

Natural Acid Rock Drainage: Examples from Montana

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Chicago Gulch, Judith Mountains

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Why study natural acid rock drainage? (NARD)

- Interesting!
- Paleoclimate studies (e.g. ferricretes)
- Exobiology, Mars, origin of life
- NARD and global climate change
- May be useful guide to estimate baseline water quality in watersheds polluted by legacy mining



Argentina



Brooks Range, N. Alaska

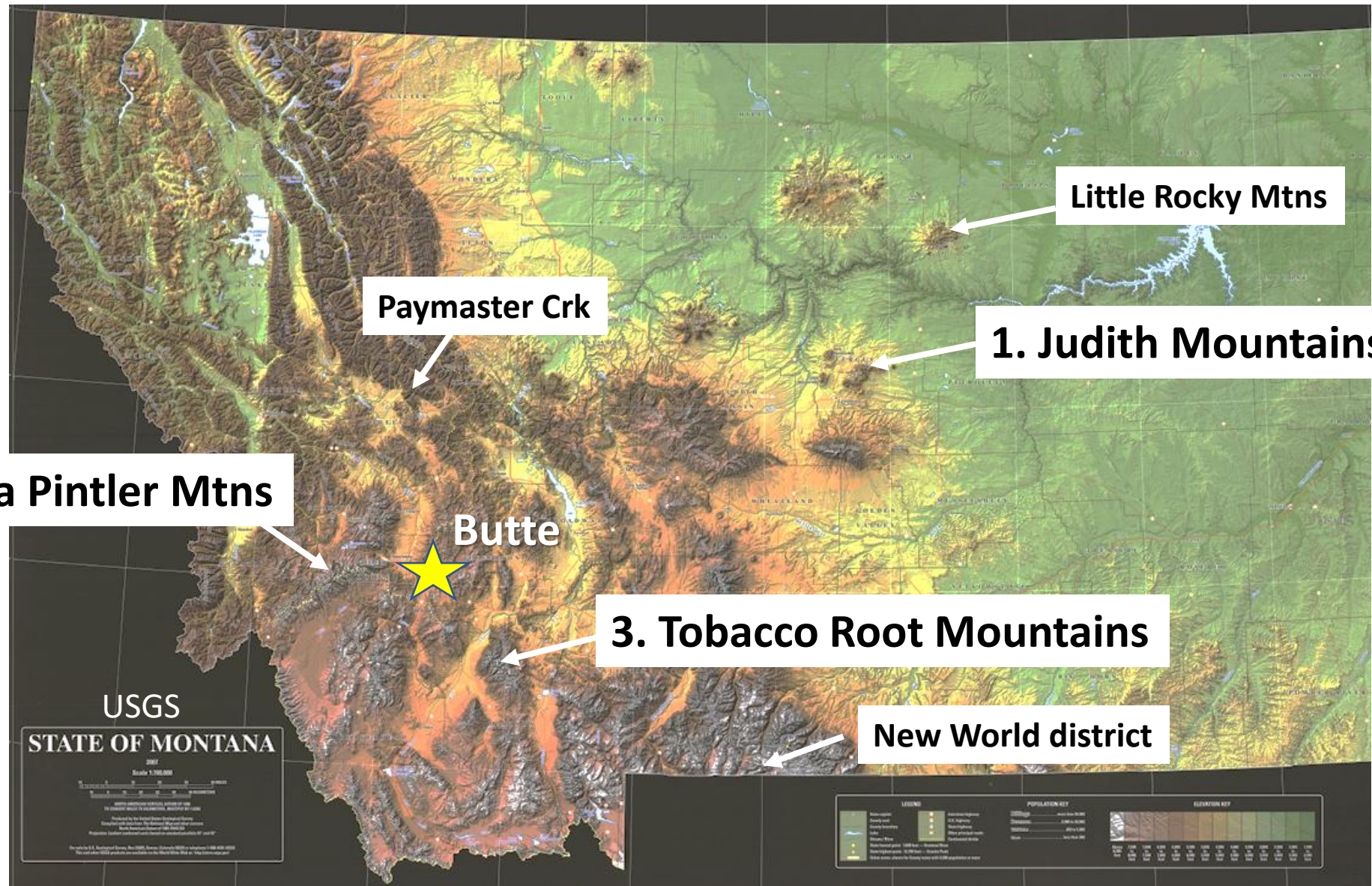


Greenland

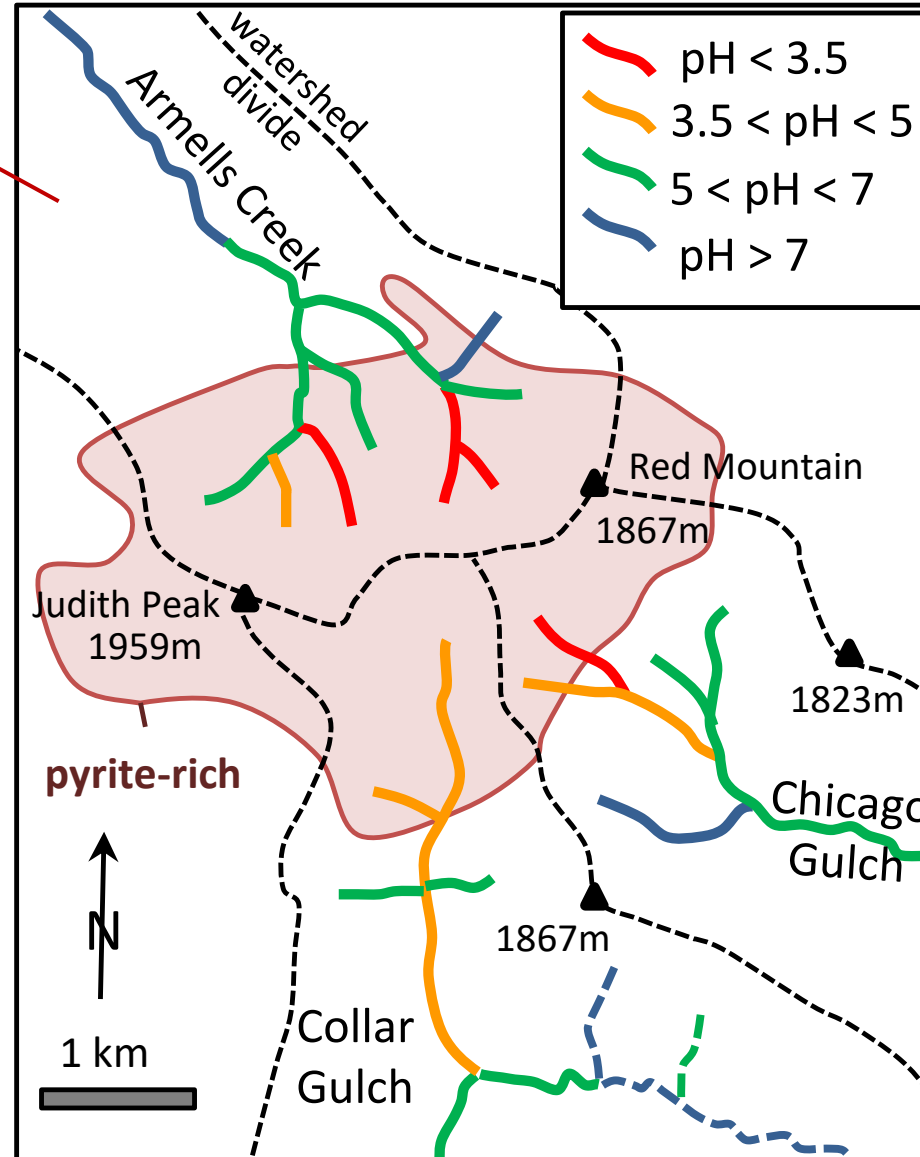
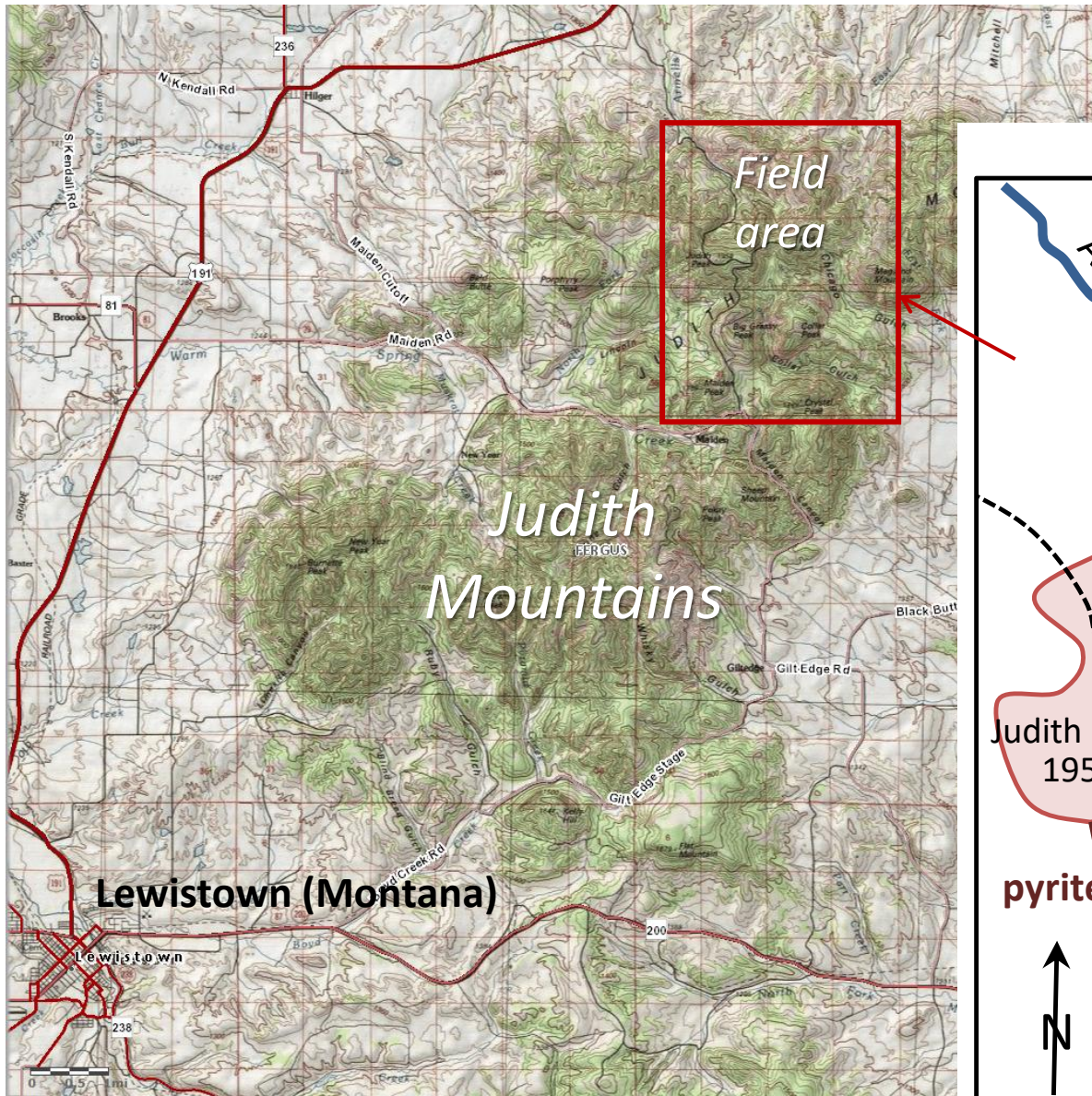


