Towards a better understanding of meteoric ^{10}Be and ^{9}Be dynamics in river sediments

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MS Thesis Defense
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main objectives

Part 1. ^{10}Be and ^{9}Be dynamics in fluvial systems

gain understanding of the meteoric ^{10}Be proxy system by analyzing the composition of sediment grain coatings

assess the relative influences of remobilization processes, spatial heterogeneity of ^{10}Be and ^{9}Be inputs, and denudation rates on meteoric $^{10}Be/^{9}Be$ ratios of fluvial sediments

Part 2. meteoric $^{10}Be/^{9}Be$-denudation rates

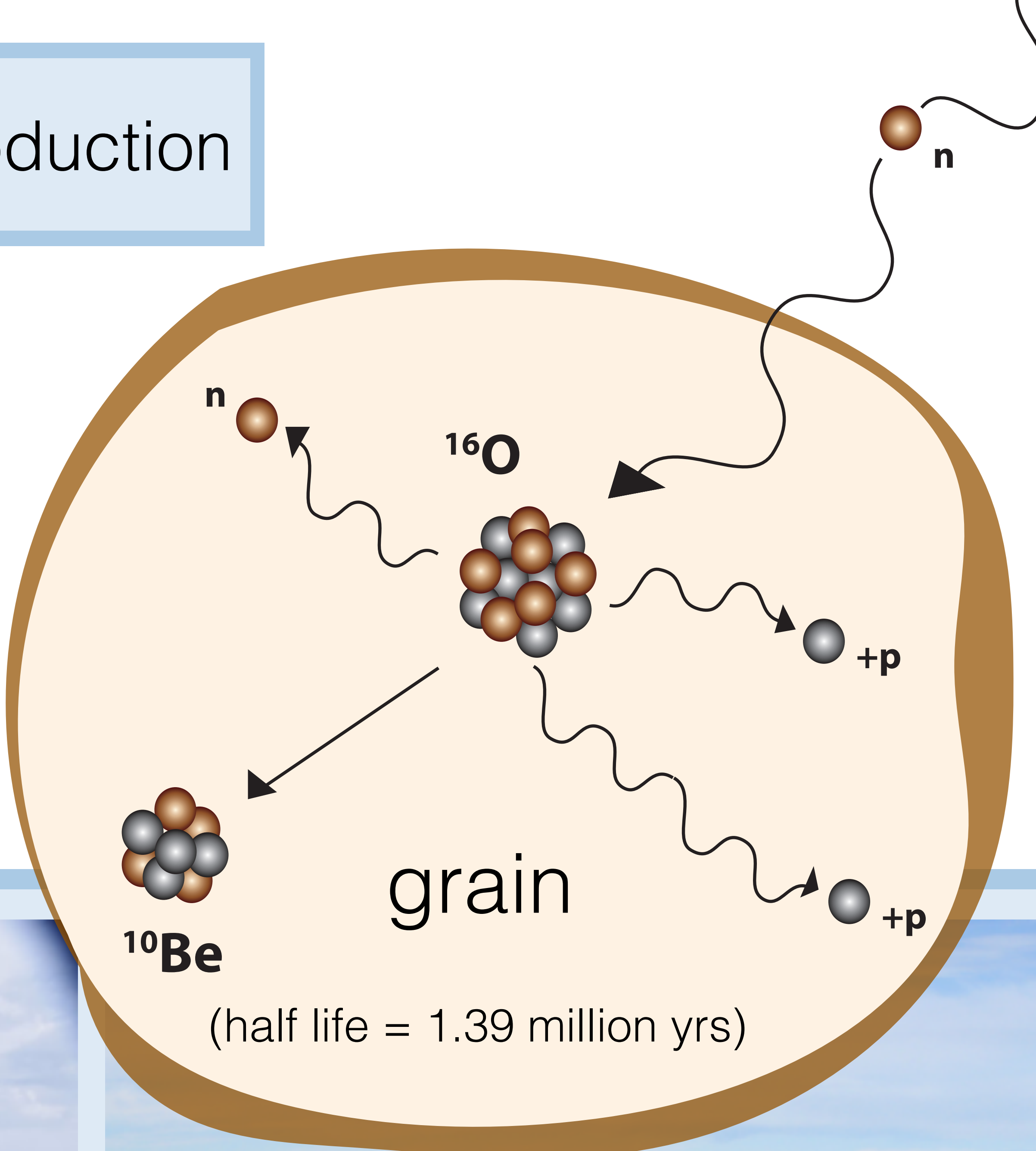
Compare meteoric $^{10}Be/^{9}Be$ denudation rates to known denudation rates (in situ based)

Outline

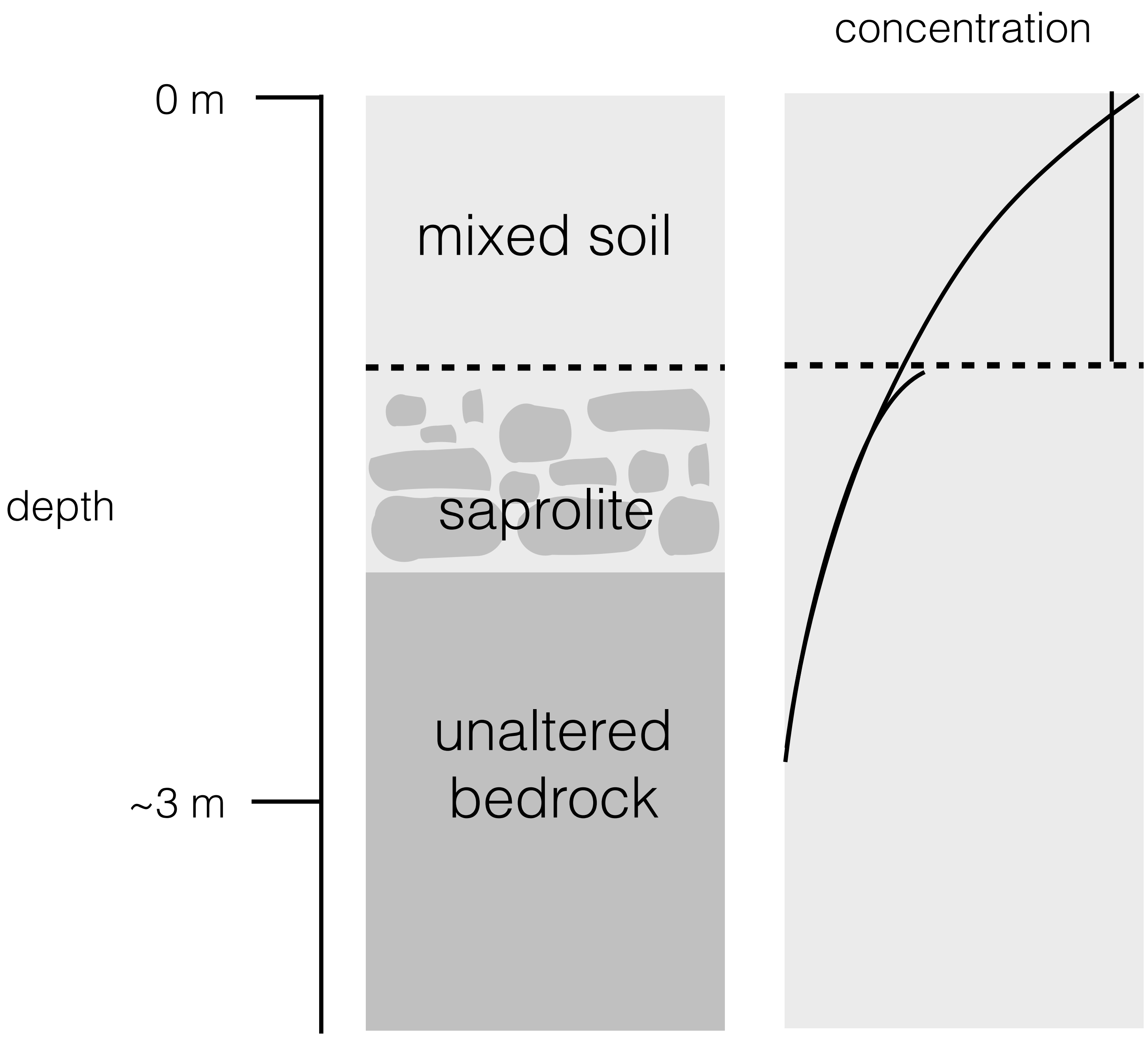
- Background
  - *in situ* ^{10}Be
  - *meteoric* ^{10}Be
  - *native* ^{9}Be
  - *meteoric* $^{10}Be/^{9}Be$ *denudation rates*
- Motivation and goals
- Methods
- Results
- Discussion
- Conclusions

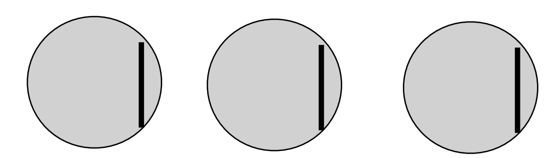
background, part 1. *in situ* ^{10}Be production

- ^{10}Be trapped in mineral grains
- Production determined by well-understood physics



background, part 1. *in situ* ^{10}Be denudation rates



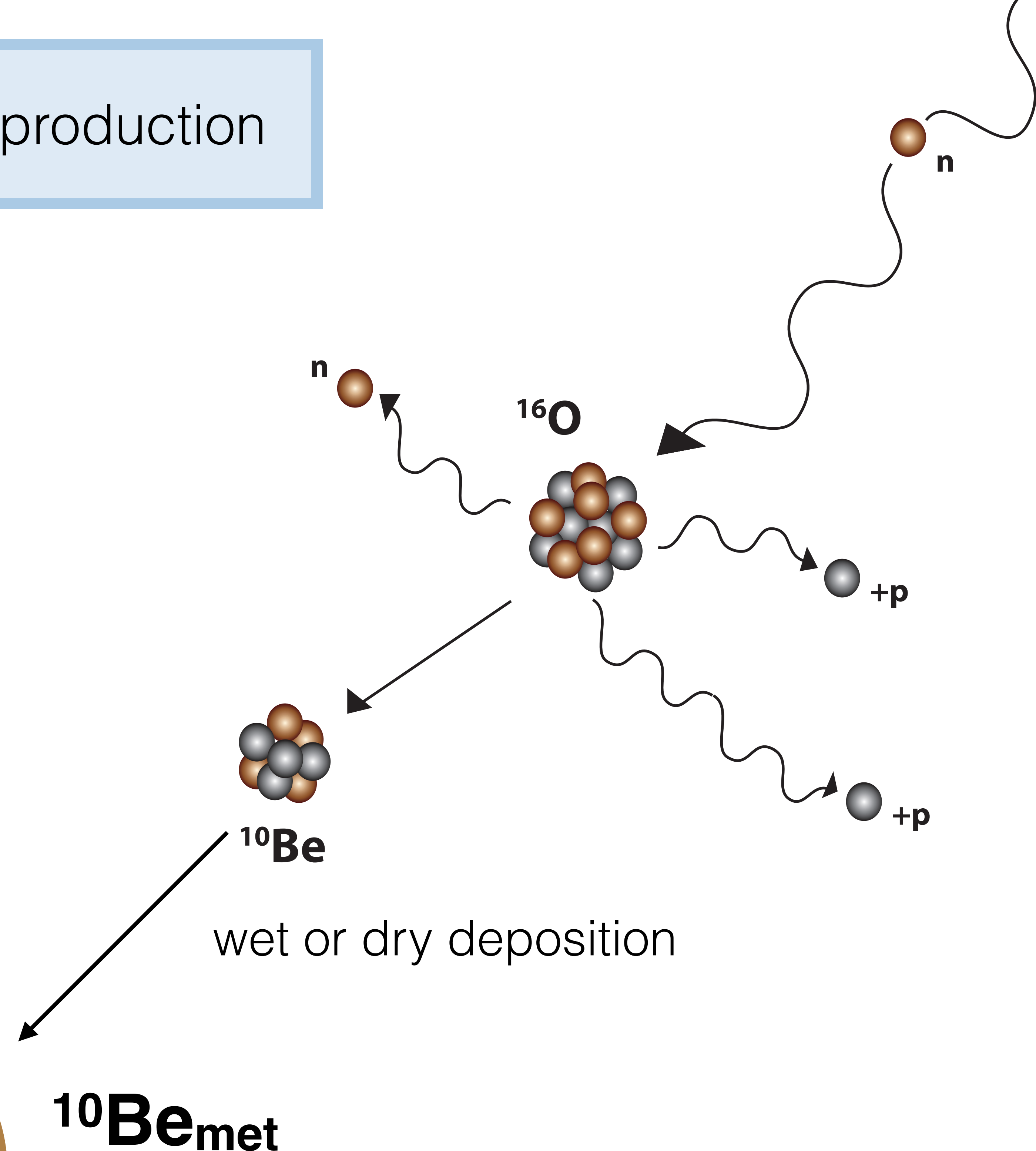


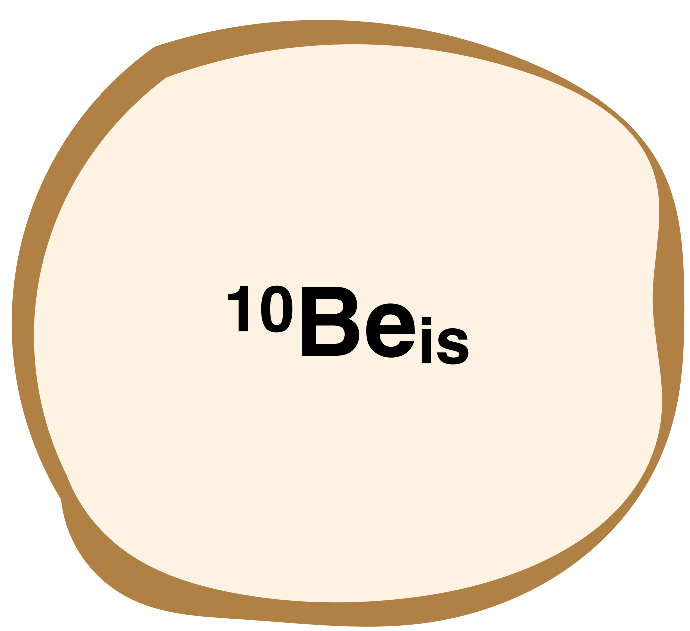
- slower denudation rates —> more in situ ^{10}Be in grains
- need to have sand-size grains or greater and quartz lithology

background, part 1. meteoric ^{10}Be production

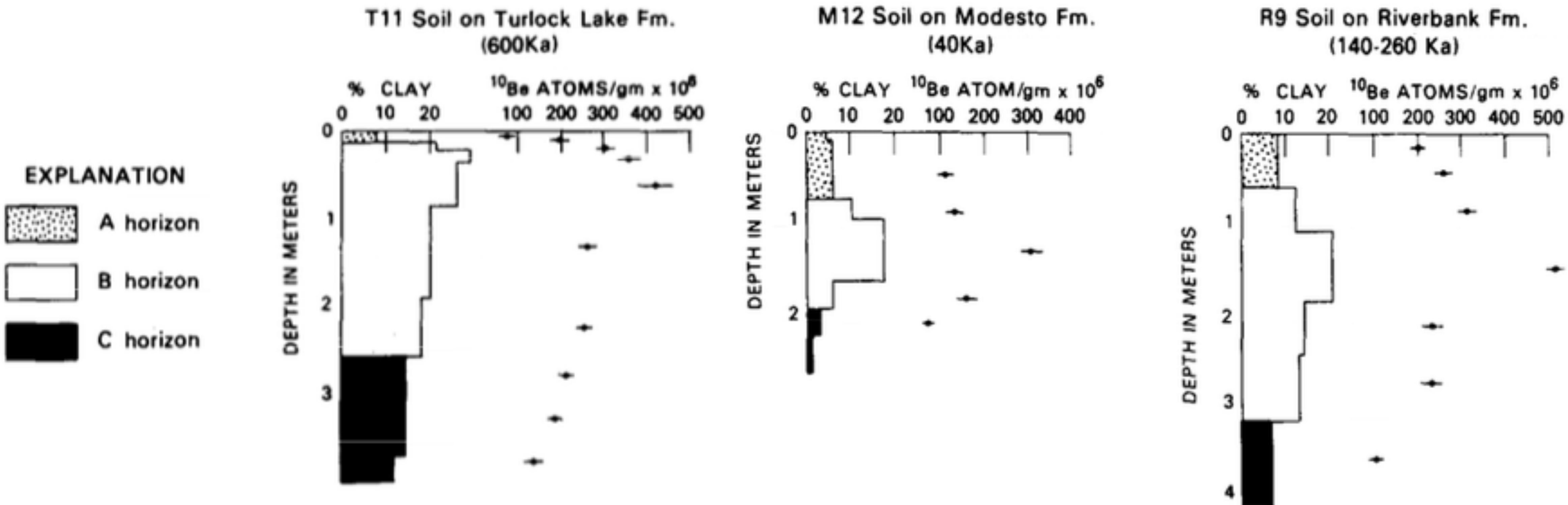
- meteoric ^{10}Be stored primarily in grain coatings; mobile
  - sorption potential varies by substrate, pH

- Delivery rate depends on
  - irradiation conditions
  - atmospheric mixing rates
  - precipitation rates
  - rates of dust deposition

