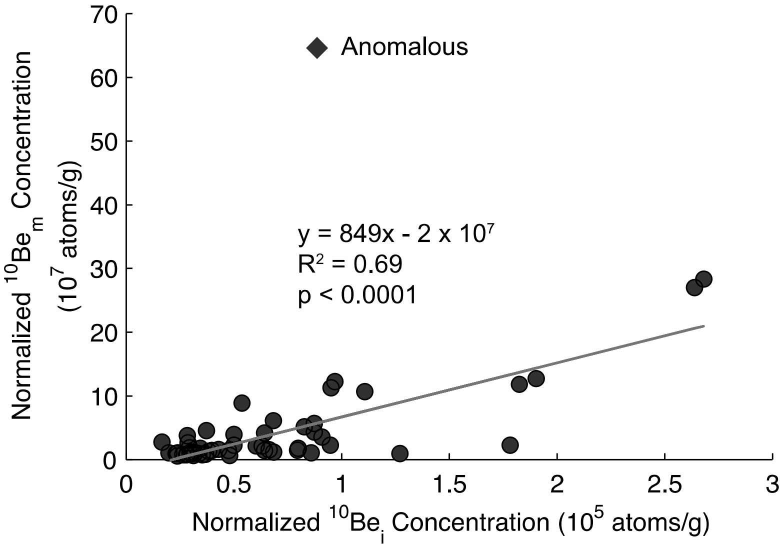
^{10}Be Results



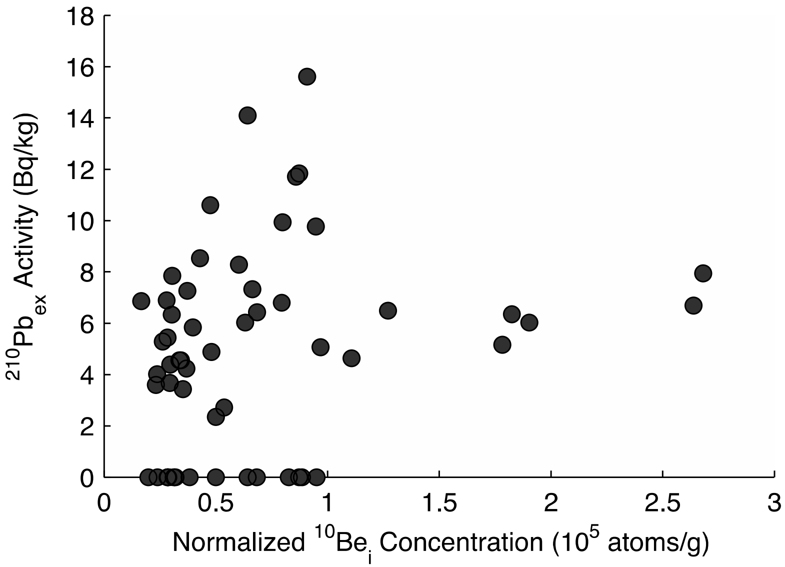


Elevation above sea level
Hillslope angle
Normalized channel steepness
Land-use
Basin 35
Basin 49
Basin 11
0
5 km
0
20 km
0
19 km
62%
77%
48%
Elevation (m)
Low: 700
High: 4000
Slope (°)
Low: 0
High: 30
Mean Basin Ksn
33-53
54-72
73-86
87-96
97-100
110-120
130-150
160-180
190-250
Cultivated
Forest
Grassland
Wetland
Water
Artifical
Shrubland