Pyrenees

NARD sites in Montana investigated by our group



1. Judith Mountains



Upper Chicago Gulch
pH ~ 4.0

Ferricrete terrace (inactive)

Ferricrete terrace (active)

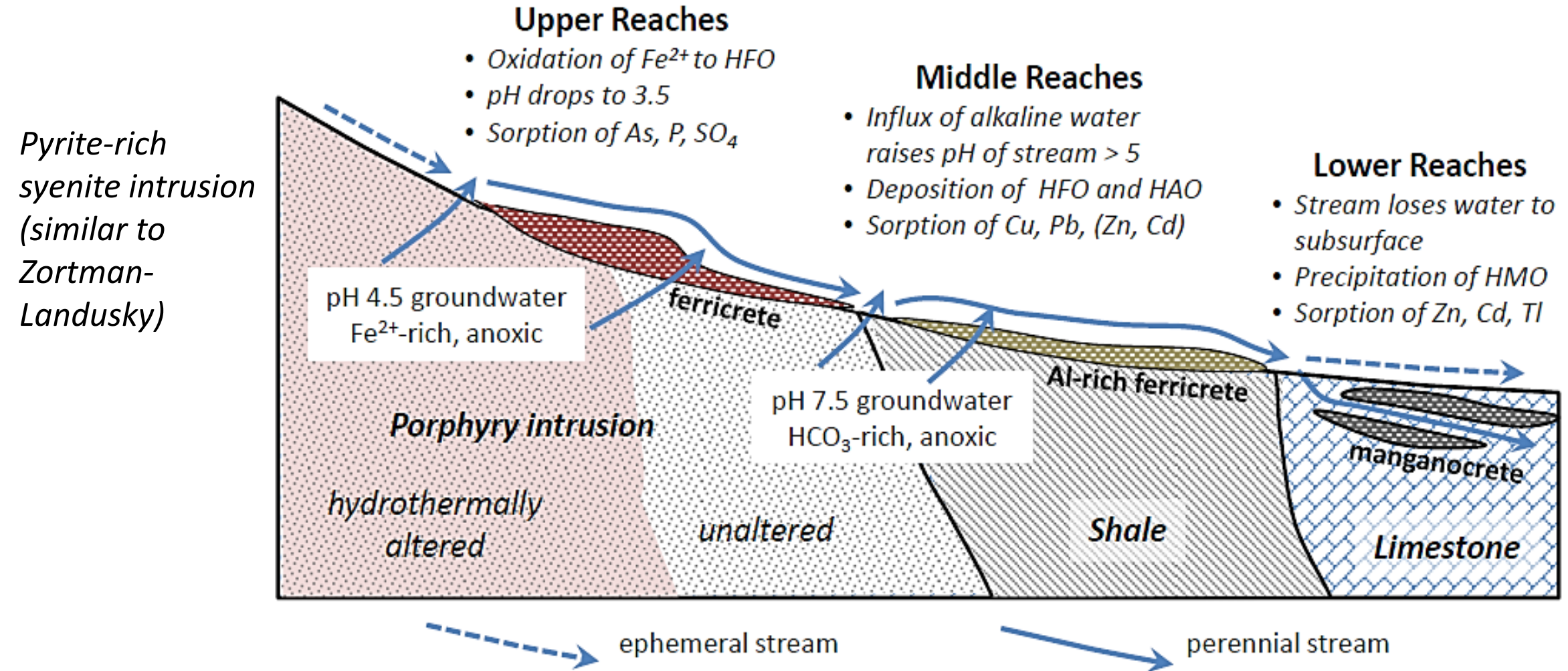


Upper Collar Gulch
pH ~ 5.5 [HAO, basaluminite]

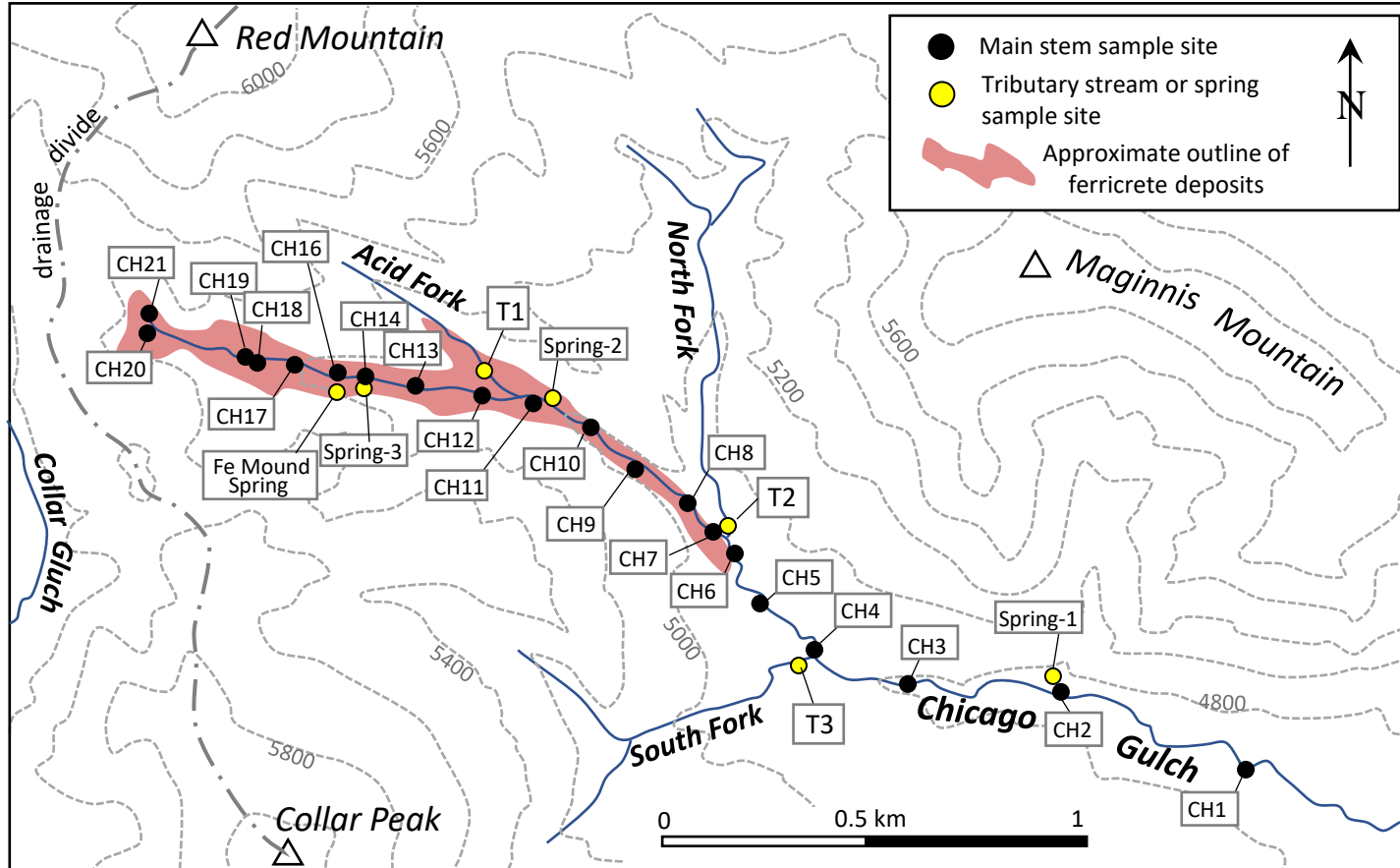
Fe/Al-crete terrace
(inactive)

Mangano-crete hardpans in subsurface
(exposed by 100-yr flood scour)