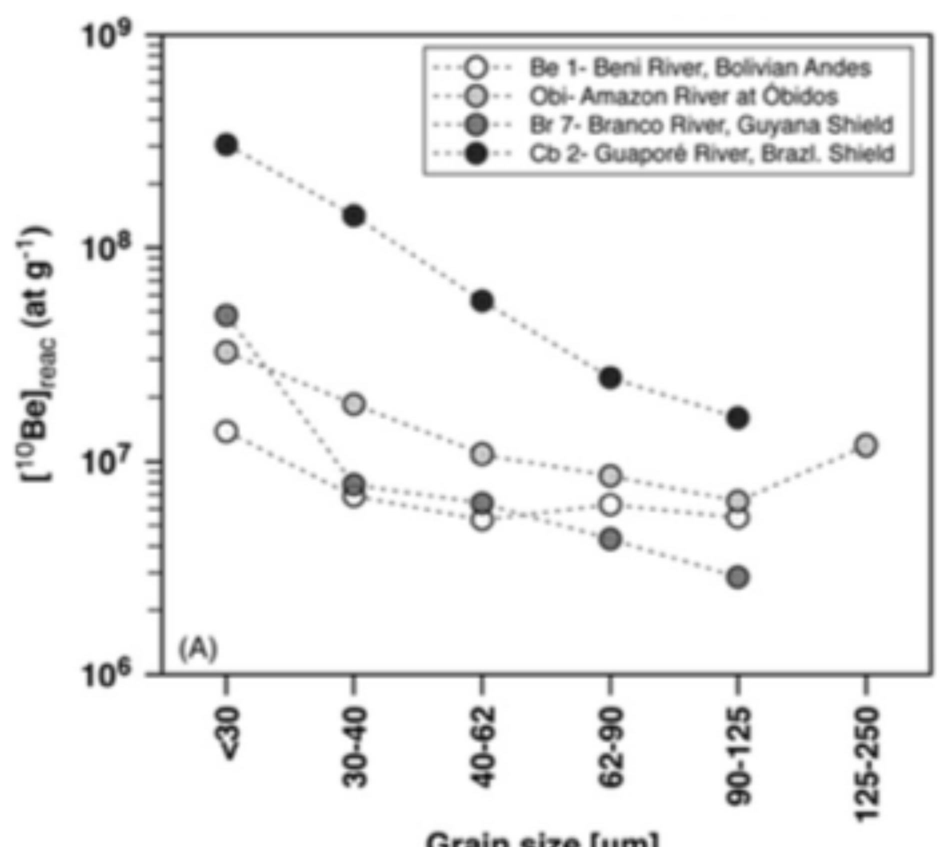




background, part 1. meteoric ^{10}Be dynamics



...iver terraces, California. *Geochimica et Cosmochimca Acta.*



- correlates to % clay in soil profile
  - mineralogy (Cation Exchange Capacity)
  - grain size
- meteoric ^{10}Be abundance can be difficult to interpret

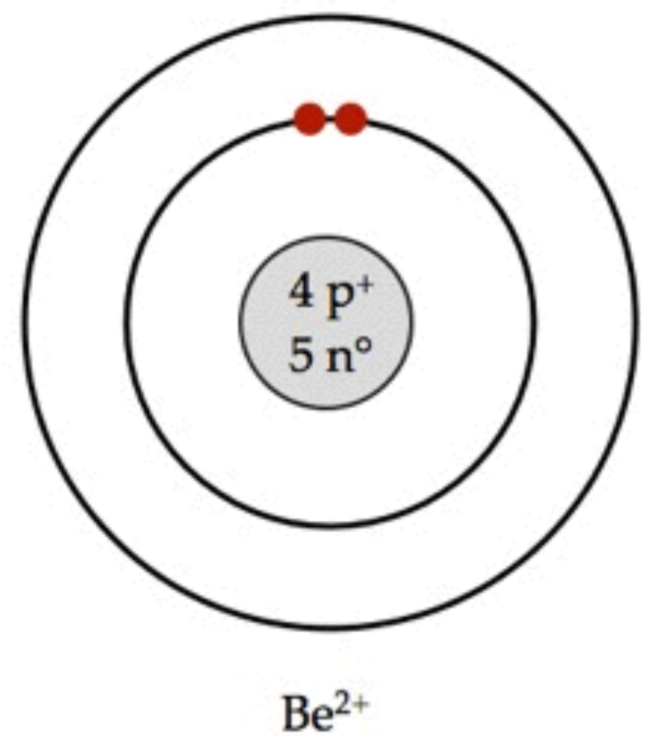
modified from Wiittmann et al. (2012). The dependence of meteoric ^{10}Be concentrations on particle size in Amazon River bed sediment and the extraction of reactive $^{10}Be/^{9}Be$ ratios. *Chemical Geology.*

background, part 1. native ^{9}Be

~100% of natural abundance

beryl $Be_3Al_2(SiO_3)_6$

Be $^{2+}$ ion



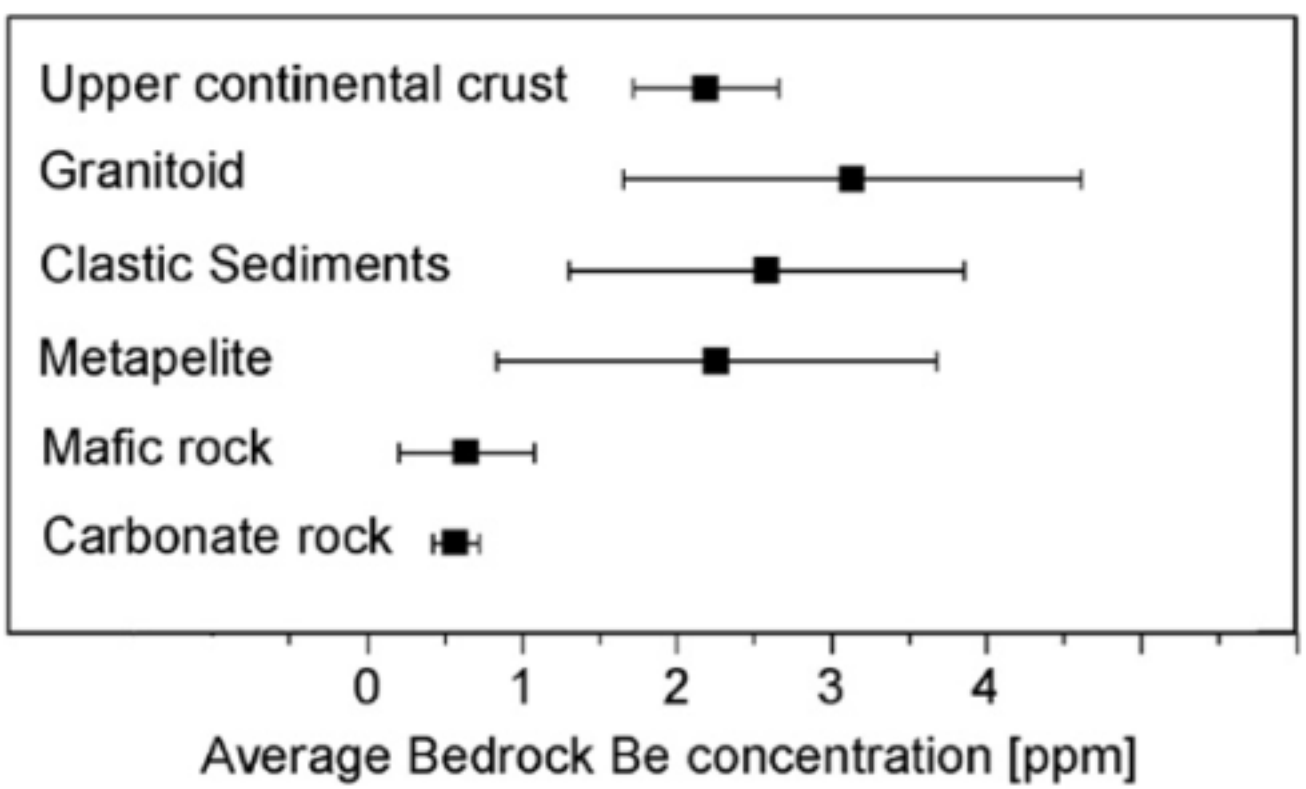
(similar charge to radius ratio to Al^{3+})

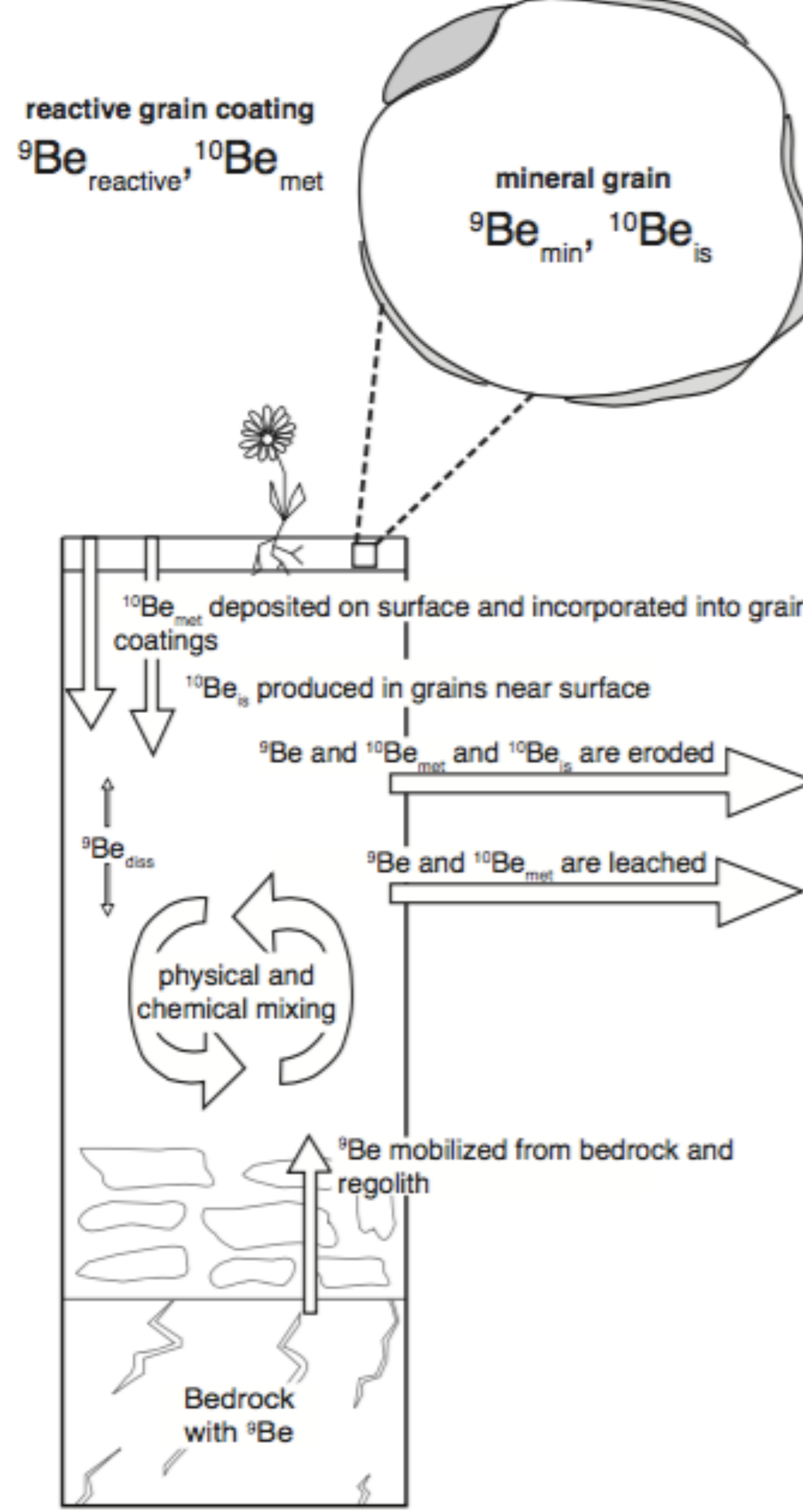
background, part 1. ^{9}Be dynamics, sources