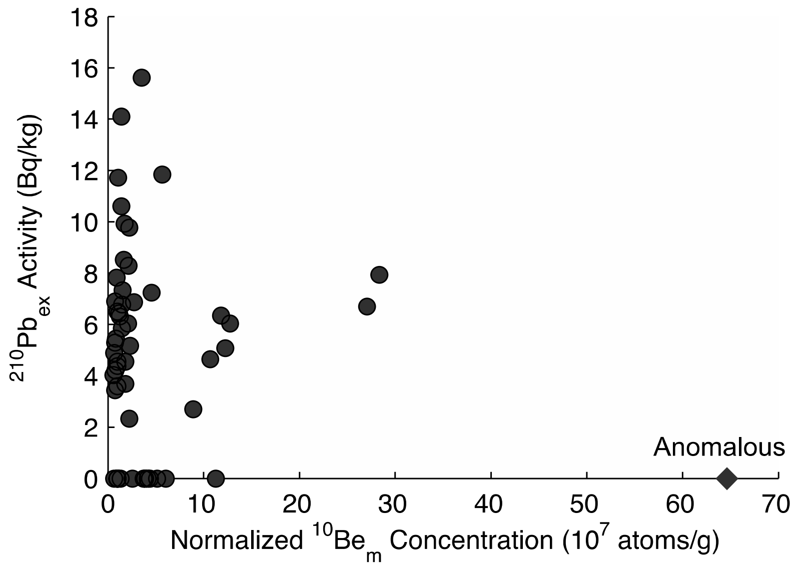
Results



Anomalous
y = 849x - 2 x 10⁷
R² = 0.69
p < 0.0001
Normalized ¹⁰Beₘ Concentration (10⁷ atoms/g)
Normalized ¹⁰Beᵢ Concentration (10⁵ atoms/g)



²¹⁰Pbₑₓ Activity (Bq/kg)
Normalized ¹⁰Beᵢ Concentration (10⁵ atoms/g)



²¹⁰Pbₑₓ Activity (Bq/kg)
Anomalous
Normalized ¹⁰Beₘ Concentration (10⁷ atoms/g)

Isotopes used for contemporary erosion

Unsupported ^{210}Pb

- $t_{1/2}$ = 22.2 yr
- Naturally occurring as part of ^{238}U decay series
- Fraction of total ^{210}Pb in soil derived from ^{222}Rn gas that leaves soil
- Delivered back to soil through fallout

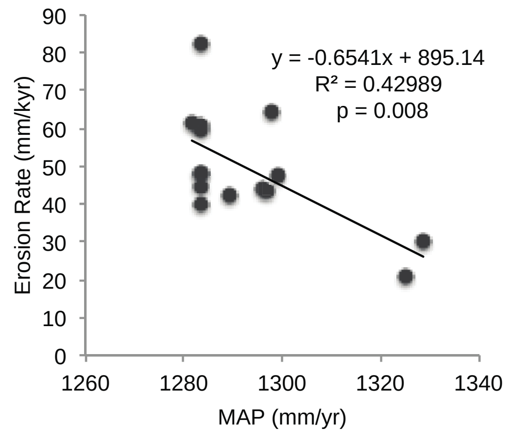
^{137}Cs

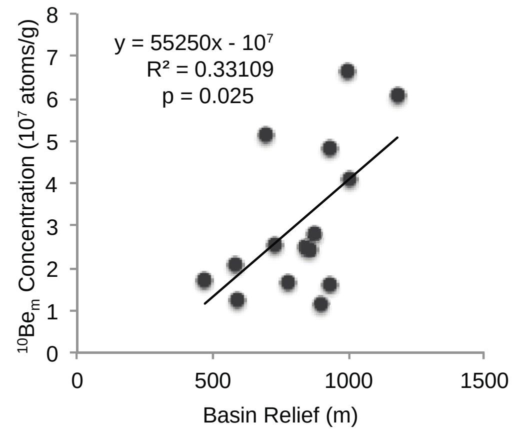
- $t_{1/2}$ = 30.2 yr
- Created from nuclear weapons testing and accidents
- Delivered to soil through fallout
- Only deposited globally from 1950's to 1970's

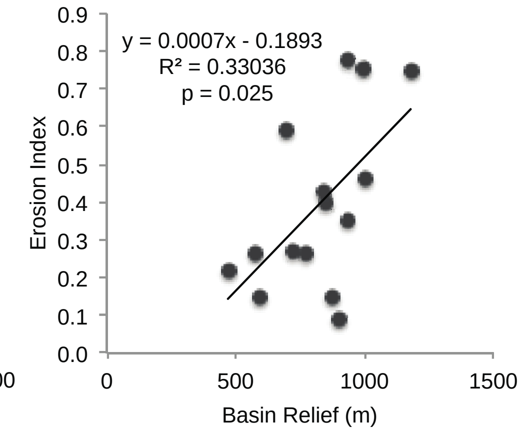
Controls of erosion in basin 11

- Modest statistically significant relationships between long-term measures of erosion and MAP and relief