NARD in Judith Mountains: Conceptual Model



Detailed synoptic sampling

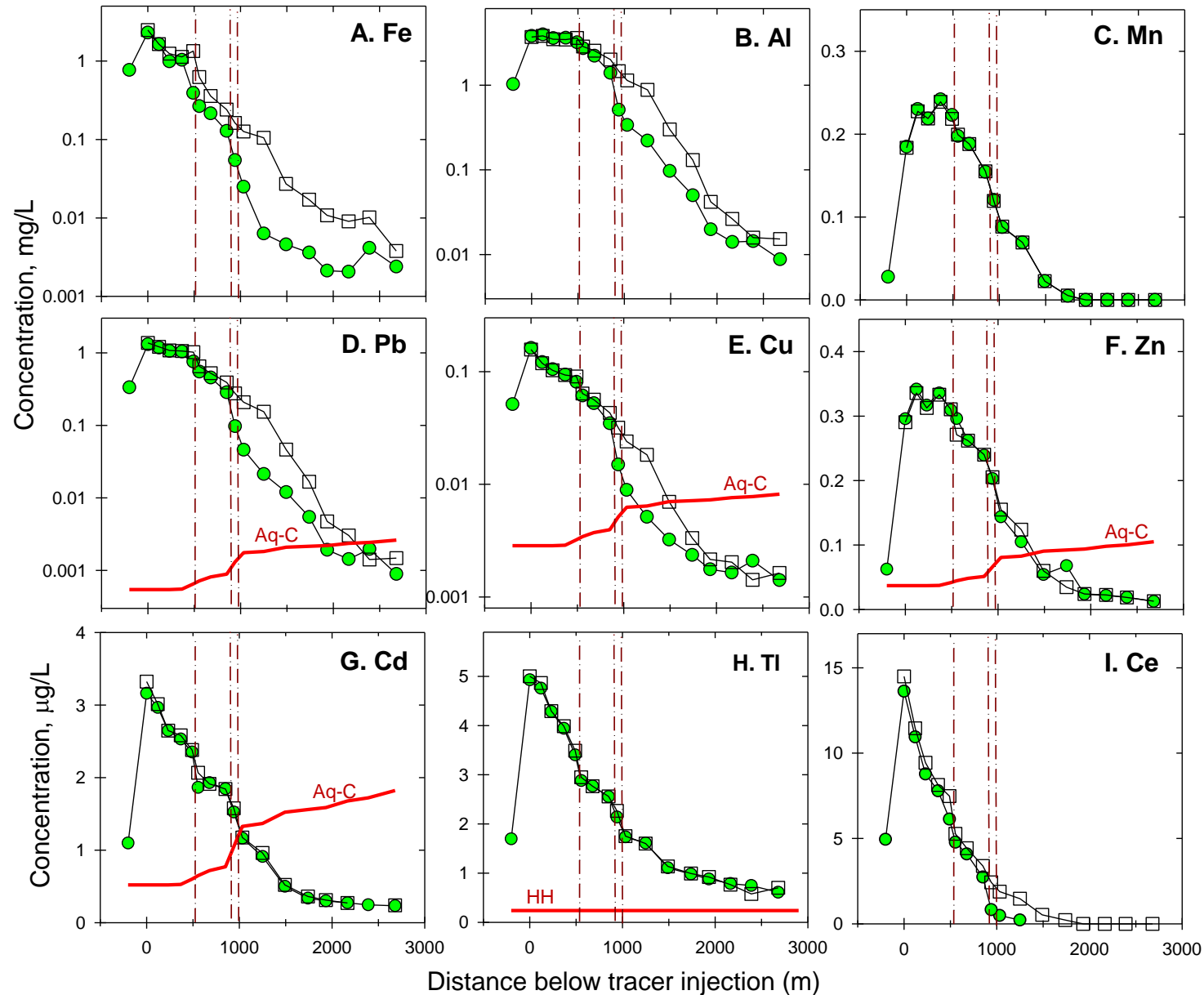


Streamflow: Continuous tracer (LiBr) injection or NaCl-slug tracer.

Paired filtered and non-filtered samples.

Major solutes + trace element concentrations and loads.