"mineral" ^{9}Be

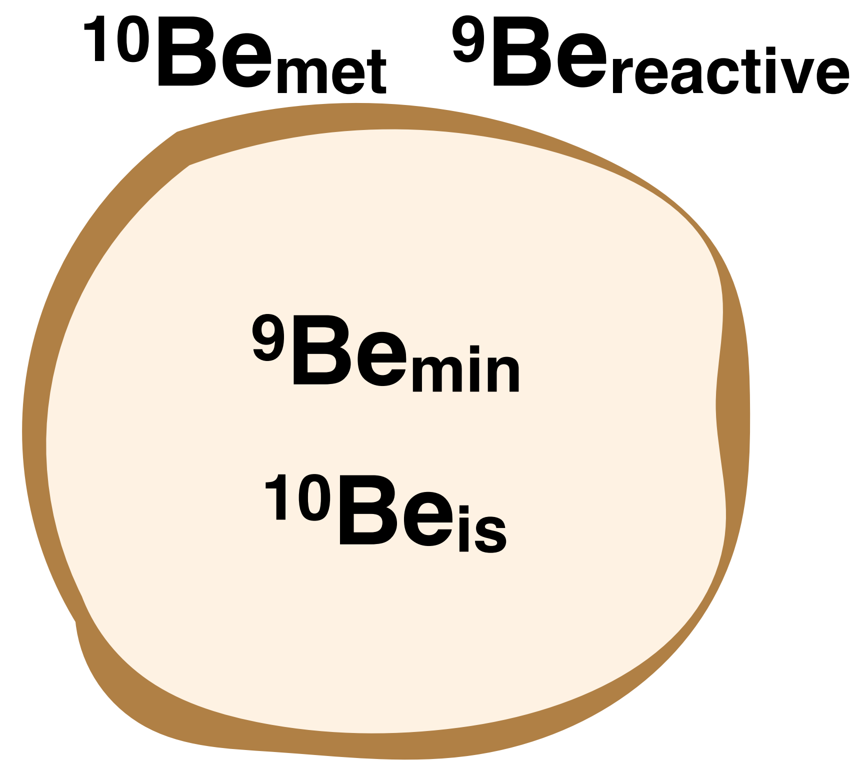
"reactive" ^{9}Be "dissolved" ^{9}Be

"parent" or "total" ^{9}Be

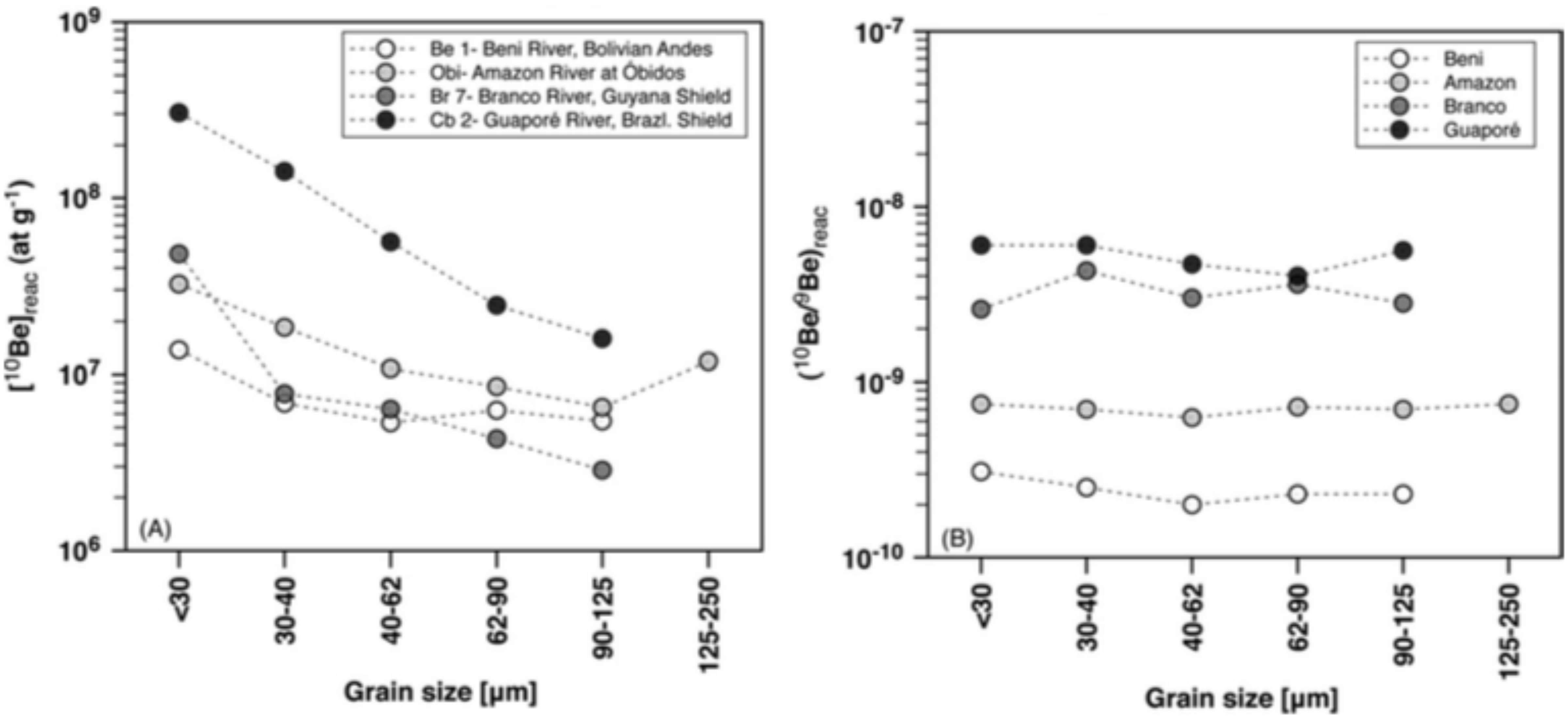




background, part 1. $^{10}Be/^{9}Be$ dynamics, sources



$$\frac{^{10}Be_{met}}{^{9}Be_{reactive}} \propto {}^{10}Be_{is}$$

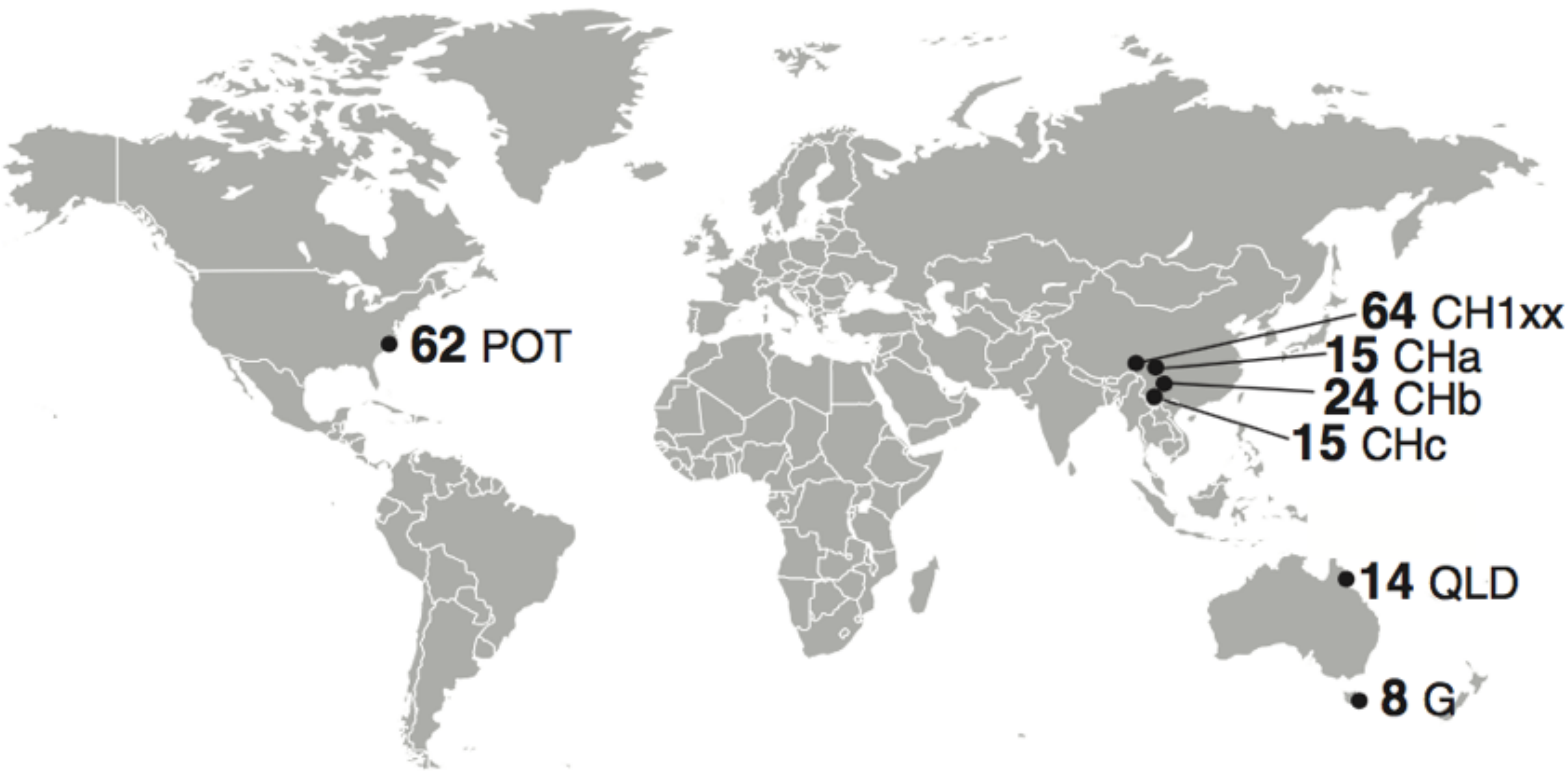


modified from Wiittmann et al. (2012). The dependence of meteoric ^{10}Be concentrations on particle size in Amazon River bed sediment and the extraction of reactive $^{10}Be/^{9}Be$ ratios. *Chemical Geology.*

part 1. motivation

- samples with known meteoric and *in situ* ^{10}Be
    - can look at regional trends and trends across diverse study areas
- unique opportunity to compare *in situ* ^{10}Be, meteoric ^{10}Be, ^{9}Be, total grain coating composition, and basin characteristics

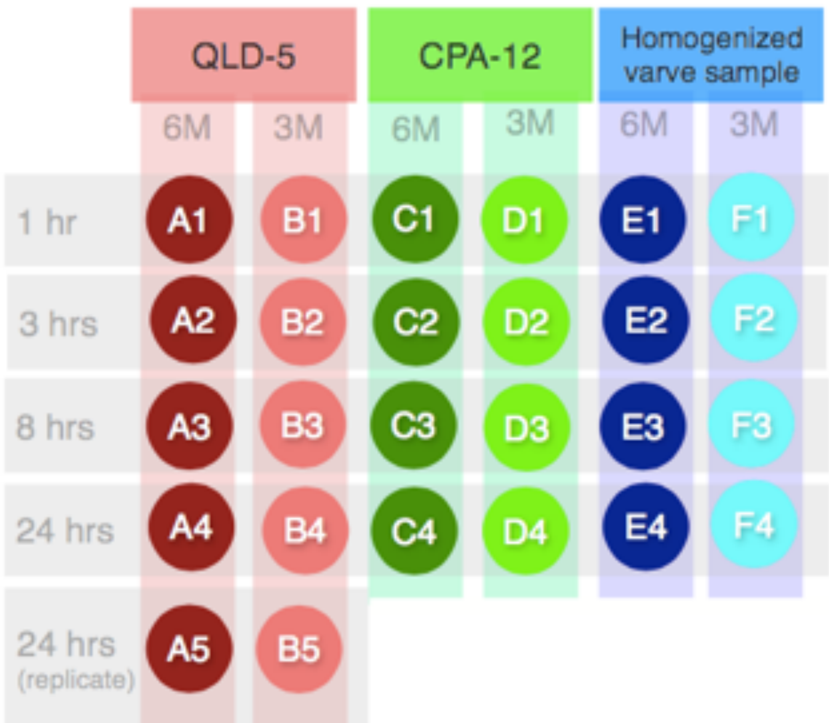
available samples



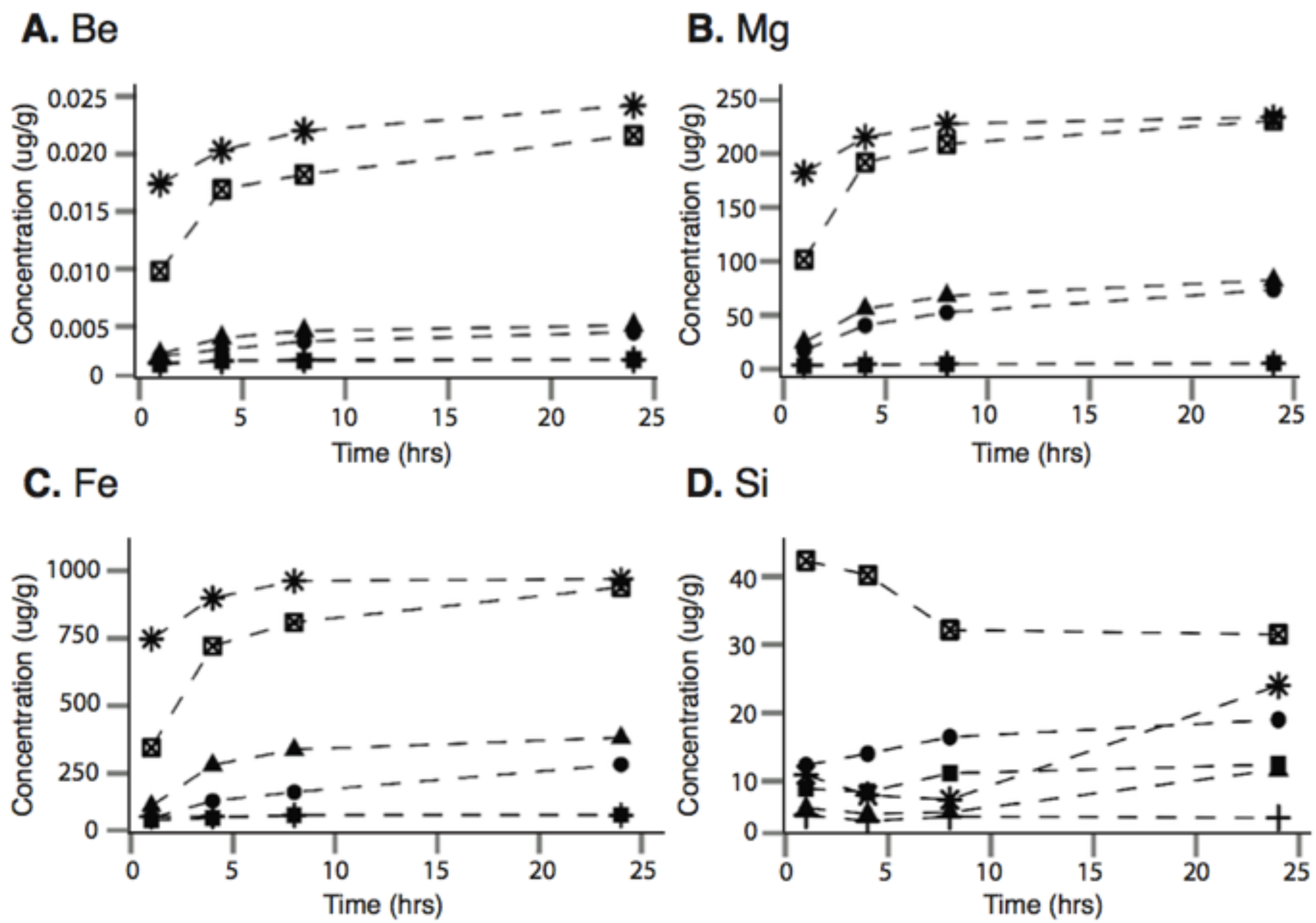
202 fluvial sediment samples

(72 soil samples, 222 glacial lake varve samples, 60 suspended sediment samples)

methods, part 1. Extracting ^{9}Be and method development



- testing 3 samples types with 2 acid treatments over 4 extraction times
- measured **Be**, Fe, Mg, Mn, Al, Si, Ti, Na, and K on Inductively Coupled Plasma Optical Emission Spectrometer



- **final method**: 0.250 g, 2 mL 6M HCl, 24 hours extraction in heated ultrasonic bath

methods, part 1. Total grain digest (n = 140)

residual sediment

step 1: DI rinse — rinsed and centrifuged (x3), dried overnight

organic fraction

step 2: HNO_3 digest — 1:1 HNO_3 followed by aliquots of conc. HNO_3, heated at 95

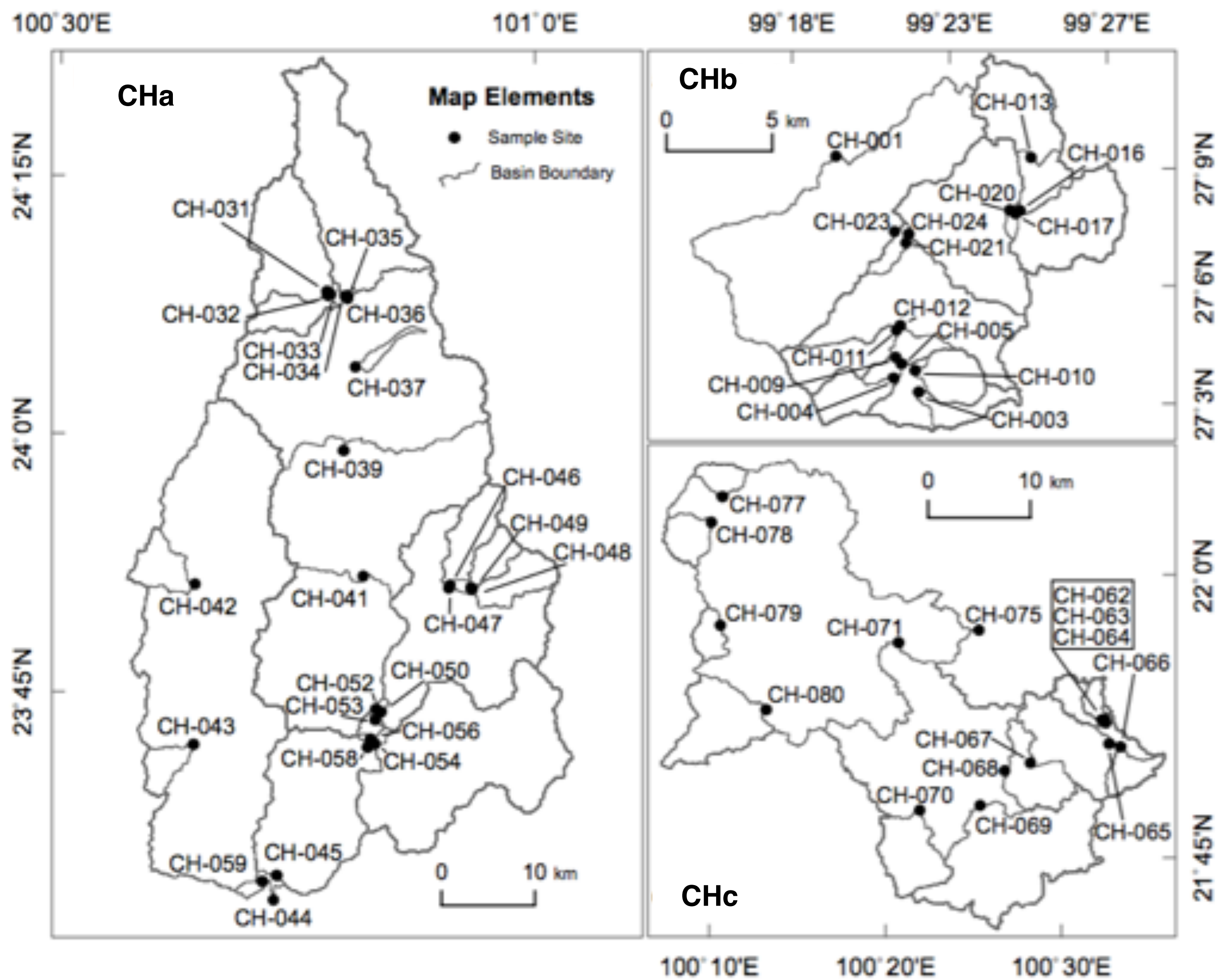
step 3: H_2O_2 digest — 1:1 H_2O_2, followed by aliquots of conc. H_2O_2, heated at 85

silicates

step 4: $HClO_4$, H_2SO_4, HF digest — cocktail of $HClO_4$, H_2SO_4, and HF digested overnight at 105, evaporated to dryness at 110, evaporated at 230 ~3 hrs.

diluted solution for ICP-OES

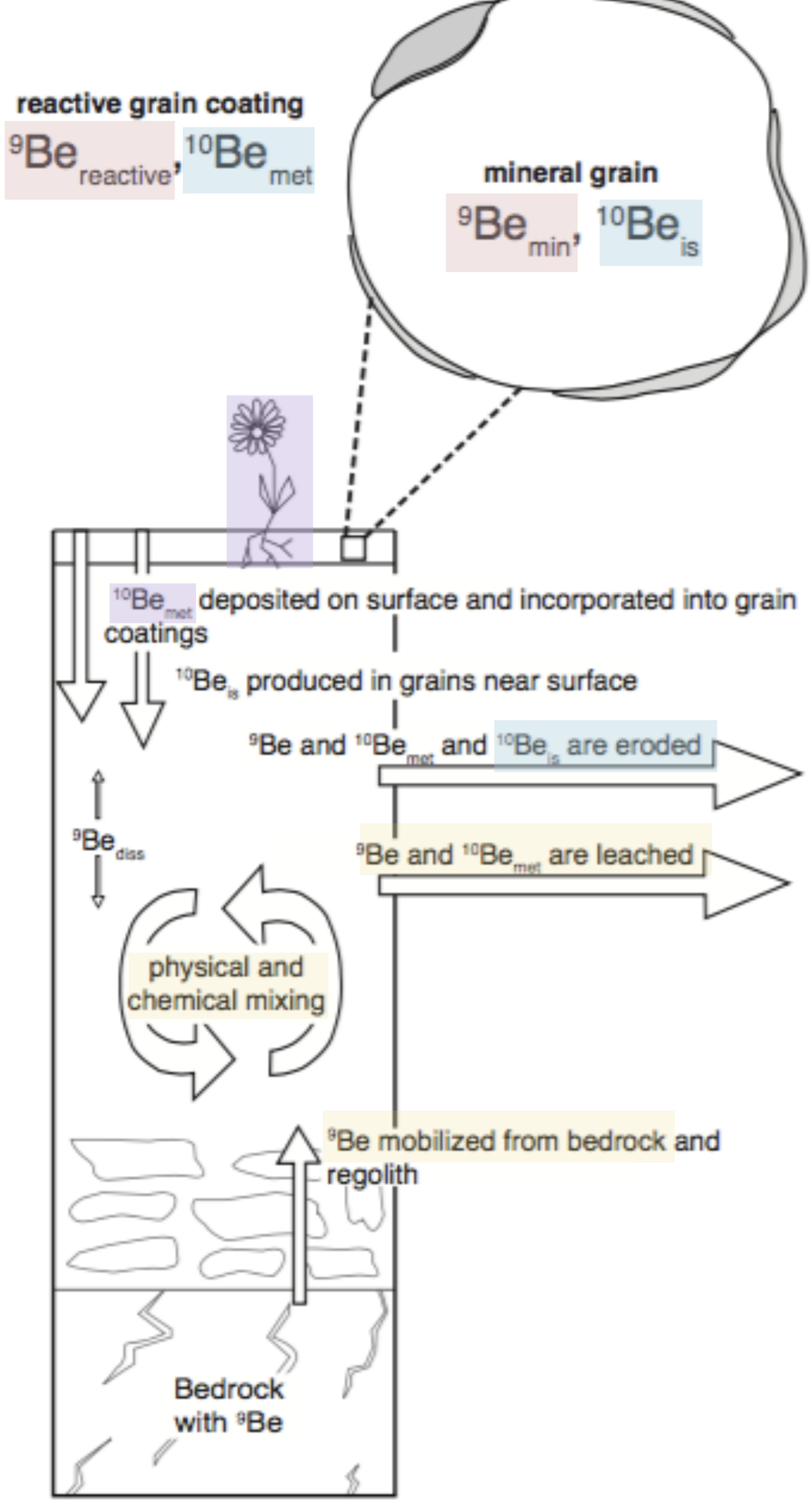
methods, part 1. Calculating basin parameters



modified from Nielson (2016). Using long and short-lived sediment associated isotopes to track erosion and sediment movement through rivers in Yunnan, SW China. (MS thesis)

mean basin slope
total basin relief
mean elevation
mean latitude
mean annual precipitation

latitude and precipitation used to calculate mean basin **meteoric ^{10}Be delivery rates**