- Unclear what, if any, processes might be driving these relationships – likely result of extensive agriculture

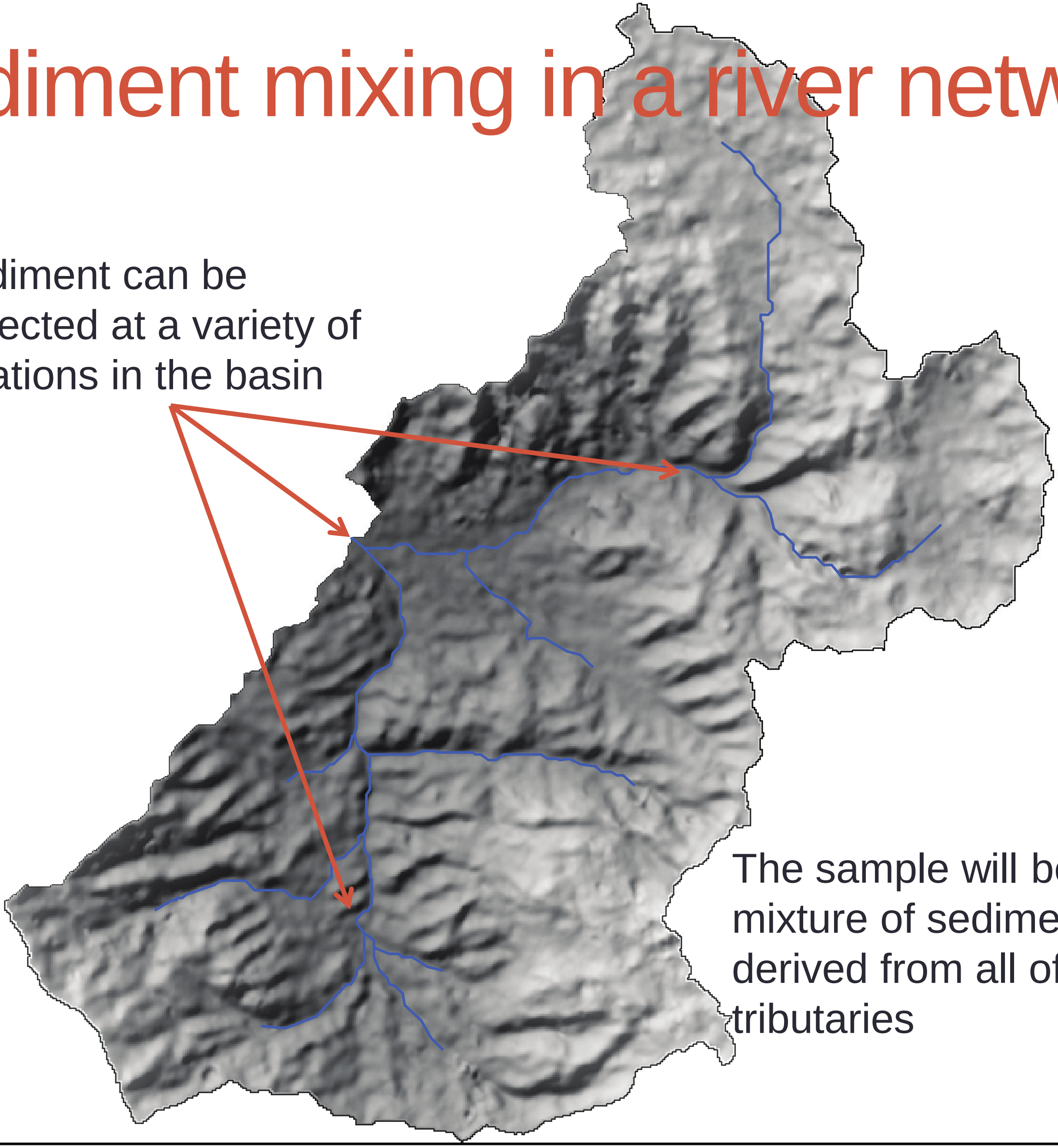






Sediment mixing in a river network

Sediment can be collected at a variety of locations in the basin



The sample will be a mixture of sediment derived from all of the tributaries