Example data: concentrations vs. distance downstream

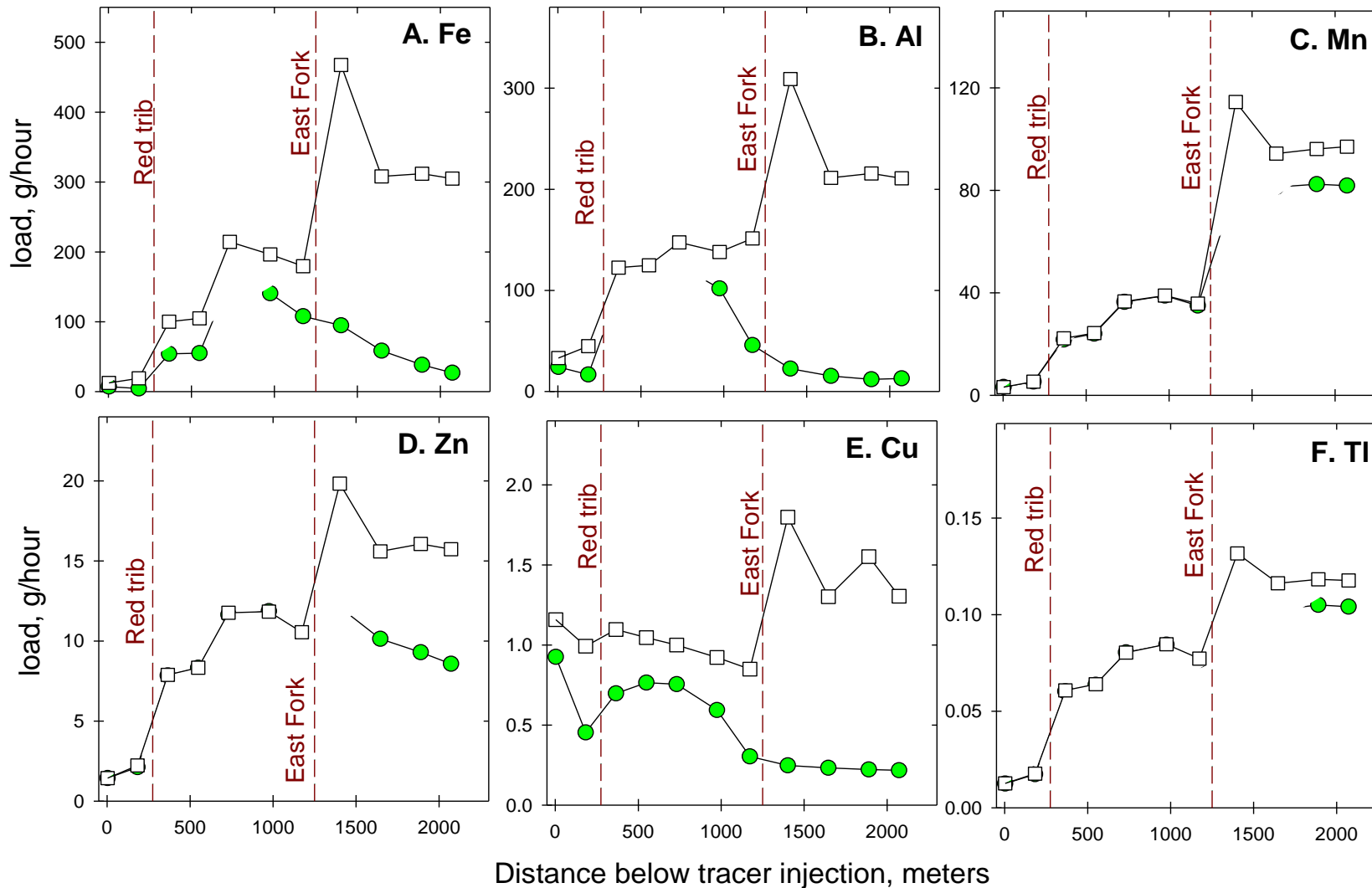


□ = total
■ = dissolved

Aq-C = DEQ7 chronic aquatic life standard

HH = EPA human health standard

Example data: loads vs. distance downstream



Load =
concentration x flow

□ = total

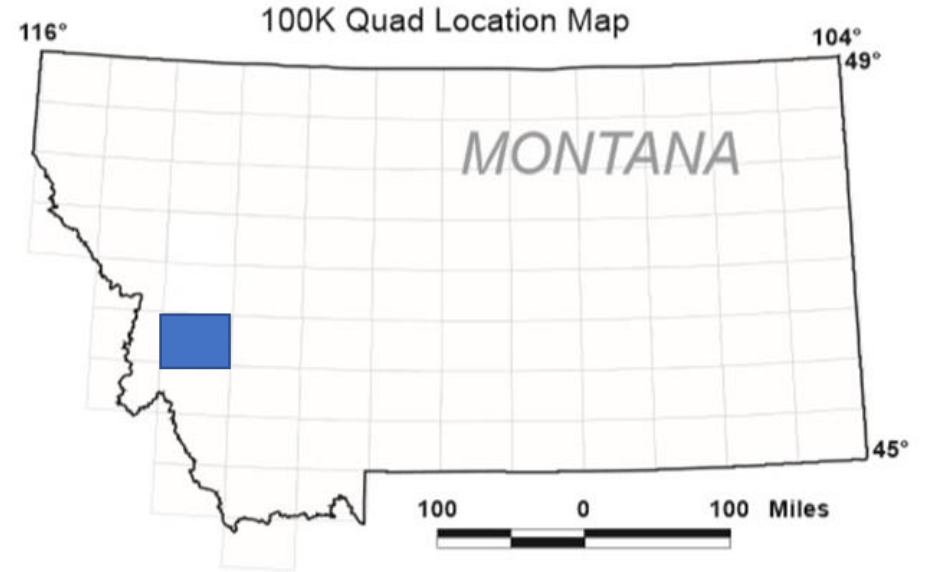
■ = dissolved

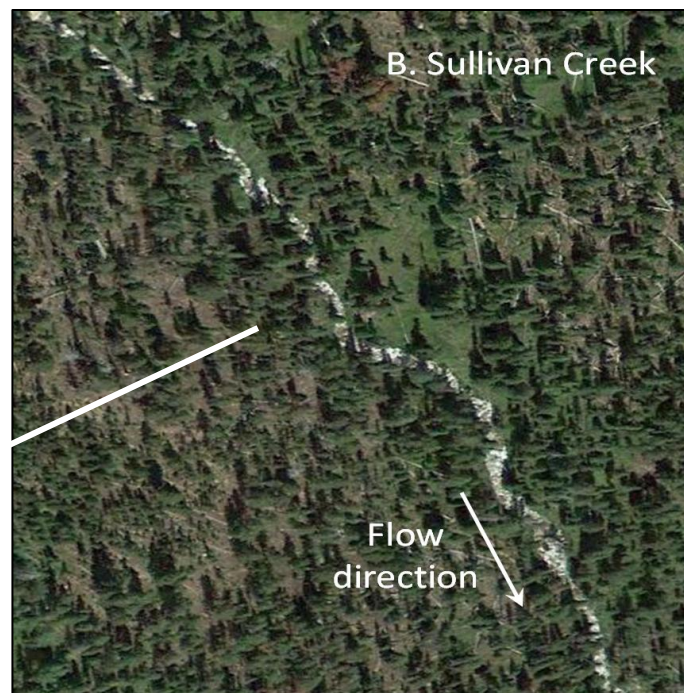
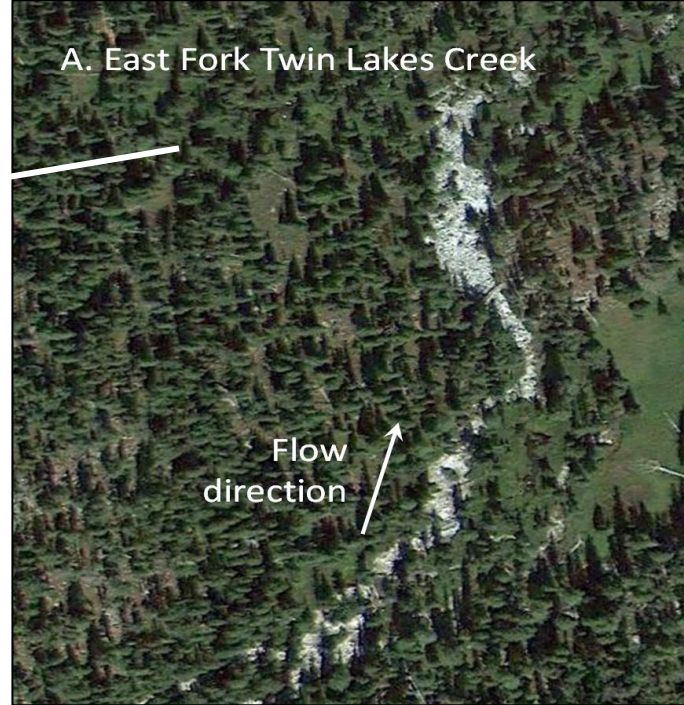
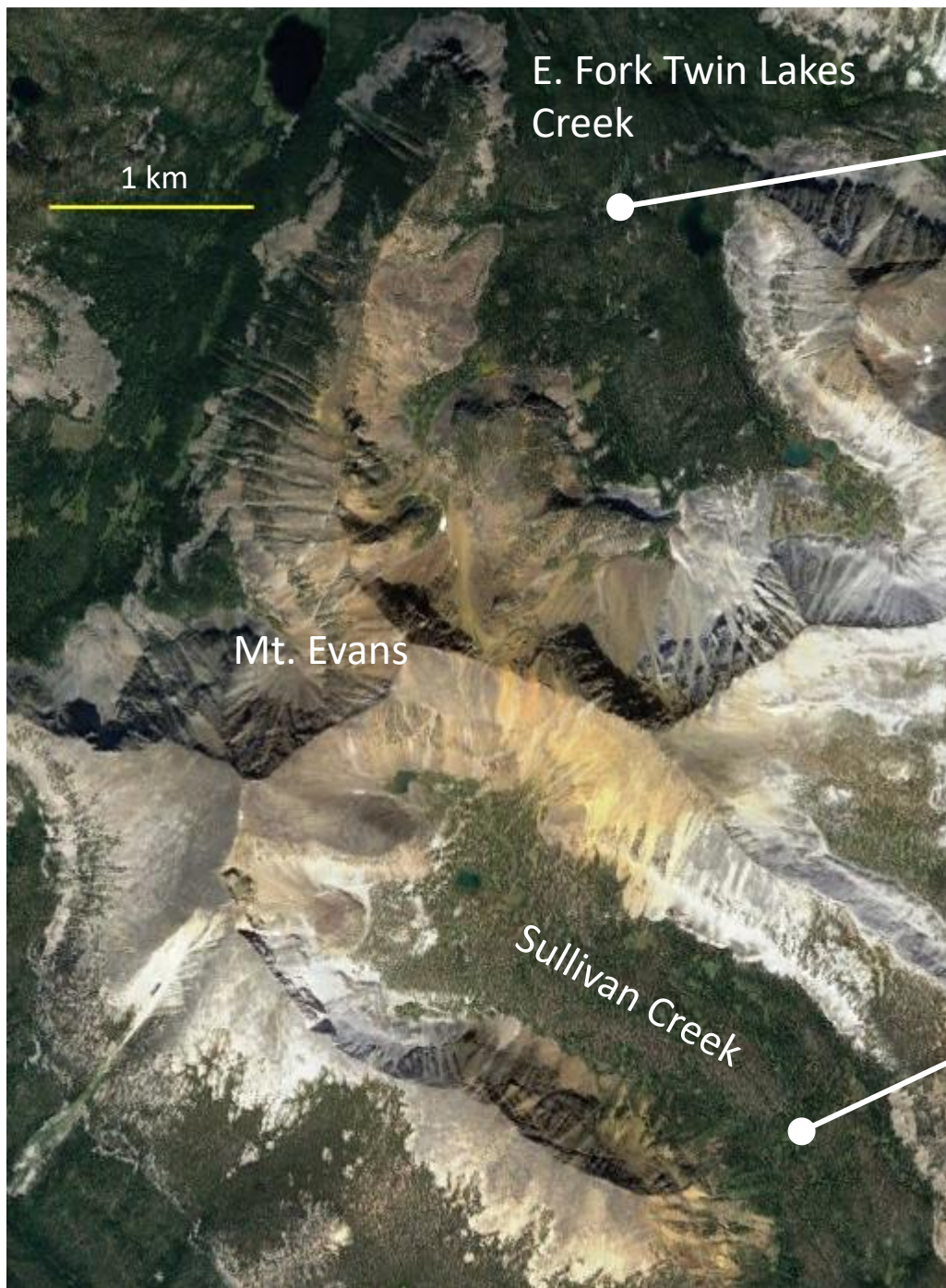
Trace metals are
mostly dissolved in
upper reaches

Mostly suspended
solids in lower reaches

2. Mount Evans, Anaconda-Pintler Range

Precambrian Belt Supergroup
Oxidized massive sulfide deposit?

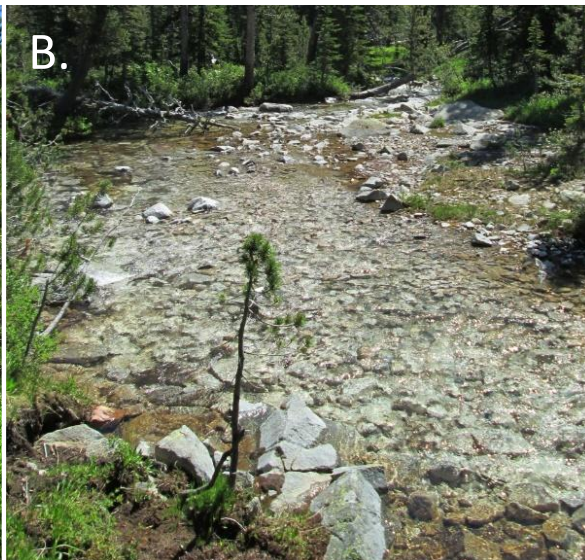




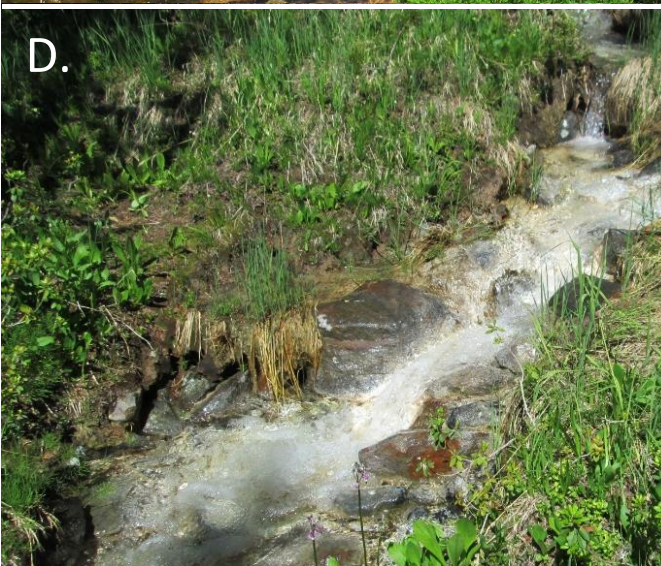
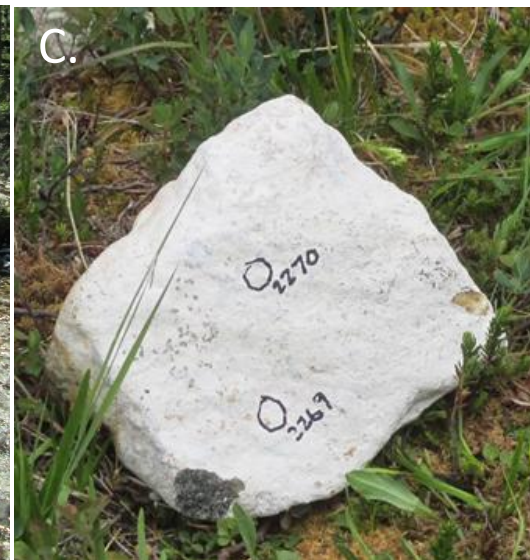
Red Fork, pH ~ 4.3