Methods, part 1. In Review

What I was given:

- *in situ* ^{10}Be
- meteoric ^{10}Be
- calculated *in situ* ^{10}Be-derived denudation rates

What I measured:

- reactive ^{9}Be
- mineral ^{9}Be

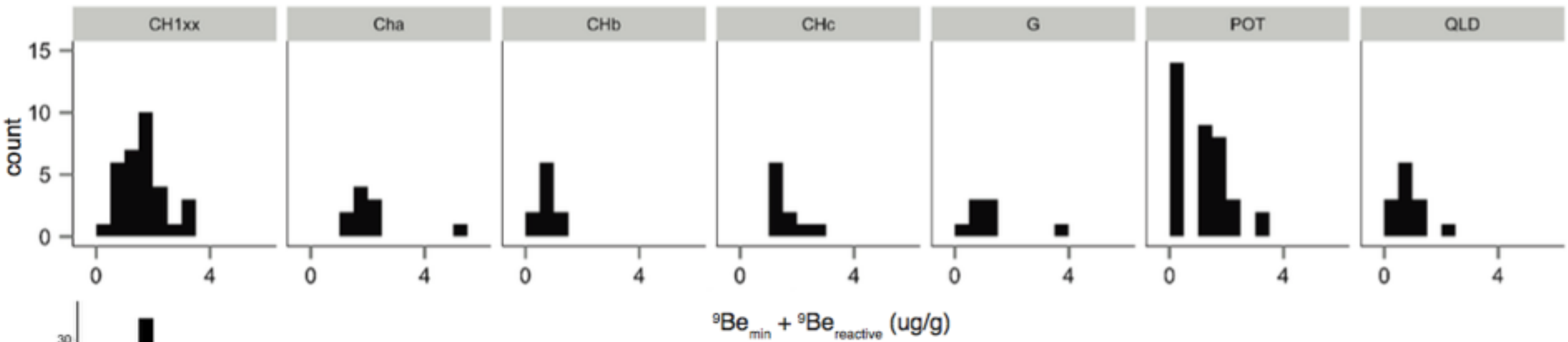
What I calculated:

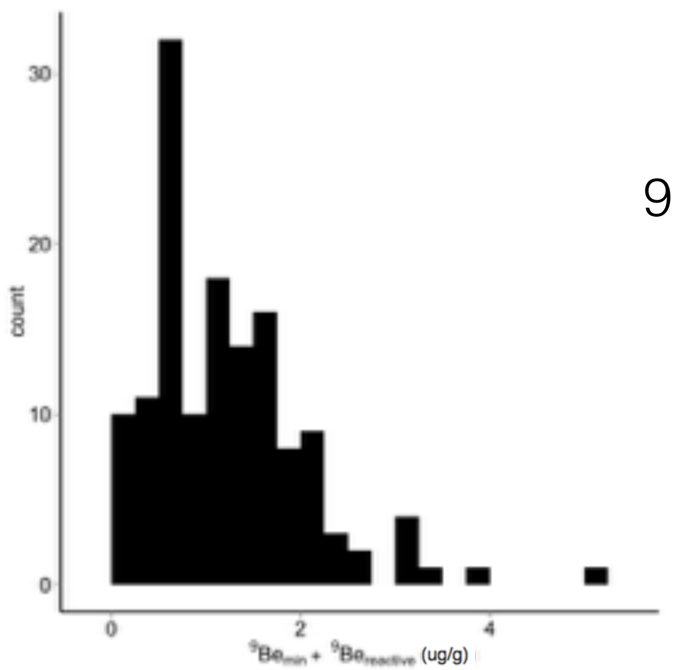
- basin characteristics, meteoric ^{10}Be delivery rates

What I want to learn more about:

- ^{9}Be and parent materials
- meteoric ^{10}Be and ^{9}Be mixing
- relative importance of controls on ^{9}Be and meteoric ^{10}Be concentrations in grain coatings

results: part 1. ^{9}Be abundances



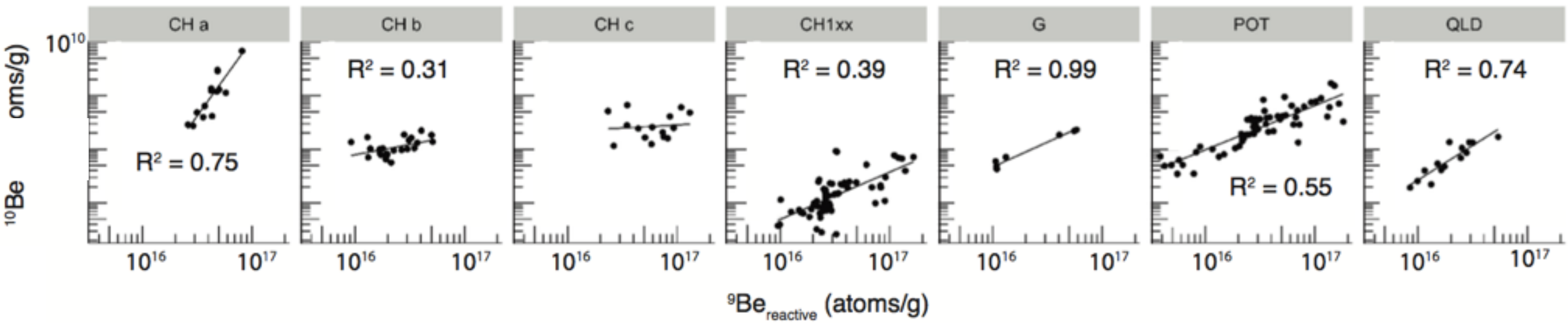


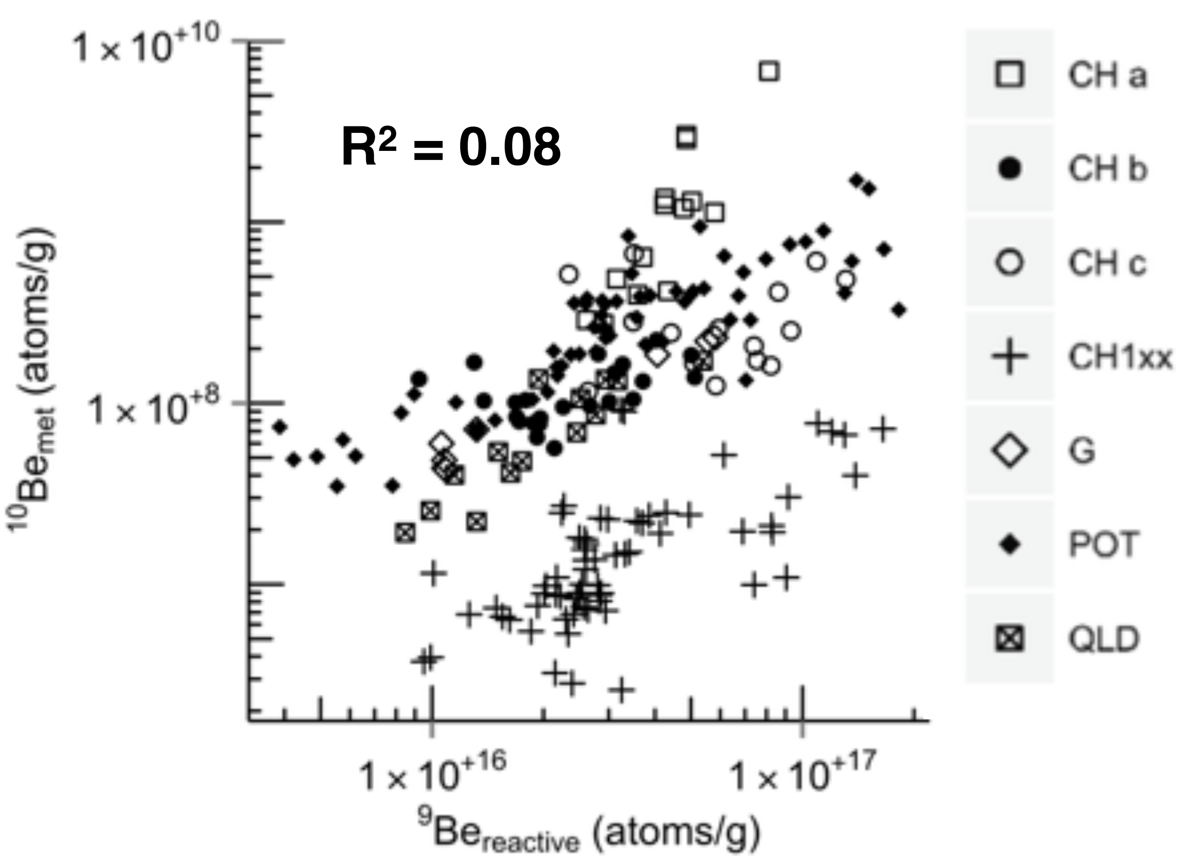
$^{9}Be_{min}$+$^{9}Be_{reactive}$ range all samples: 0.10-5.12 ug/g

mean: 1.23 ± 0.82 ug/g

(mean crustal abundance = 2.50 ug/g)

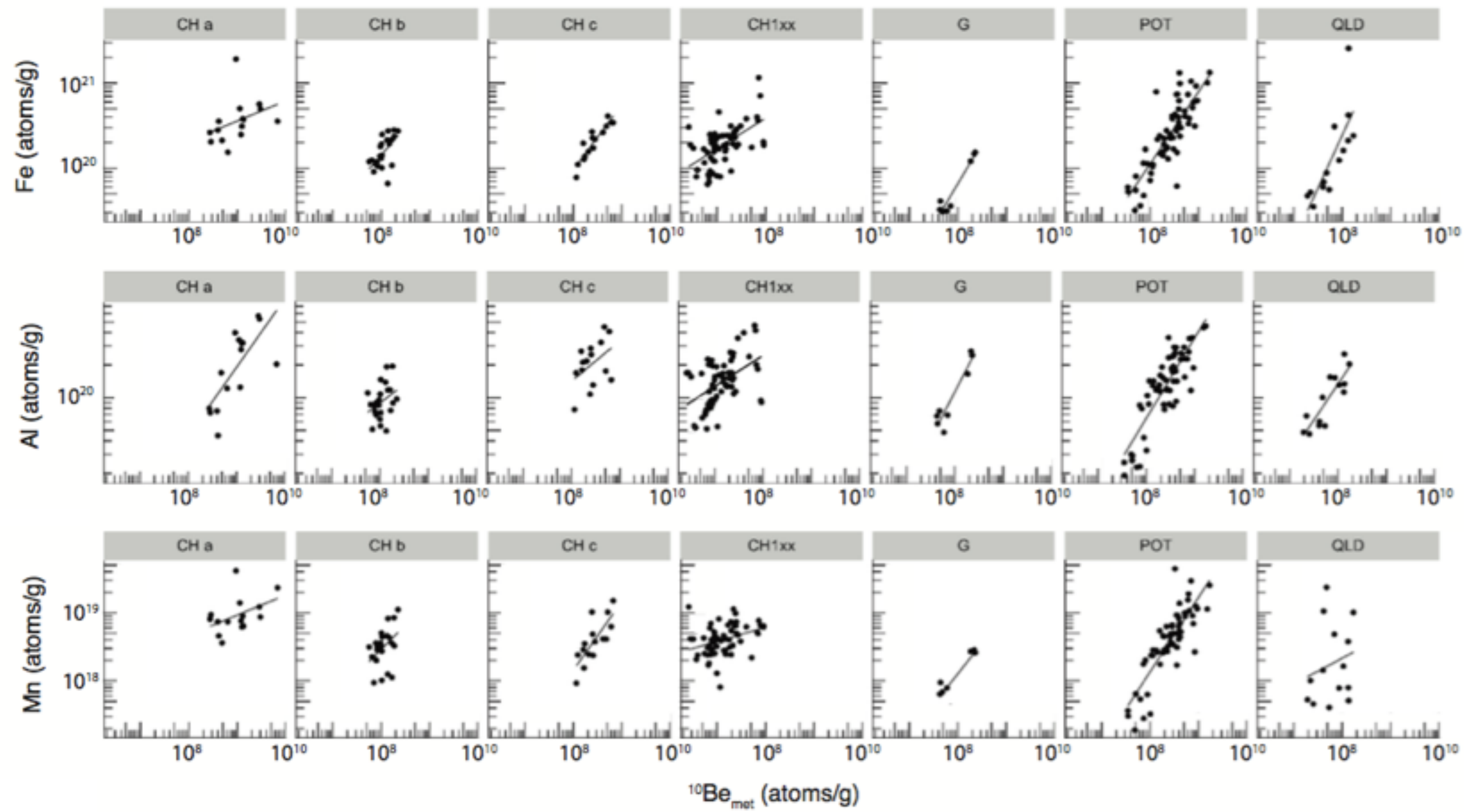
results: part 1. ^{9}Be and meteoric ^{10}Be are correlated





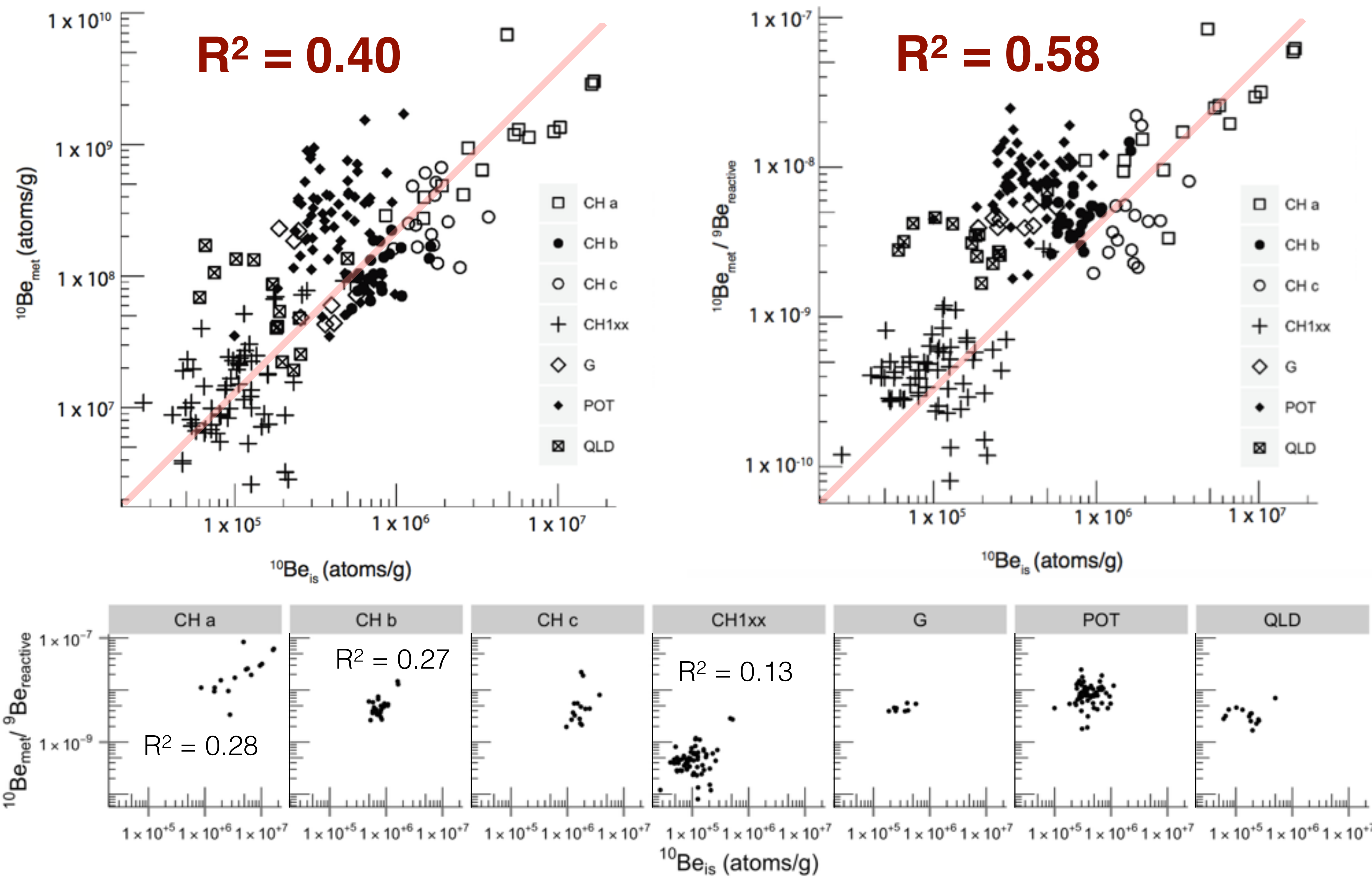
- correlations denoted with R^2 have p value < 0.05
- only site with non-significant correlation is CHc
- weak correlation considering all samples

results: part 1. ^{9}Be and meteoric ^{10}Be correlated to Al, Mn, and Fe in study areas