pH ~ 4.6
White Fork, HAO ppts



HAO ppts

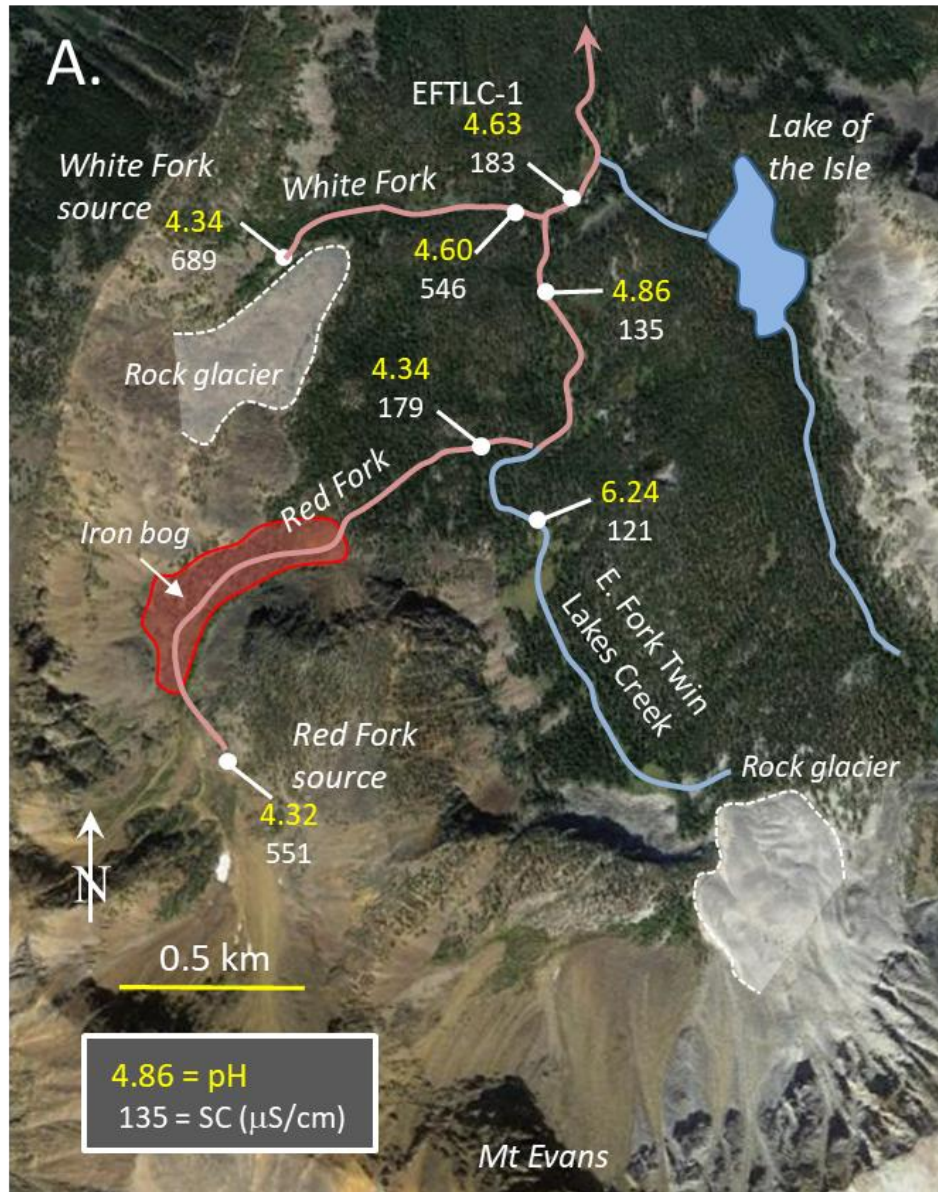


“White Trib”, heavy HAO

Iron bog

Sullivan Crk. Ferricrete

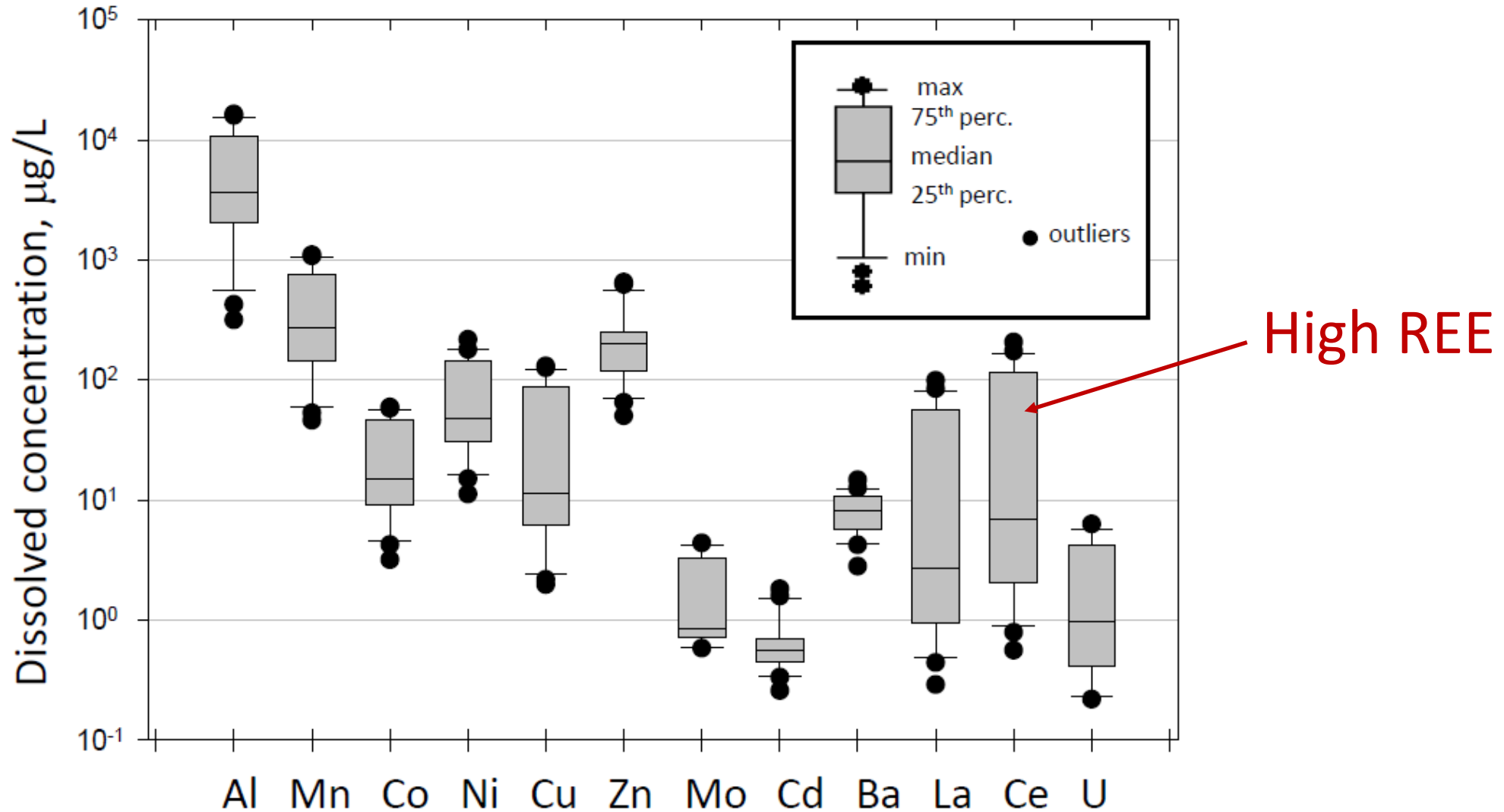
East Fork Twin Lakes Creek



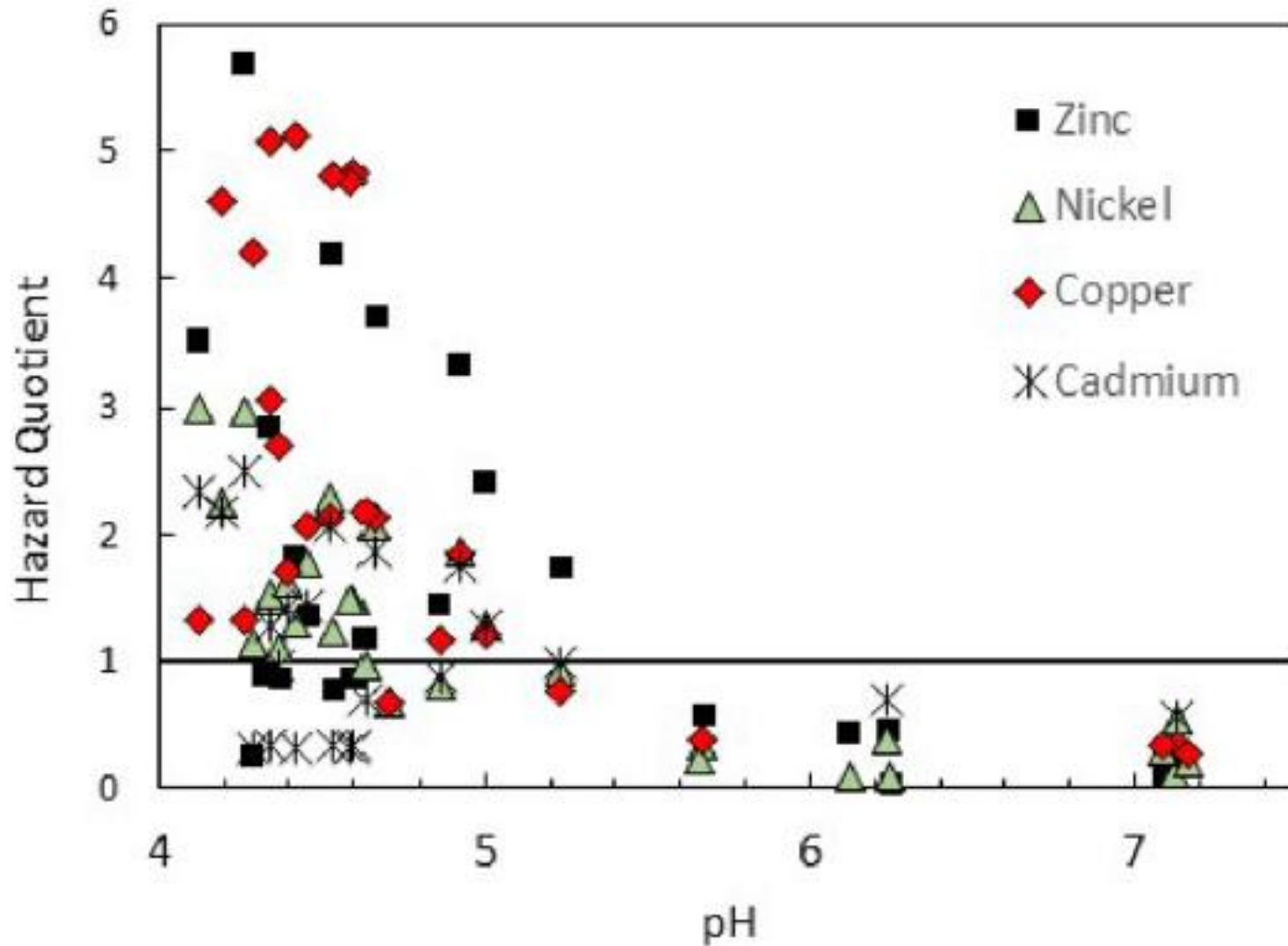
Sullivan Creek



Mt. Evans area: Trace elements in all samples with pH < 5



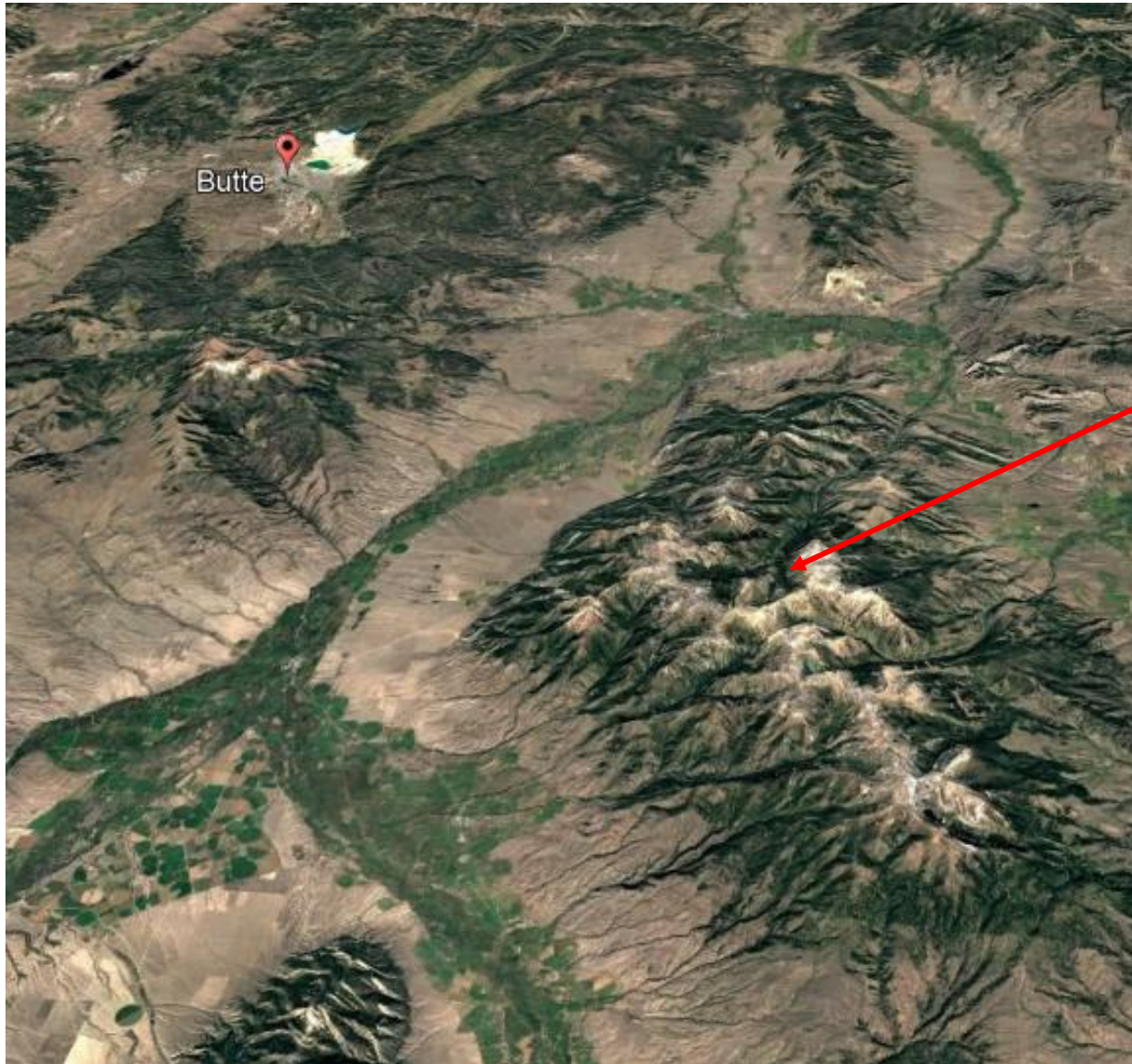
Mt. Evans area: Stream Hazard Quotients (HQ)



$$HQ = \frac{\textit{concentration}}{\textit{regulatory standard}^*}$$

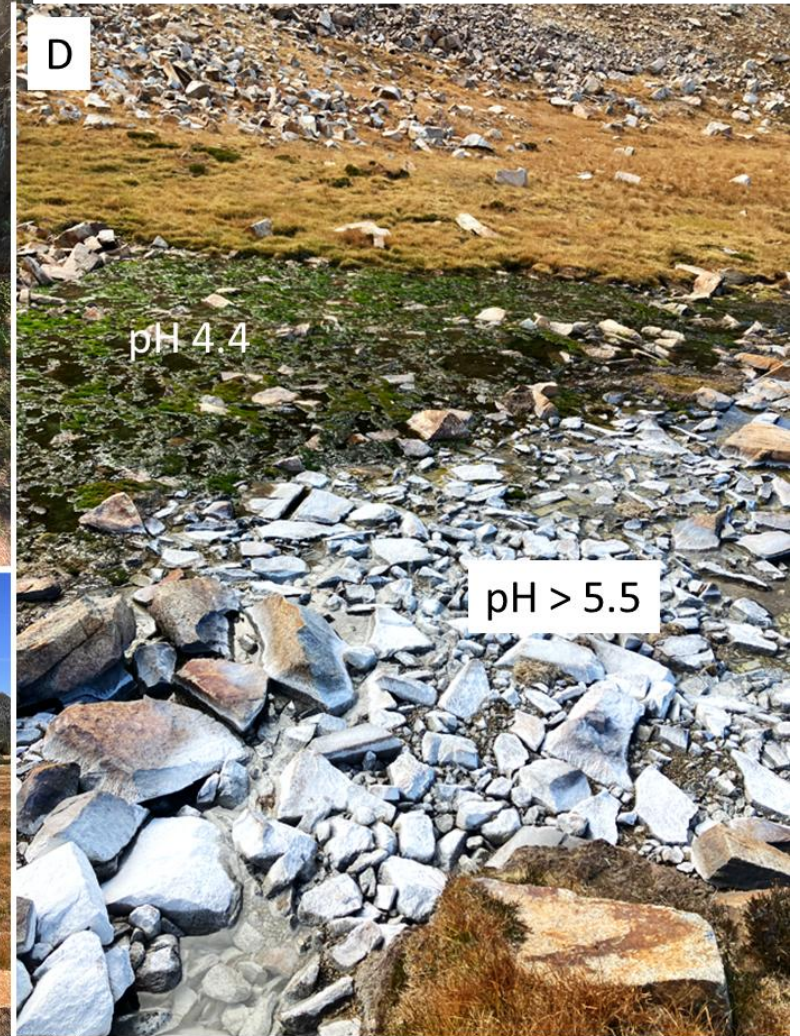
*chronic aquatic life

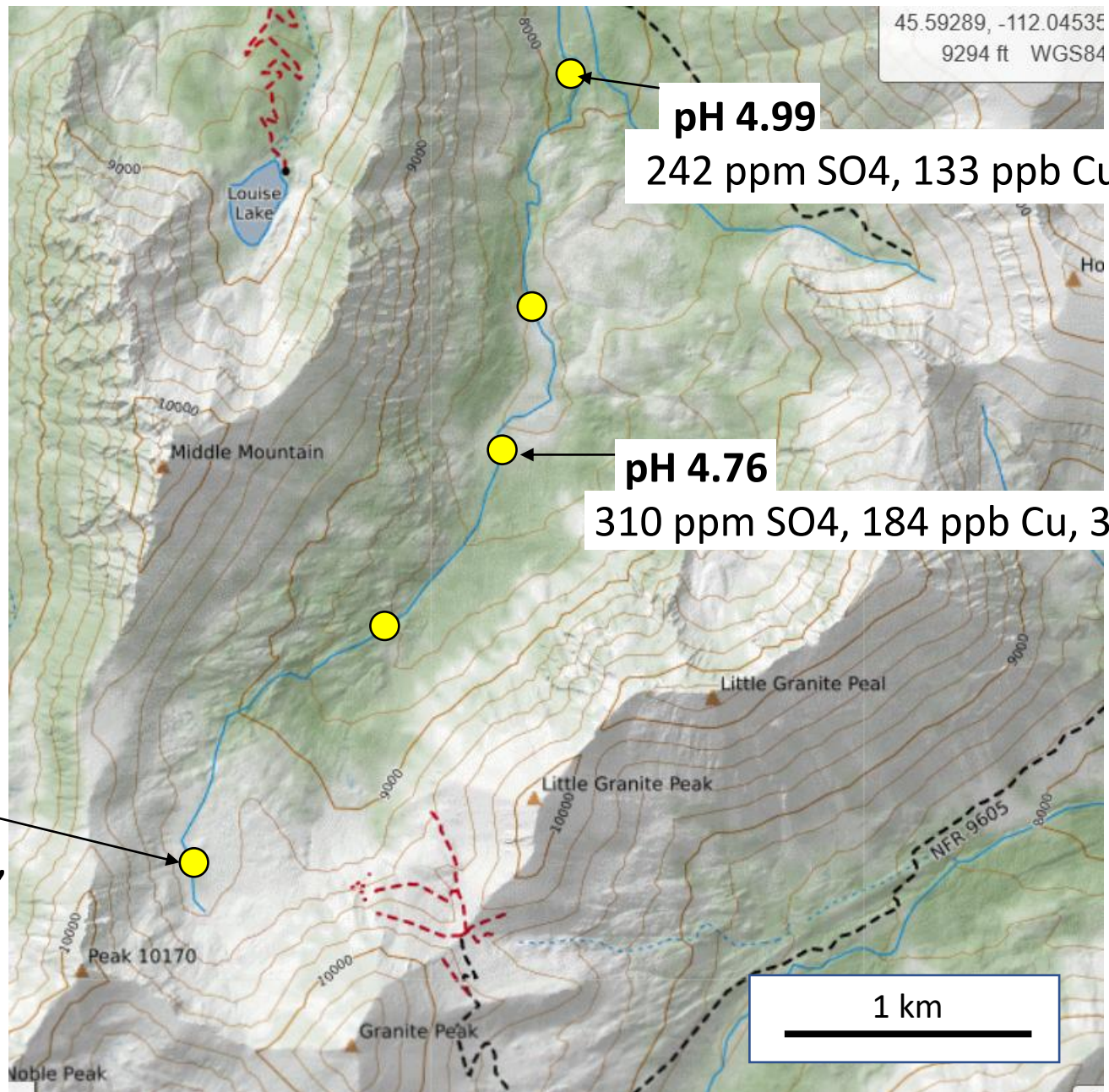
3. South Boulder River, Tobacco Root Mtns