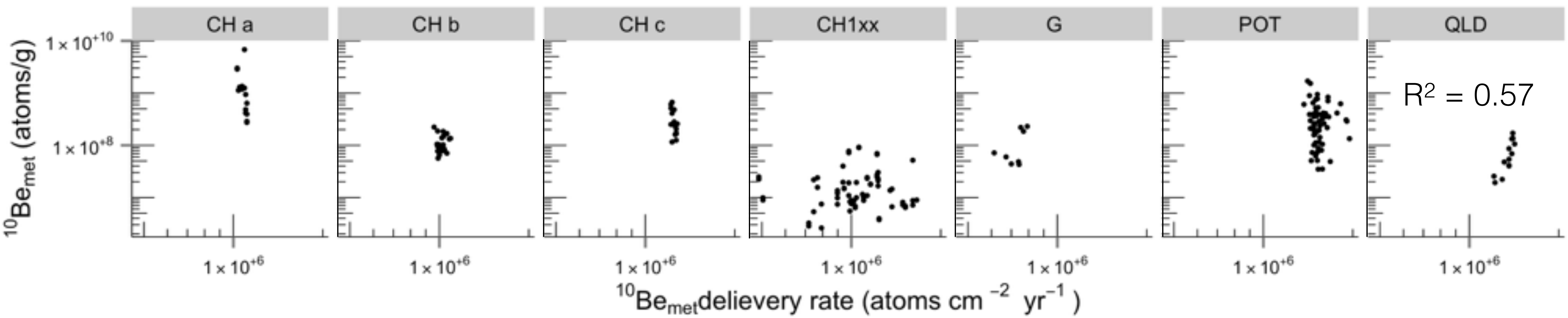


- strong correlation in many study areas; no correlation in others
- Al, Fe, and Mn make up the largest percentage by mass of HCl-extractable materials

results: part 1. meteoric $^{10}Be/^{9}Be$ correlated to *in situ* ^{10}Be

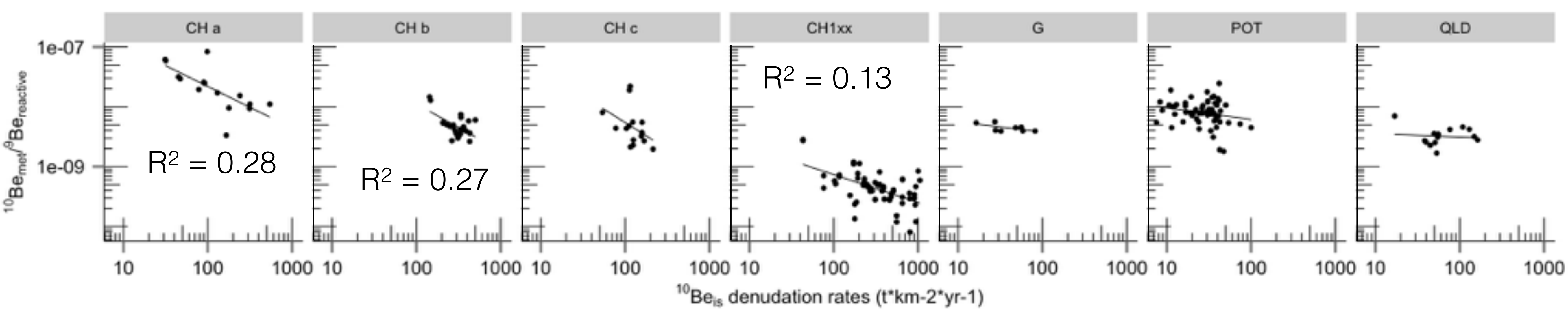


results: part 1. meteoric ^{10}Be not correlated to $^{10}Be_{met}$ delivery rates



no strong correlation across all samples

results: part 1. meteoric $^{10}Be/^{9}Be$ not correlated to denudation rates



no strong correlation across all samples

results: part 1. not many significant correlations between Be isotopes and basin characteristics

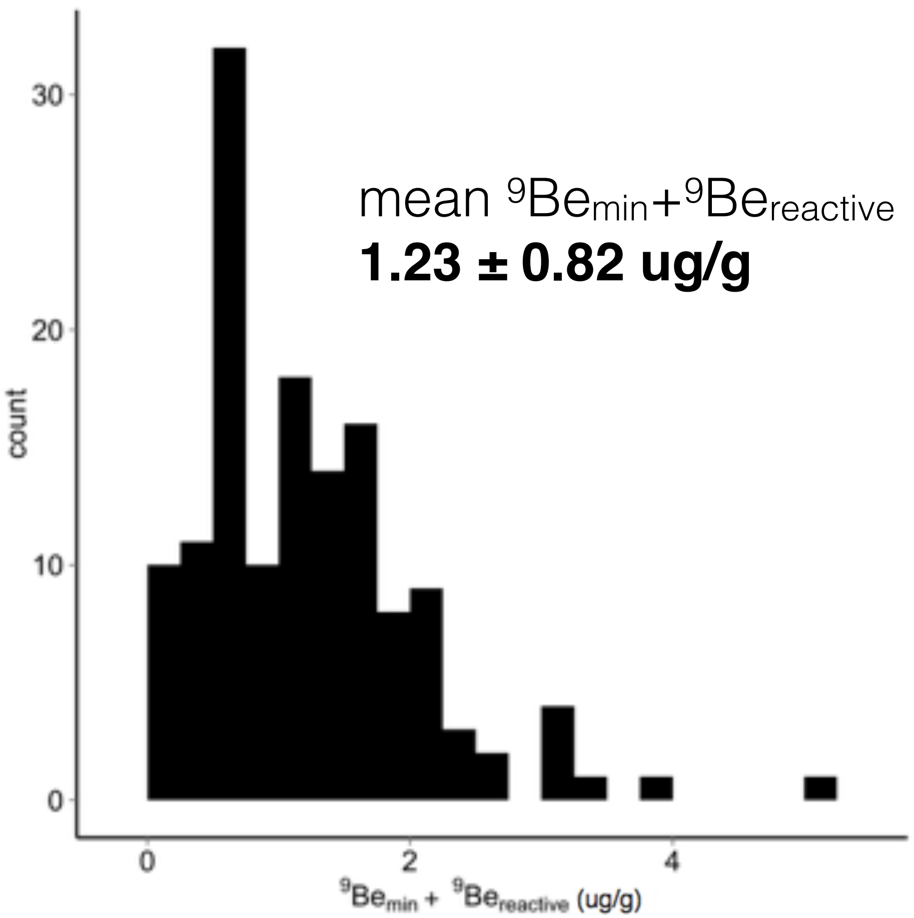
Table 3.

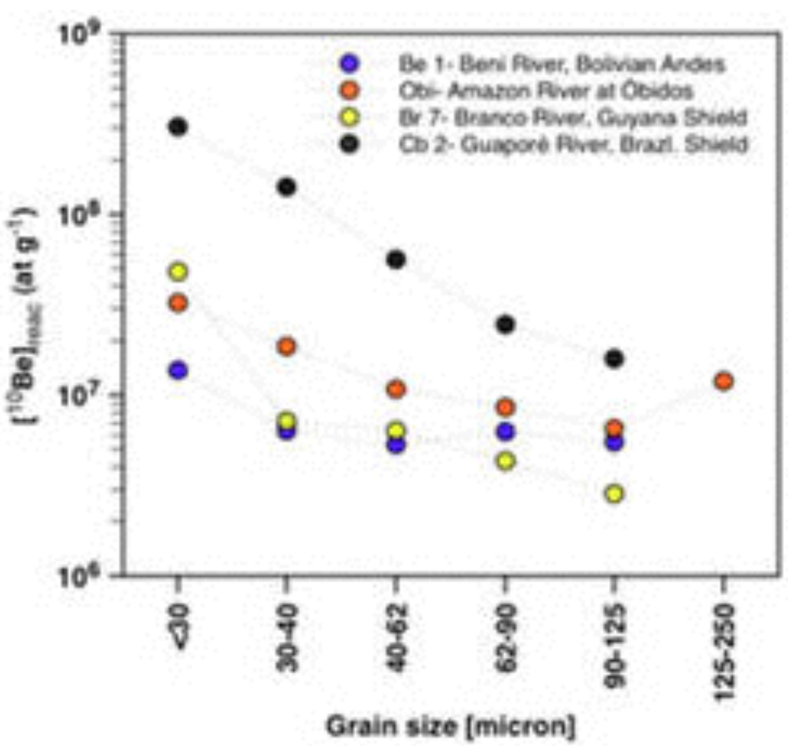
R^2 and p values of correlations between Be isotopes concentrations and MAP, mean basin slope, and total relief for each study area and for all samples.

			$^{10}Be_{is}$		$^{10}Be_{met}/^{9}Be_{reactive}$		$^{10}Be_{is}$ denudation rate		$^{10}Be_{met}/^{9}Be_{reactive}$-derived denduation rate ^{d}	
study ID	n	basin parameter	R^2	p	R^2	p	R^2	p	R^2	p
All samples	202	MAP	<0.01	0.53	0.03	0.01	0.01	0.18	<0.01	0.45
		mean basin slope	<0.01	0.46	0.03	0.01	**0.46**	**<0.01**	0.17	<0.01
		total relief	0.02	0.03	0.11	<0.01	**0.55**	**<0.01**	**0.42**	**<0.01**
		mean elevation	0.08	0.07	<0.01	0.62	**0.43**	**<0.01**	0.22	<0.01
		mean latitude	0.01	0.25	0.03	0.01	0.10	<0.01	0.05	<0.01
		basin size	0.01	0.09	0.04	0.01	**0.33**	**<0.01**	0.24	<0.01

- correlations in bold print have $R^2 > 0.30$ and p value < 0.05
- significant correlations between *in situ* denudation rates and slope, total relief, mean elevation, and basin size (positive correlations)
- not strong and significant correlations between meteoric $^{10}Be/^{9}Be$ or *in situ* ^{10}Be and basin parameters

discussion, part 1. ^{9}Be concentrations in grains lower than bedrock





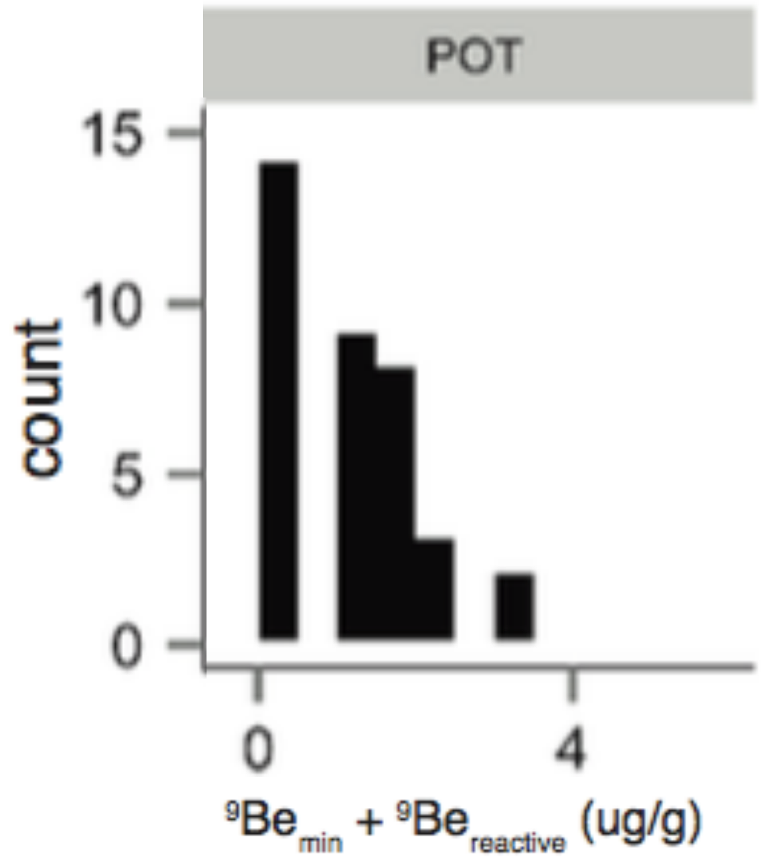
modified from Wittmann et al., (2012). The dependence of meteoric ^{10}Be concentrations on particle size in Amazon River bed sediment and the extraction of $^{10}Be/^{9}Be$ ratios, California. *Chemical Geology*

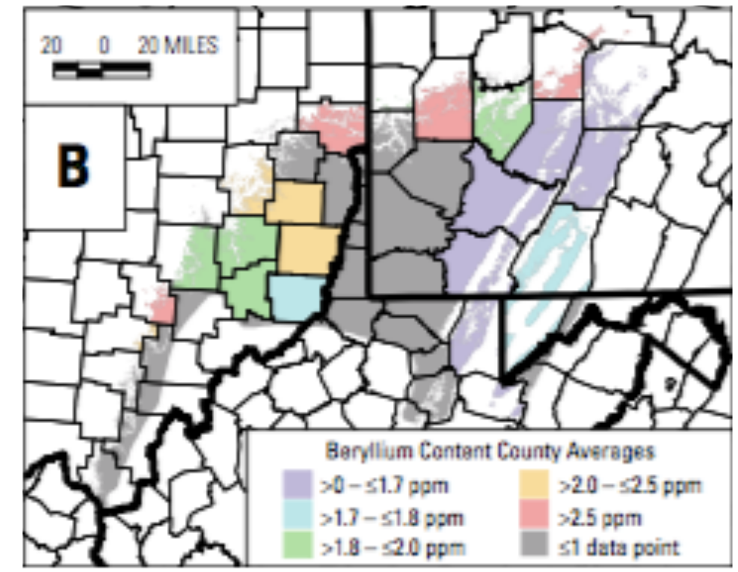
- mineral and reactive ^{9}Be concentrations lower than mean crustal abundance (2.5 μg/g)
    - sand sized sediments collected (250-850 μm)
    - ^{9}Be in dissolved phase

Sample	$f^{^9Be}_{diss}$	$f^{^9Be}_{reac}$	$f^{^9Be}_{min}$	$f^{^9Be}_{reac}+f^{^9Be}_{diss}$
Amazon at Macapa/Obidós	0.029	0.23	0.74	0.26
Solimoes at Manaus	0.018	0.11	0.87	0.13
Negro at Manaus	0.65	0.29	0.06	0.94
Amazon Andean Rivers	0.002	0.29	0.71	0.29
Beni	0.001	0.31	0.69	0.31

discussion, part 1. wide range of ^{9}Be reactive concentrations

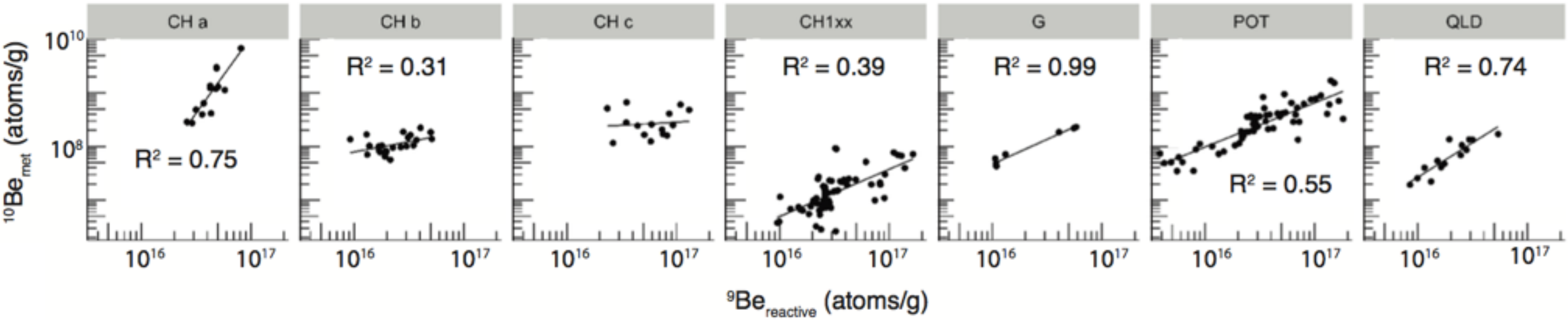
Figure 8. Photograph of the Upper Freeport coal bed in Pennsylvania. Person is pointing to the upper contact of the coal bed. Note the overlying sandstone. (Photograph courtesy of James Shaulis, Pennsylvania Bureau of Topographic and Geologic Survey.)





- Upper Freeport coal bed enriched in Be relative to sediment: mean concentration = 1.80 ± 0.81 μg/g, max concentration = 5 μg/g
- higher reactive ^{9}Be concentrations in samples from north branch of Potomac River than main stem
- ^{9}Be in parent materials influences ^{9}Be in grain coatings, even in regional studies

discussion, part 1. meteoric ^{10}Be and ^{9}Be correlated in grain coatings



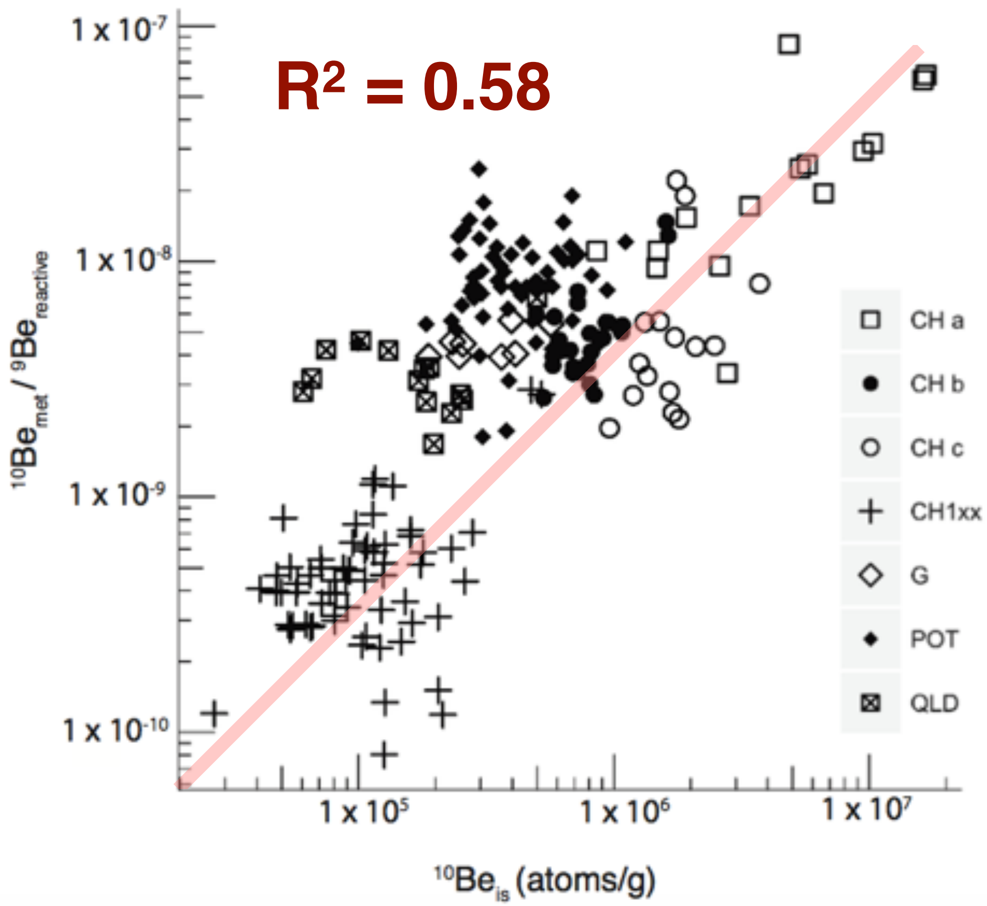
CH-079

Parent Basin: 11
Collection Date: 6/8/13
Latitude: 21.958 **Longitude:** 100.179
Sample Type: RS
Additional Notes: Small tributary of N. arm of basin 11 with anabranching channel. Sample collected from immediately above small diversion structure.

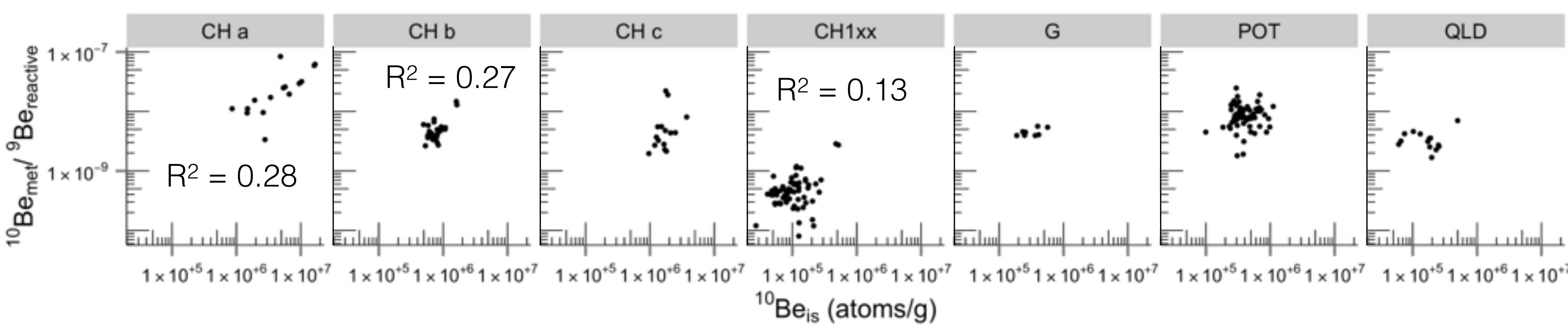
Terraced agriculture

- correlation suggests $^{10}Be_{met}$ deposited on the surface and ^{9}Be weather from buried bedrock are mixed in grain coatings
- exception = CHc study area
- anoxia in flooded hillslopes prevents biotic mixing

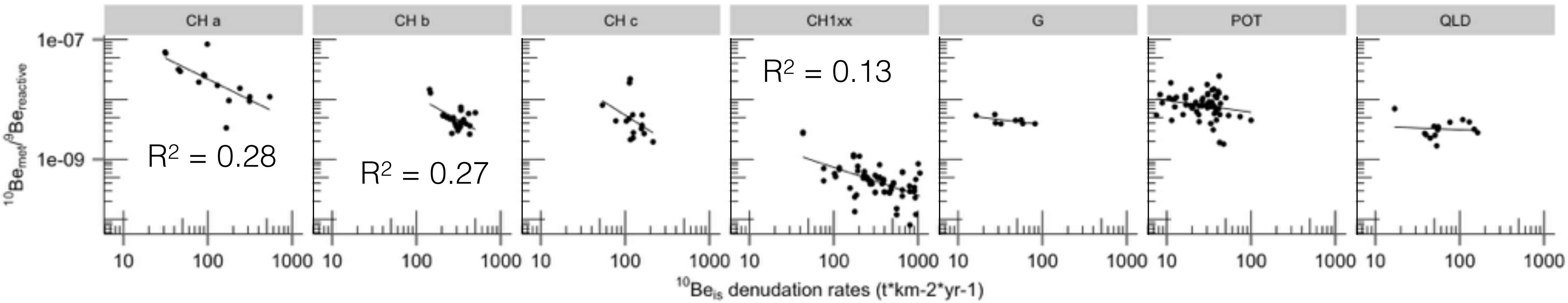
discussion, part 1. stronger correlation between meteoric $^{10}Be/^{9}Be$ ratios and $^{10}Be_{is}$ than $^{10}Be_{met}$ alone



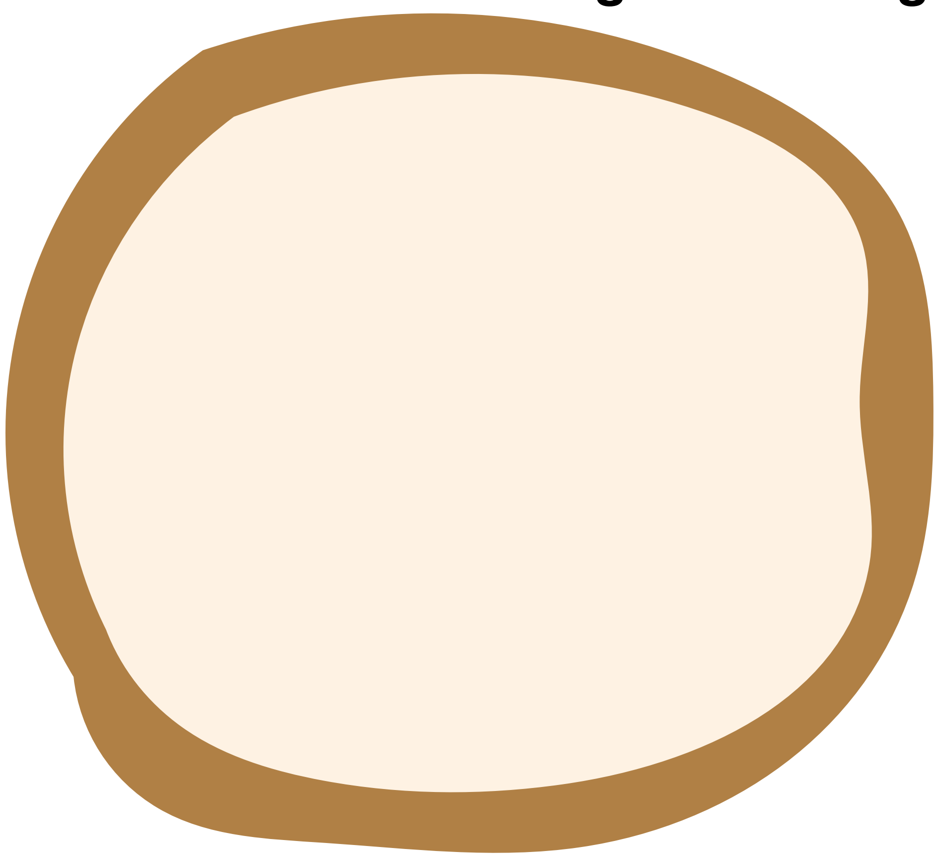
- significant correlation with $^{10}Be_{is}$ for all data
- weak correlation (or none at all) when considering regional data
- biological remobilization, leaching processes influence meteoric $^{10}Be/^{9}Be$
- these effects obscure correlations when only considering $^{10}Be_{is}$ that span a few orders of magnitude



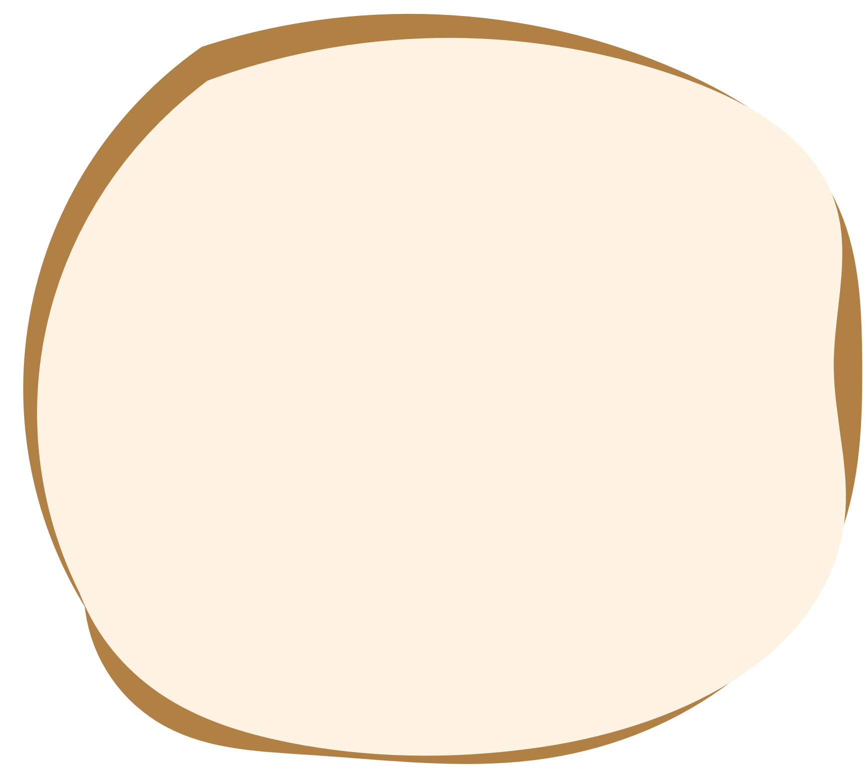
discussion, part 1. $^{10}Be_{met}/^{9}Be$ ratios not correlated to denudation rates



more time in soil profile —> more $^{10}Be_{met}$ and ^{9}Be accumulated in grain coatings



more leaching —> less $^{10}Be_{met}$ and ^{9}Be in grain coatings



- indicates influence of remobilization and leaching discussion, part 1. processes that decouple grains and grain coatings

- acidic soil environments; leaching
- anoxic environments; leaching
- physical abrasion

discussion, part 1. not many significant correlations between Be isotopes and basin characteristics

Table 3.

R^2 and p values of correlations between Be isotopes concentrations and MAP, mean basin slope, and total relief for each study area and for all samples.

			$^{10}Be_{is}$		$^{10}Be_{met}/^{9}Be_{reactive}$		$^{10}Be_{is}$ denudation rate		$^{10}Be_{met}/^{9}Be_{reactive}$-derived denduation rate [d]	
study ID	n	basin parameter	R^2	p	R^2	p	R^2	p	R^2	p
All samples	202	MAP	<0.01	0.53	0.03	0.01	0.01	0.18	<0.01	0.45
		mean basin slope	<0.01	0.46	0.03	0.01	**0.46**	**<0.01**	0.17	<0.01
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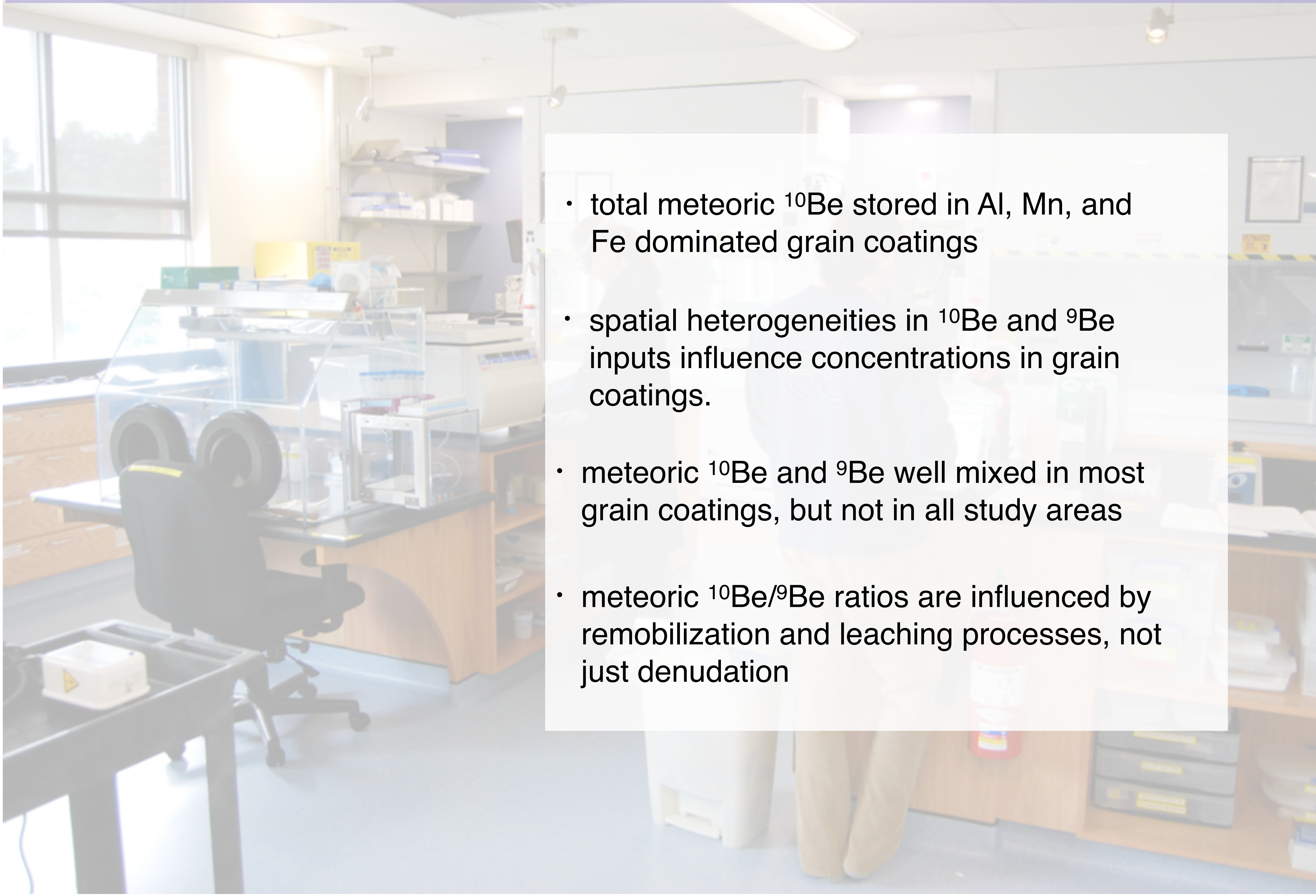
		mean latitude	0.01	0.25	0.03	0.01	0.10	<0.01	0.05	<0.01
		basin size	0.01	0.09	0.04	0.01	**0.33**	**<0.01**	0.24	<0.01

- confirms previous findings of correlation between *in situ* denudation rates and slope, total relief, mean elevation, and basin size (positive correlations)

- lack of correlations affirms suggestion that meteoric $^{10}Be/^{9}Be$ ratios are influenced by remobilization, grain size, and heterogeneous source materials

conclusions, part 1.

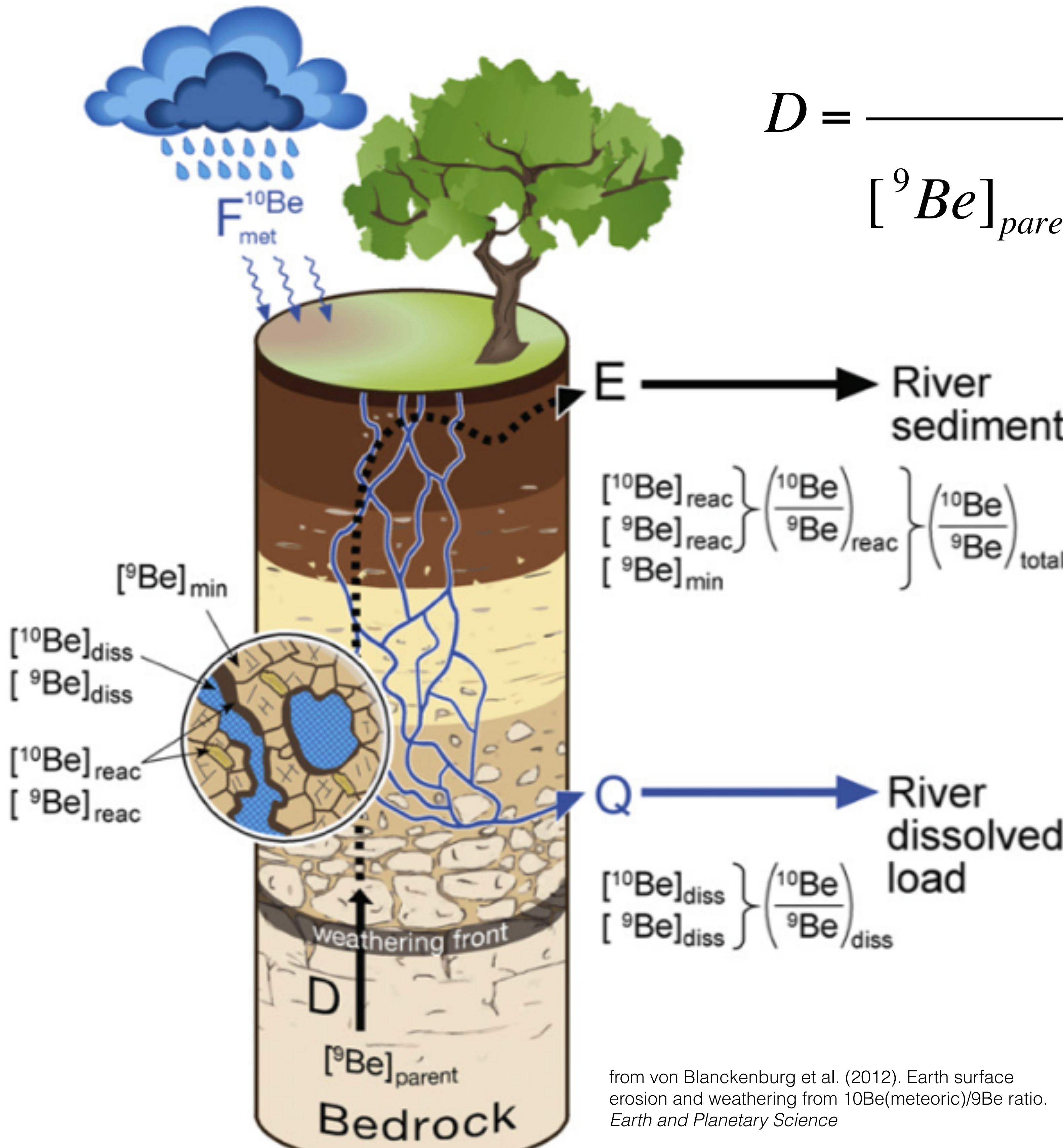


- total meteoric ^{10}Be stored in Al, Mn, and Fe dominated grain coatings
- spatial heterogeneities in ^{10}Be and ^{9}Be inputs influence concentrations in grain coatings.
- meteoric ^{10}Be and ^{9}Be well mixed in most grain coatings, but not in all study areas
- meteoric $^{10}Be/^{9}Be$ ratios are influenced by remobilization and leaching processes, not just denudation