pH 4.6

First sampling trip: October, 2024





45.59289, -112.04535
9294 ft WGS84

pH 4.99

242 ppm SO₄, 133 ppb Cu, 266 ppb Zn

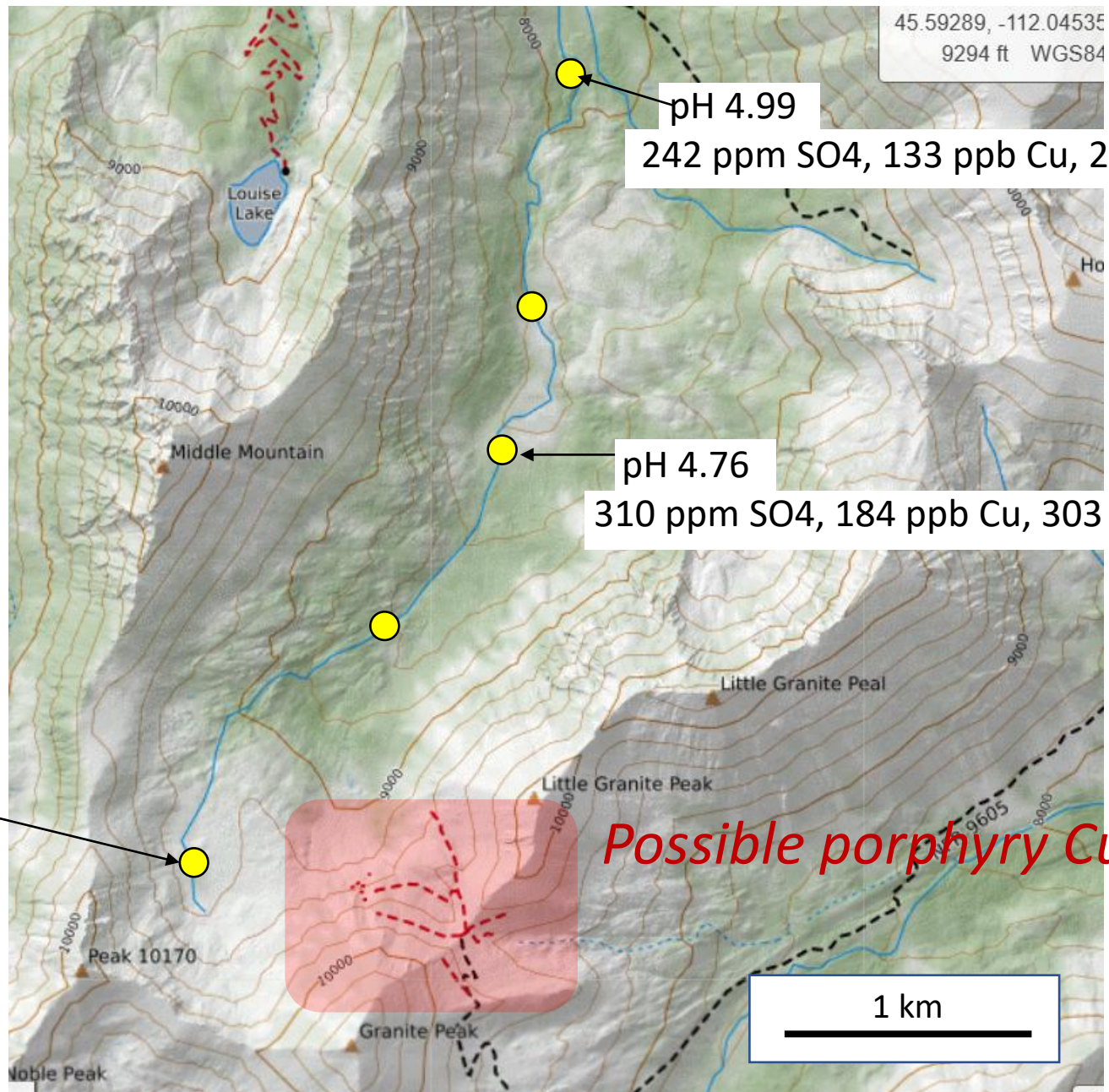
pH 4.76

310 ppm SO₄, 184 ppb Cu, 303 ppb Zn

pH 4.42

254 ppm SO₄,
874 ppb Cu,
1180 ppb Zn

1 km



How best to compare one watershed to another?

Solute concentrations

Dissolved vs. total vs.
suspended solids

mg/L, $\mu\text{g/L}$

Fish care about this!

Solute loads

$$= \frac{\text{Concentration}}{\text{Streamflow}}$$

mg/sec, kg/day

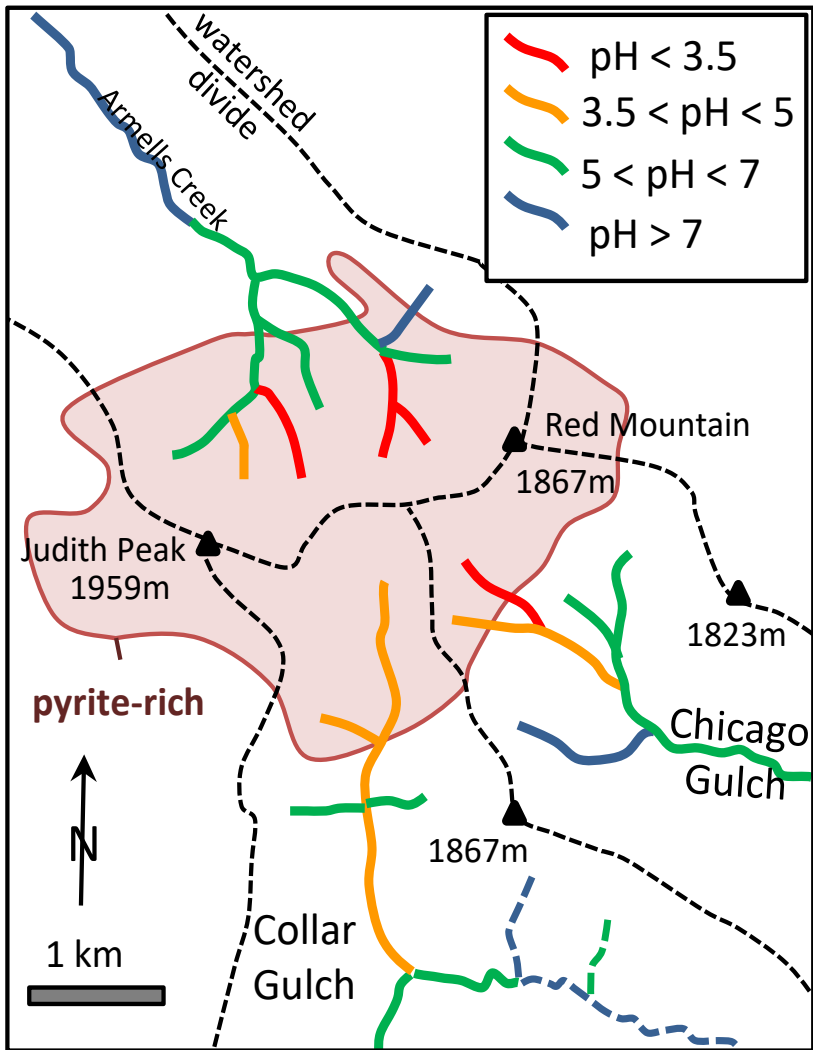
TMDL regulators
care about this!

Solute fluxes

$$= \frac{\text{Load}}{\text{Watershed area}}$$

g/hour/km²
kg/day/km²

Nobody cares
about this!



Solute fluxes at base-flow conditions for streams draining Red Mountain.

Drainage	Mineralized area, km ²	flux, g/km ² /hour					
		SO ₄ ²⁻	F ⁻	Al	Zn	Mn	Tl
Chicago Gulch	1.86	2680	71	66.2	5.2	14.7	0.05
Collar Gulch	1.61	1041	97	29.3	3.9	2.6	0.20
East Fork Armells	1.46	2757	67	n.a.	3.8	23.3	0.04
West Fork Armells	2.17	2693	92	31.9	5.9	15.8	0.07
Judiths average		2293	82	42.5	4.7	14.1	0.09

	flux, g/km ² /hour					
	SO ₄ ²⁻	F ⁻	Al	Zn	Mn	Tl
Judiths average	2293	82	42.5	4.7	14.1	0.09

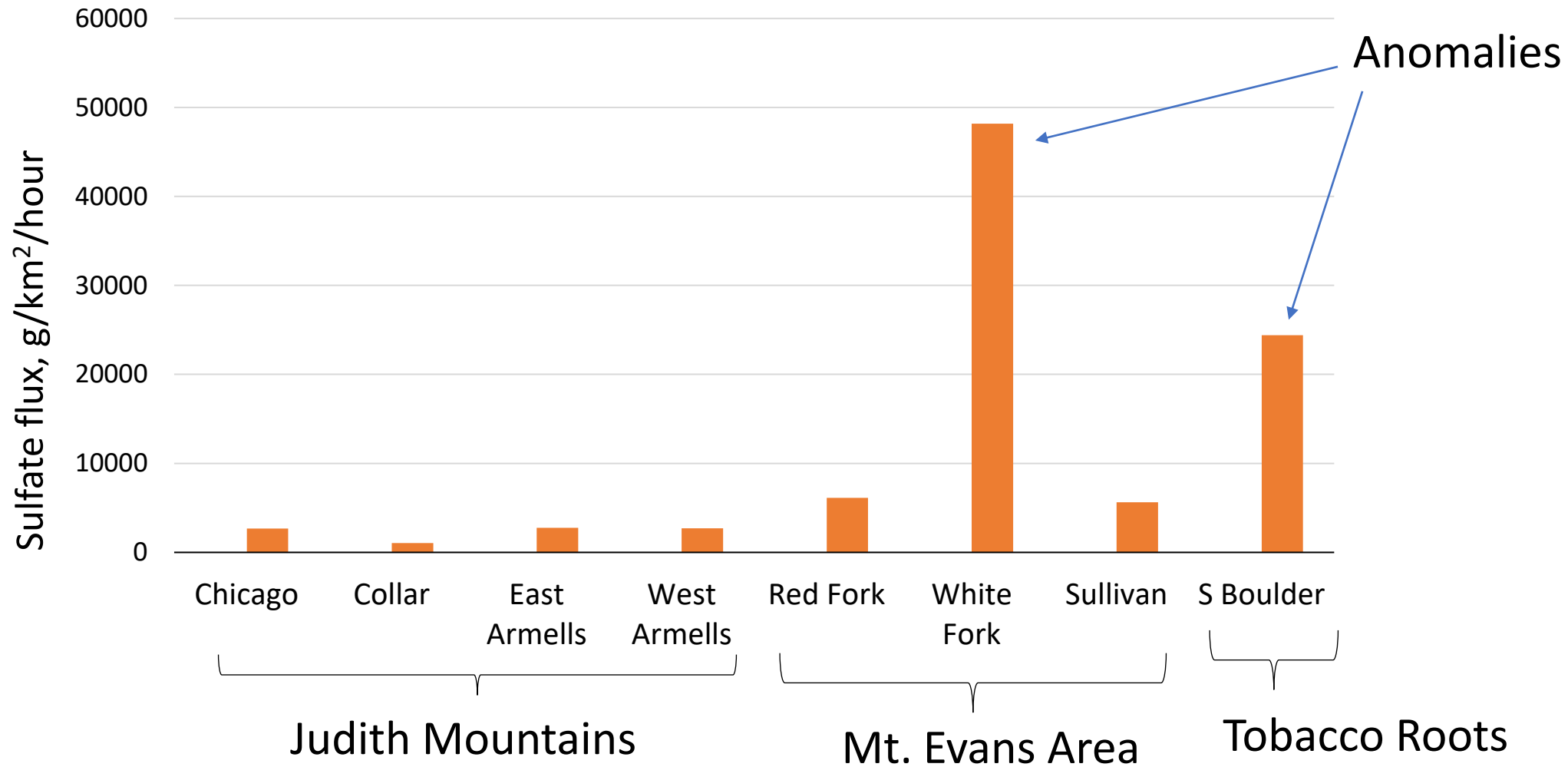
These flux values might be used to estimate pre-mining solute loads and concentrations for other areas with similar climate, topography and geology.