part 2. meteoric $^{10}Be/^{9}Be$ derived denudation rates

- mass balance model that controls for heterogeneity in inputs, and calculates meteoric $^{10}Be/^{9}Be$-derived denudation rates
  - assumptions needed to apply model
  - compare meteoric $^{10}Be/^{9}Be$ based denudation rates to *in situ* based denudation rates

background, part 2. mass balance model for $^{10}Be/^{9}Be$ denudation rates



from von Blanckenburg et al. (2012). Earth surface erosion and weathering from 10Be(meteoric)/9Be ratio. *Earth and Planetary Science*

$$D = \frac{F_{met}^{^{10}Be}}{[^{9}Be]_{parent} * (f_{reac}^{^{9}Be} + f_{diss}^{^{9}Be}) * \left(\frac{^{10}Be_{met}}{^{9}Be_{reactive}}\right)}$$

eq. 1

$$f_{reac}^{^{9}Be} + f_{diss}^{^{9}Be}$$

fraction of ^{9}Be in the dissolved and reactive phase;
i.e. **f.factor**

methods, part 2. estimating constants

$$D = \frac{F_{met}^{^{10}Be}}{[^9Be]_{parent} * f.factor * \left(\frac{^{10}Be_{met}}{^9Be_{reactive}}\right)}$$ **eq. 1**

mean $^{10}Be_{met}$ delivery rate for the study area calculated from empirical model based on latitude and MAP (Graly et al., 2011)

total measured $^{10}Be_{met}$ and acid-extractable ^9Be for each sample

eq. 1'

$$f.factor = \frac{F_{met}^{^{10}Be}}{[^9Be]_{parent} * D * \left(\frac{^{10}Be_{met}}{^9Be_{reactive}}\right)}$$

D = *in situ* ^{10}Be-derived denudation rate

$[^9Be]_{parent}$ = 2.5 ppm

eq. 2

$$f.factor = \frac{^9Be_{reactive}}{^9Be_{reactive} + {^9Be_{\min}}}$$

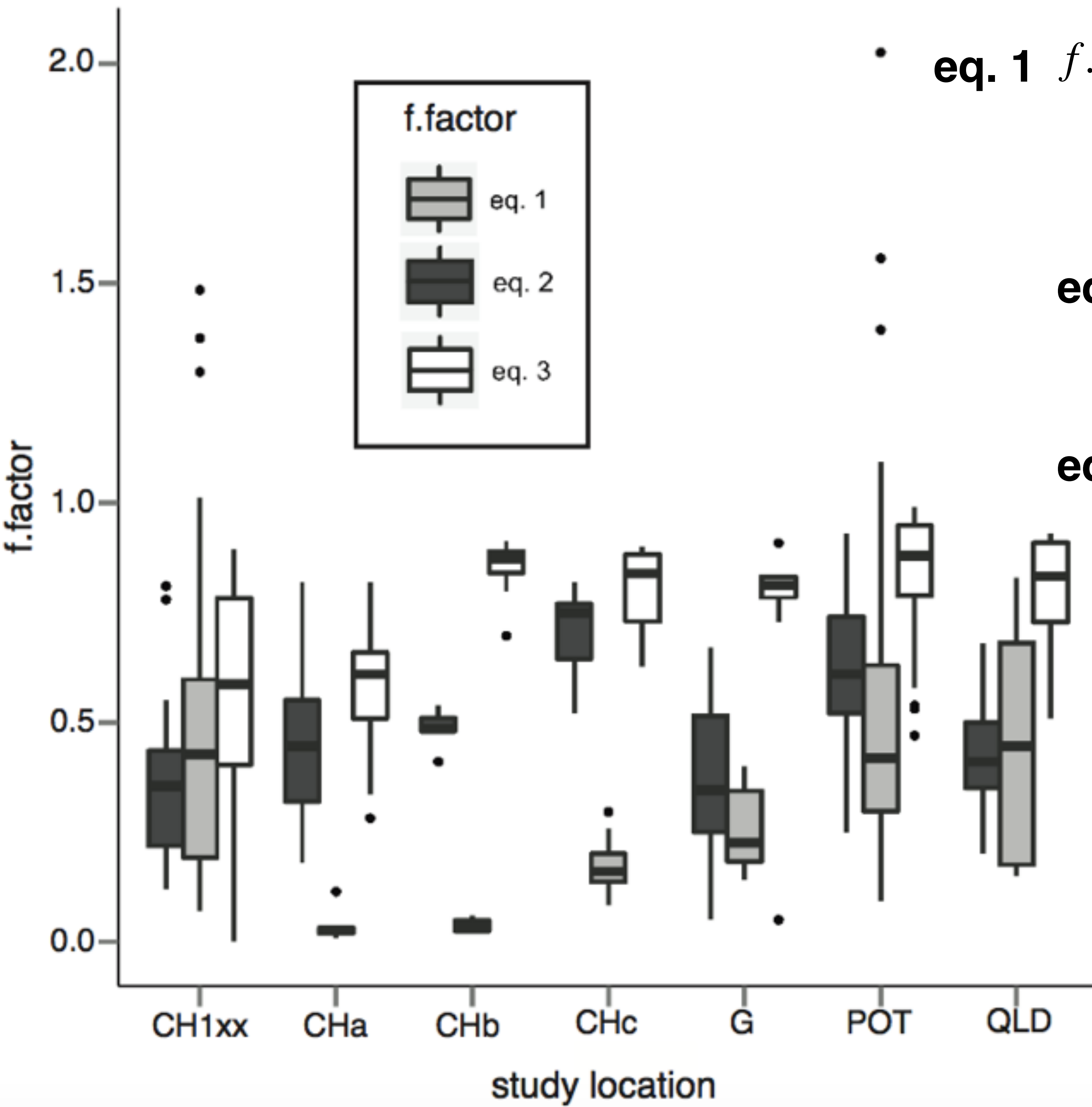
$[^9Be]_{parent} = {^9Be_{min}} + {^9Be_{reactive}}$

eq. 3

$$f.factor = \frac{^9Be_{reactive} + {^9Be_{diss}}}{2.5}$$

$[^9Be]_{parent}$ = 2.5 ppm = $^9Be_{min} + {^9Be_{reac}} + {^9Be_{diss}}$

results: part 2. methods of calculating f.factor do not agree



eq. 1 $$f.factor = \frac{F_{met}^{^{10}Be}}{[^{9}Be]_{parent} * D * \left(\frac{^{10}Be_{met}}{^{9}Be_{reactive}} \right)}$$

eq. 2 $$f.factor = \frac{^{9}Be_{reactive}}{^{9}Be_{reactive} + ^{9}Be_{\min}}$$

eq. 3 $$f.factor = \frac{^{9}Be_{reactive} + ^{9}Be_{diss}}{2.5}$$

- eq 1' results in f.factors > 1
- eq 3 always results in the largest f.factor for a given study area
- methods don't agree

results, part 2. mean $^{10}Be/^{9}Be$ denudation rates

Table 4.

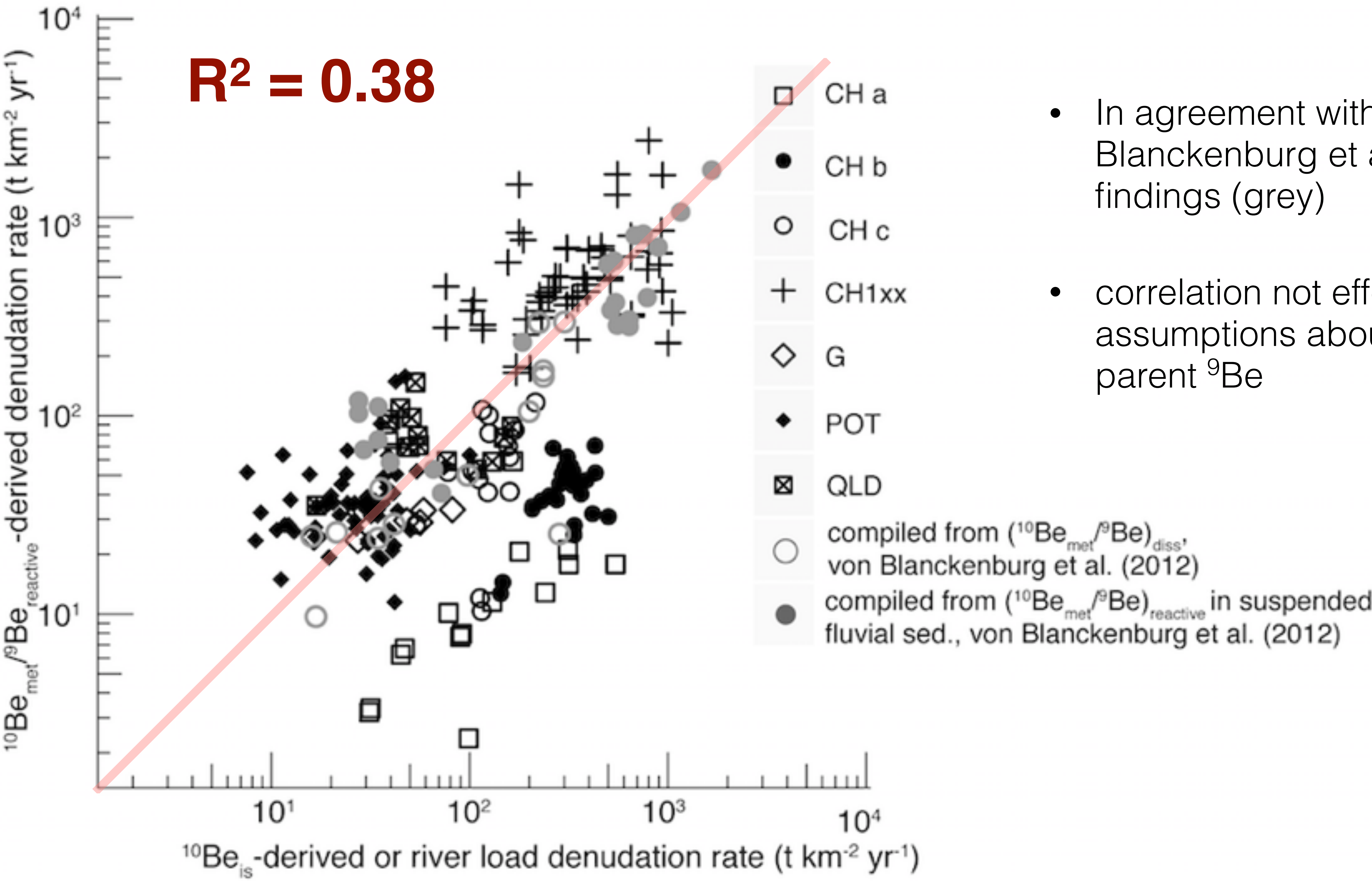
Mean denudation rates calculated from $^{10}Be_{is}$ and $^{10}Be_{met}/^{9}Be_{reactive}$ mass balance model (eq. 1) with ^{9}Be parent concentrations either assumed to be 2.5 ppm or the mean $^{9}Be_{min}+^{9}Be_{reactive}$ for each basin.

Study	mean $^{10}Be_{is}$-derived denudation rate [a]	mean $^{10}Be_{met}/^{9}Be_{reactive}$-derived denudation rate (total parent ^{9}Be = 2.5) [b]	percent difference from $^{10}Be_{is}$-derived denudation rate	mean $^{10}Be_{met}/^{9}Be_{reactive}$-derived denudation rate (total parent = $^{9}Be_{min}+^{9}Be_{reactive}$) [b]	percent difference from $^{10}Be_{is}$-derived denudation rate
	t km^{-2} yr^{-1}	t km^{-2} yr^{-1}	%	t km^{-2} yr^{-1}	%
POT	30 ± 16	40 ± 26	35	141 ± 89	370
QLD	74 ± 45	81 ± 28	10	476 ± 162	543
G	44 ± 22	30 ± 4	35	133 ± 18	202
CH1xx	403 ± 268	552 ± 396	37	2030 ± 1450	404
CHa	160 ± 142	14 ± 14	-91	24 ± 14	-85
CHb	311 ± 88	42 ± 15	-86	259 ± 91	-17
CHc	128 ± 39	61 ± 33	-52	113 ± 61	-12
all samples	202 ± 226	205 ± 226	1	768 ± 1190	278

[a] calculated with the CRONUS erosion rate calculator (Balco et al., 2008) in previous studies (Trodick, 2011; Portenga and Bierman, 2011; Nichols et al., 2014; Nielson, 2016)

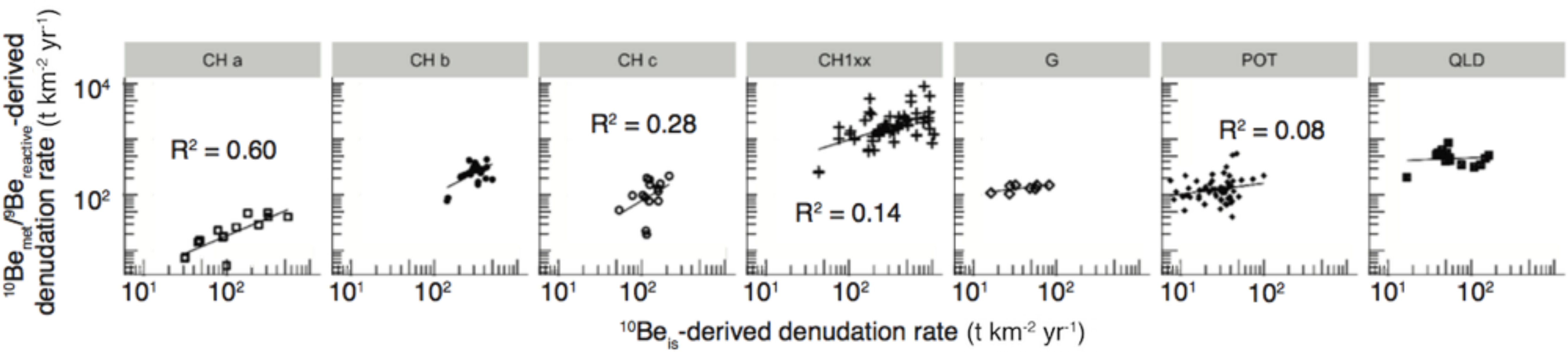
[b] total parent assumption applied to f.factor calculation and $^{9}Be_{parent}$; mean $^{10}Be_{met}$ deposition rate is used for each study area

results, part 2. meteoric $^{10}Be/^{9}Be$ denudation rates significantly correlated to *in situ* denudation rates



- In agreement with von Blanckenburg et al. (2012) findings (grey)
- correlation not effected by assumptions about f.factor or parent ^{9}Be

results, part 2. meteoric $^{10}Be/^{9}Be$ denudation rates not significantly correlated to *in situ* denudation rates in many study areas



- no statistically significant correlation in 3 of 7 study areas
- R^2 is almost always < 0.30

discussion, part 2. how assumption influence $^{10}Be/^{9}Be$ denudation rates

$$D = \frac{F_{met}^{^{10}Be}}{[^{9}Be]_{parent} * f.factor * \left(\frac{^{10}Be_{met}}{^{9}Be_{reactive}} \right)}$$

eq. 2

$$f.factor = \frac{^{9}Be_{reactive}}{^{9}Be_{reactive} + ^{9}Be_{\min}}$$

$[^{9}Be]_{parent} = {}^{9}Be_{min} + {}^{9}Be_{reactive}$

- assumes negligible ^{9}Be in dissolved phase
- underestimates dissolved ^{9}Be
- **underestimates parent ^{9}Be**

eq. 3

$$f.factor = \frac{^{9}Be_{reactive} + ^{9}Be_{diss}}{2.5}$$

$[^{9}Be]_{parent}$ = 2.5 ppm = $^{9}Be_{reac} + {}^{9}Be_{min} + {}^{9}Be_{diss}$

- assumes all "missing" ^{9}Be is from ^{9}Be in the dissolved phase instead of ^{9}Be in fine grained minerals
- overestimates dissolved ^{9}Be; **overestimates f.factor**

eq. 2 more likely to overestimate denudation rates

discussion, part 2. eq 2. does not consistently overestimate denudation rates

Table 4.

Mean denudation rates calculated from $^{10}Be_{is}$ and $^{10}Be_{met}/^{9}Be_{reactive}$ mass balance model (eq. 1) with ^{9}Be parent concentrations either assumed to be 2.5 ppm or the mean $^{9}Be_{min}+^{9}Be_{reactive}$ for each basin.

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[b] total parent assumption applied to f.factor calculation and $^{9}Be_{parent}$; mean $^{10}Be_{met}$ deposition rate is used for each study area

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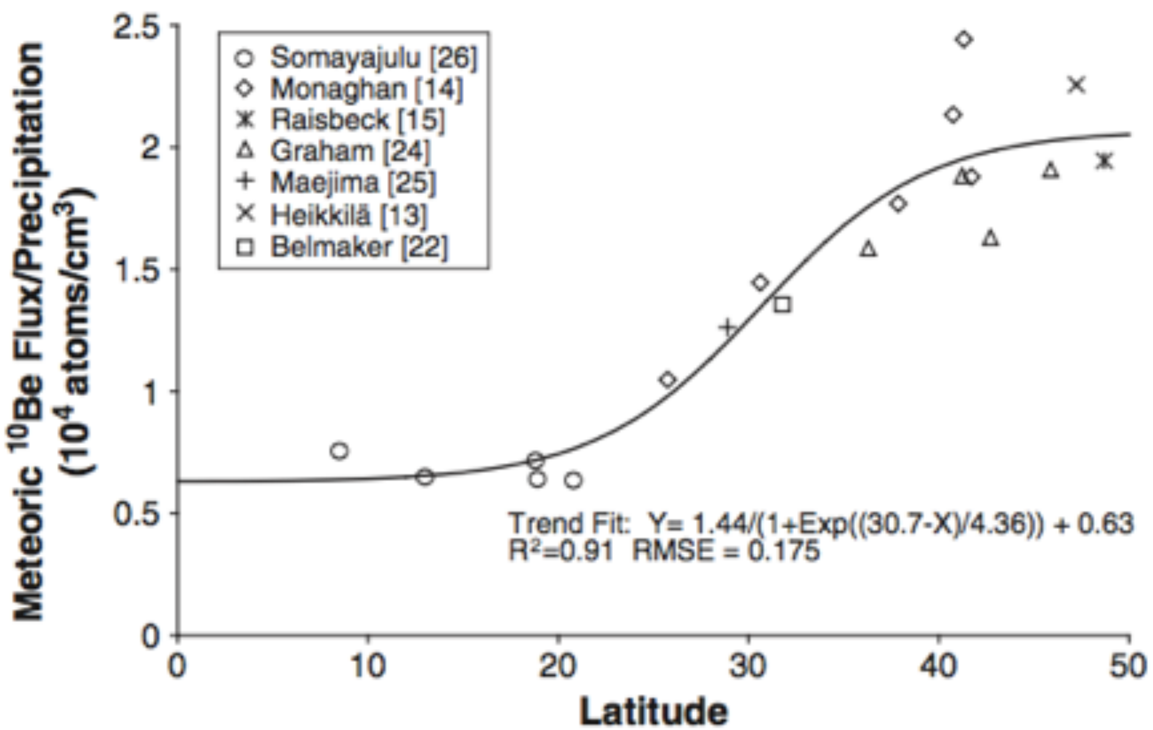
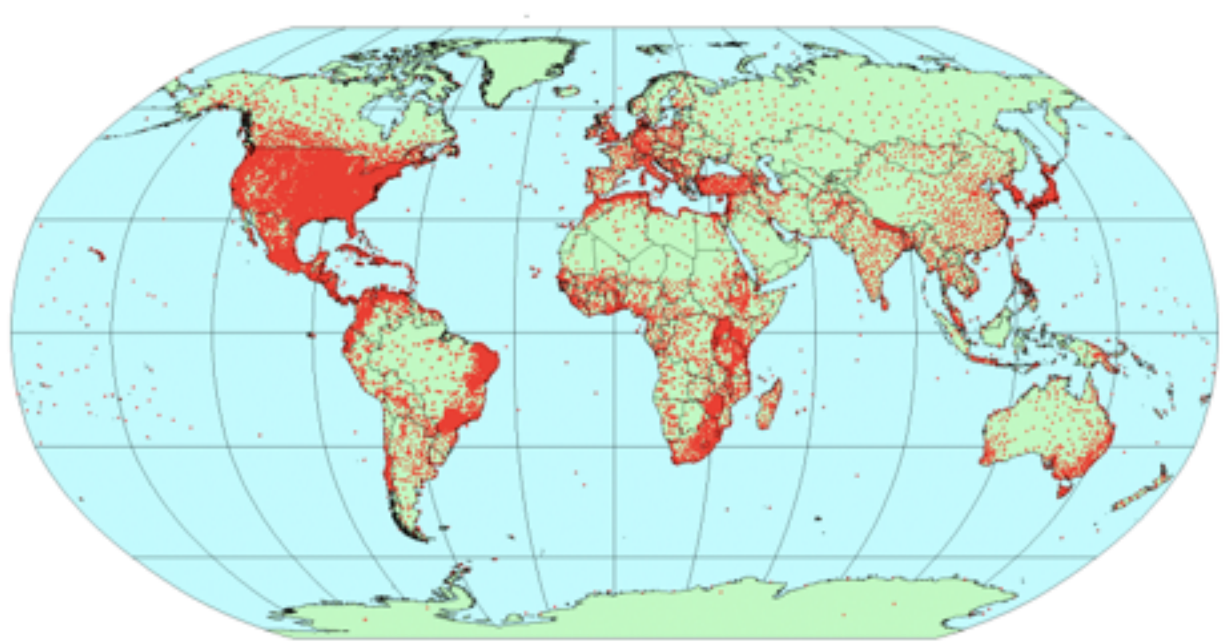
discussion, part 2. uncertainties in meteoric ^{10}Be delivery rates

Regional underestimate of meteoric ^{10}Be deposition rates in SW China study areas?





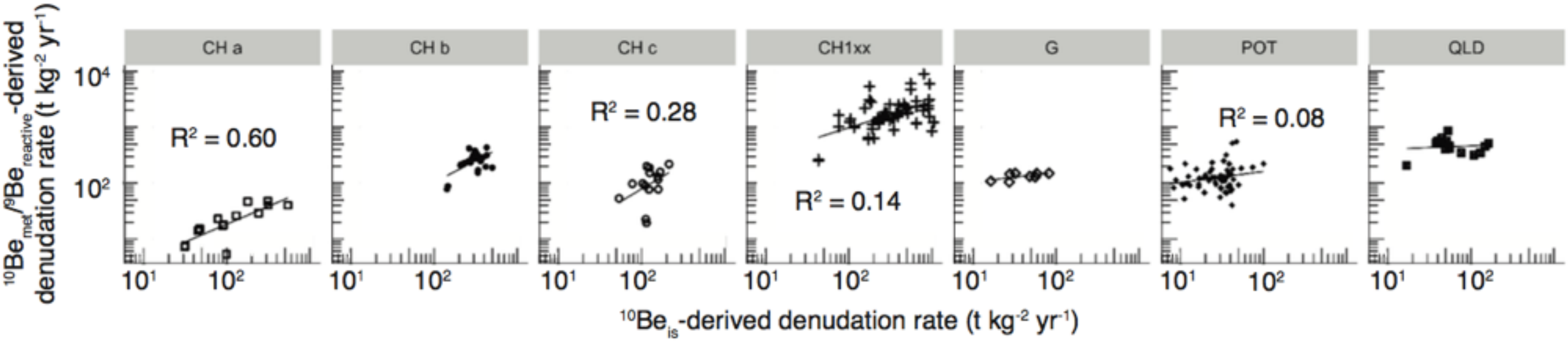
conclusions, part 2.

- Meteoric $^{10}Be/^{9}Be$ denudation rates agree with known in situ-based denudation rates across all samples

- uncertainties in parent ^{9}Be, f.factor, and meteoric ^{10}Be delivery rates, in addition to biogeochemical influences on meteoric $^{10}Be/^{9}Be$, add noise to the denudation rate proxy


Thank you!
Questions?

discussion, part 2. uncertainties in meteoric ^{10}Be delivery rates add noise to correlation between denudation rates

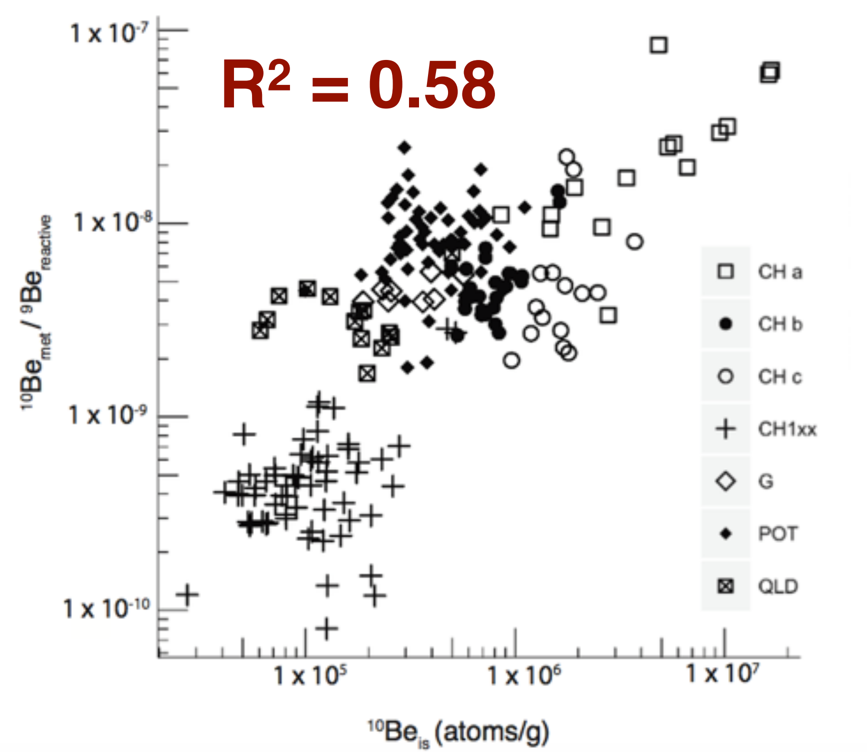


- heterogeneities in ^{9}Be parent concentrations and meteoric ^{10}Be delivery rates within study areas not quantified in mass balance model

- meteoric ^{10}Be/^{9}Be is influenced by leaching and remobilization

future work

meteoric $^{10}Be/^{9}Be$ ratios influenced by biogeochemical processes (stronger influence on regional scale) and spatial heterogeneity in Be inputs (stronger influence across all data)

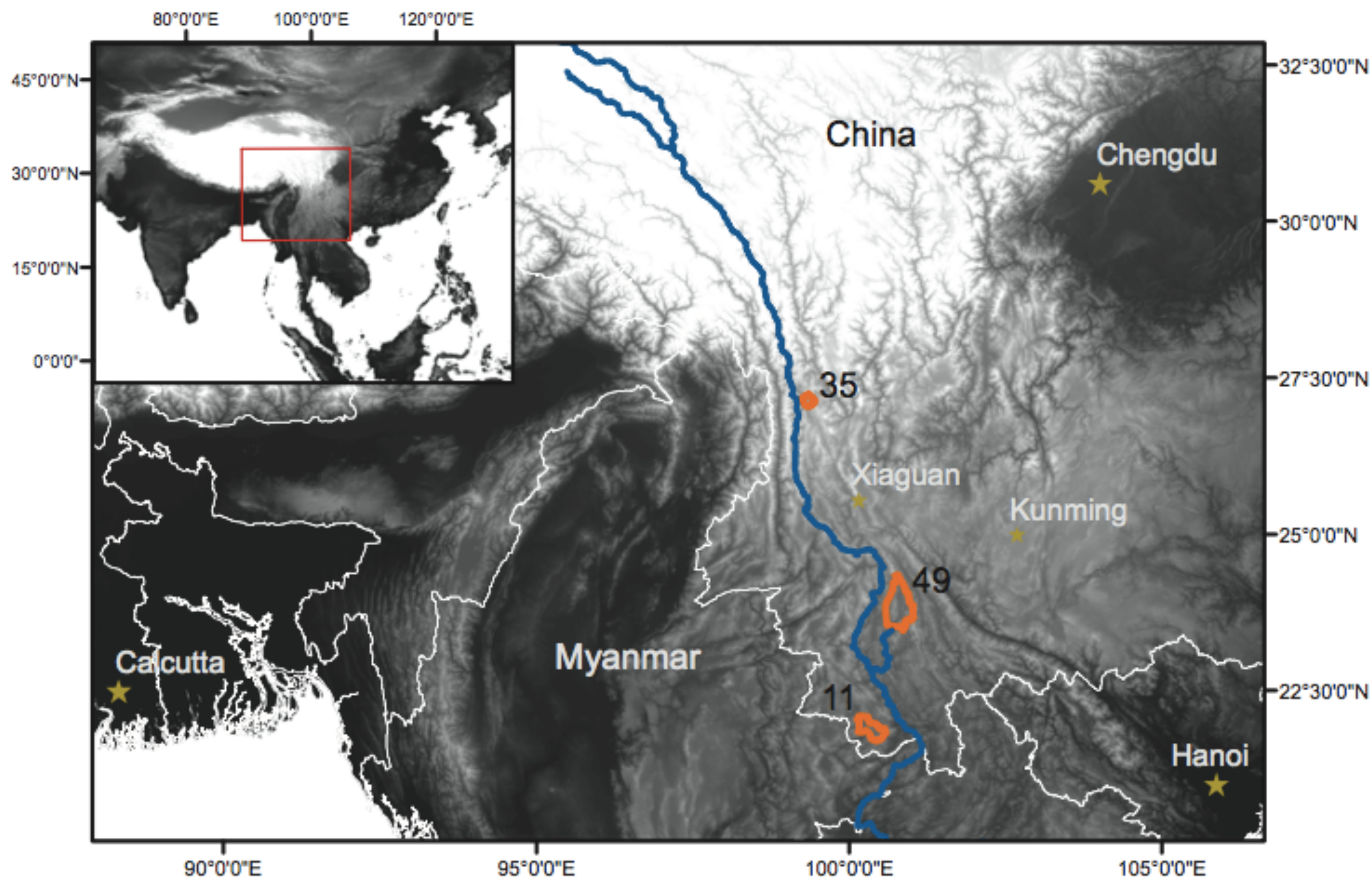


- correlation between meteoric ^{10}Be and reactive ^{9}Be

    meteoric ^{10}Be delivery rates depend on precipitation rate and latitude

    reactive ^{9}Be controlled by parent ^{9}Be concentrations and weathering rates

- no correlation between meteoric ^{10}Be to ^{10}Be delivery rates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32°30'0"N
30°0'0"N
27°30'0"N
25°0'0"N
22°30'0"N
90°0'0"E
95°0'0"E
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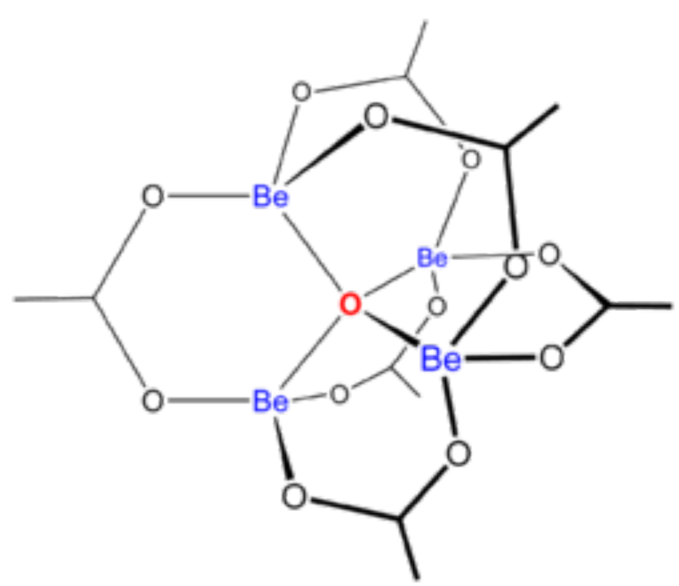
105°0'0"E
China
Chengdu
35
Xiaguan
Kunming
49
Myanmar
Calcutta
11
Hanoi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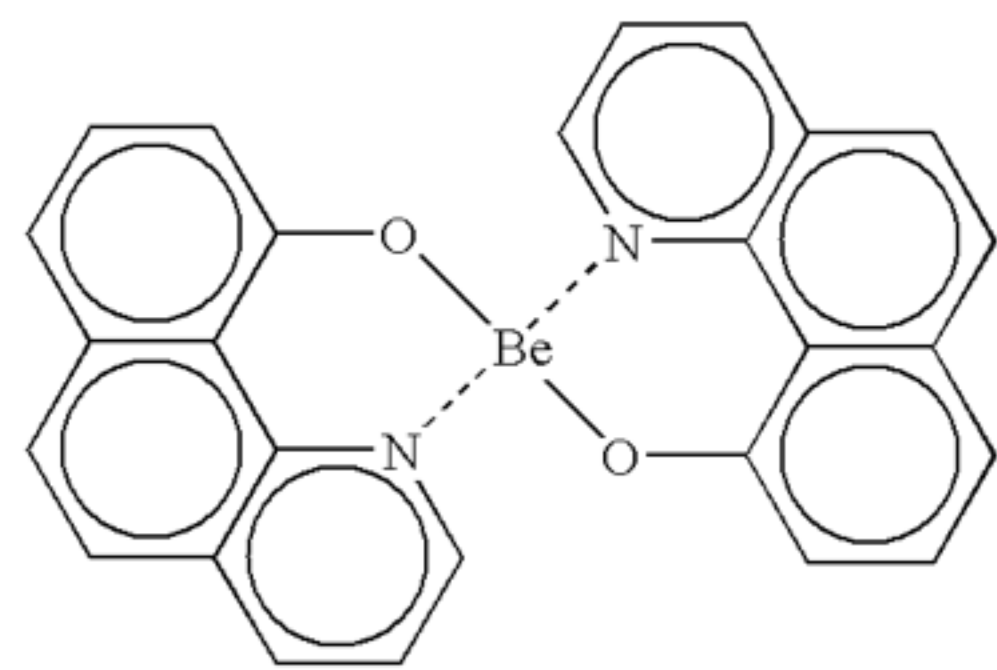
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