Example: A hypothetical site has a watershed area of 2.5 km² and a baseflow of 200 L/minute. What was the sulfate load prior to mining? What were the sulfate concentrations prior to mining?

$$\text{Sulfate load} = \text{flux} * \text{area} = 2293 \text{ g/km}^2/\text{hour} * 2.5 \text{ km}^2 = 5732 \text{ g SO}_4/\text{hour}$$

$$\text{Sulfate concentration} = \text{load}/\text{streamflow} = \frac{5732 \text{ g SO}_4/\text{hour}}{200 \text{ L/minute}} = 478 \text{ mg/L SO}_4$$

How transferable are data from the Judiths to other watersheds?



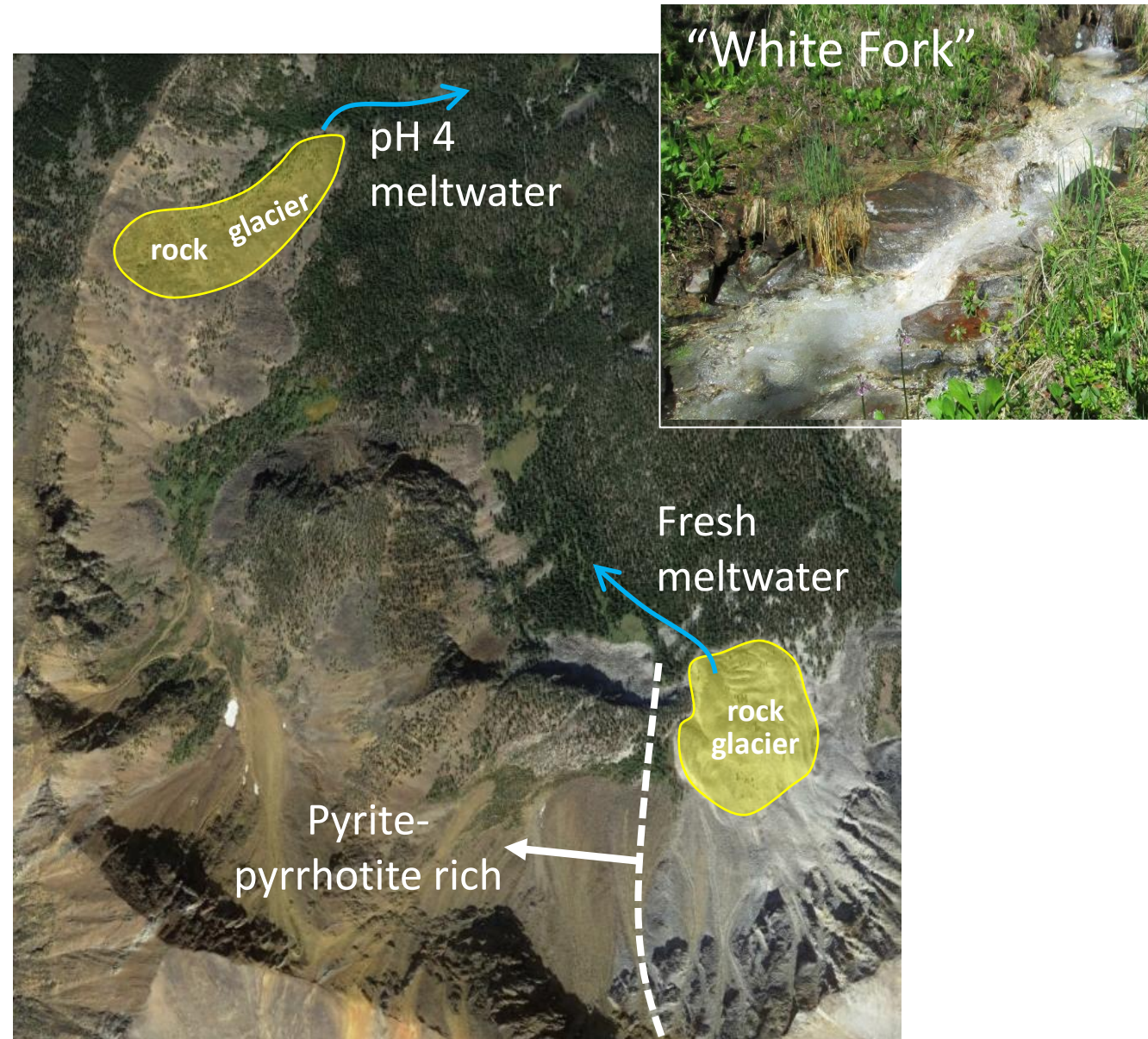
Why is the “White Fork” so anomalous?

Rock glacier meltwater!

- crushing, grinding, freeze/thaw reduces grain size and increases surface area for oxidation

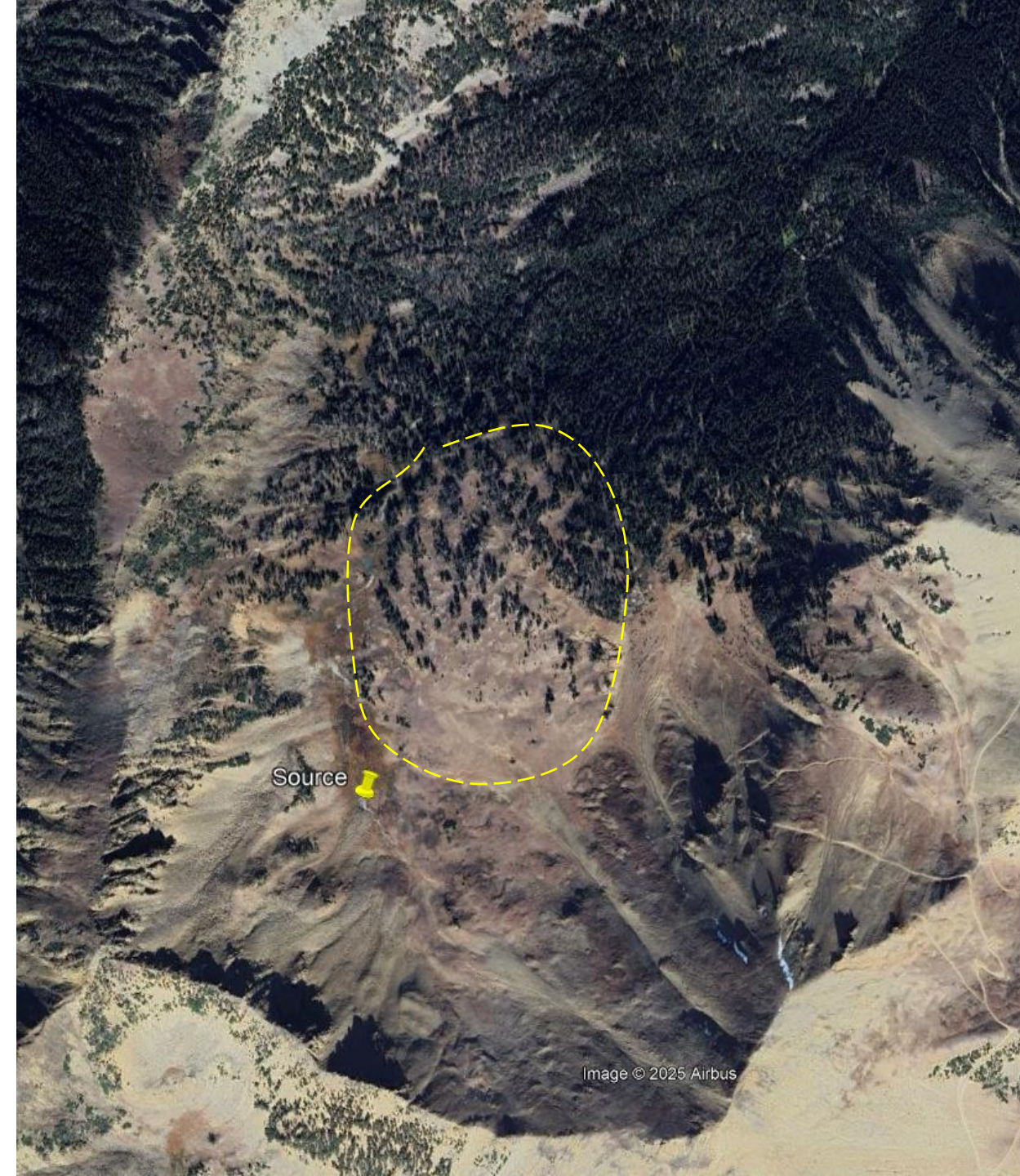
Same phenomenon noted in Pyrenees and Austrian Alps

- Situation is getting worse with global warming



S. Boulder Area

Possible melting
(extinct) rock glacier



Caution!

Much more data on NARD needs to be collected to understand the range in solute flux values as a function of geology, climate, topography

Periglacial features (melting rock glaciers, melting permafrost) may result in orders of magnitude greater fluxes than predicted otherwise

References



Contents lists available at [ScienceDirect](#)

Applied Geochemistry

journal homepage: www.elsevier.com/locate/apgeochem

An investigation of acidic head-water streams in the Judith Mountains, Montana, USA

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Applied Geochemistry

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Geochemistry of natural acid rock drainage in the Judith Mountains, Montana, part 2: Seasonal and spatial trends in Chicago Gulch

Christopher H. Gammons^{a,*}, Sara C. Edinberg^{a,1}, Stephen R. Parker^a, Yasumasa Ogawa^b

Research article

GEEA

Geochemistry: Exploration, Environment, Analysis

<https://doi.org/10.1144/geochem2021-068> | Vol. 21 | 2021 | geochem2021-068

Geochemistry of natural acid rock drainage in the Mt Evans area, Anaconda–Pintler Range, Montana, USA



C. H. Gammons^{1*}, M. F. Doolittle¹, K. A. Eastman¹ and S. R. Poulson²