Estimating Mineral Weathering Rates in Catskills Watersheds

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Erosion, Denudation and Weathering

- Erosion: Generally refers to the *transport of physical matter* by water and wind.
- Weathering: Breakdown of rocks/minerals.
  - Physical
  - Chemical
- Denudation: Net lowering of the landscape.
  - Result of physical and chemical processes.

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Chemical Weathering

- Dissolution of minerals in soils and parent material.

$$CaAl_2Si_2O_8\ (s) + 6H_2O + 2H^+ = 2Al(OH)_3\ (s) + Ca^{2+} + 2H_4SiO_4\ (aq)$$

- Releases dissolved substances to groundwaters.
  - Basic Cations: Ca, Mg, K, Na
  - Silica: H_4SiO_4
  - Aluminum: potentially toxic to aquatic biota
- Neutralizes acidity.
  - Crucial to sustainable water quality
  - Largely determines "critical load" of acid deposition in forested ecosystems.

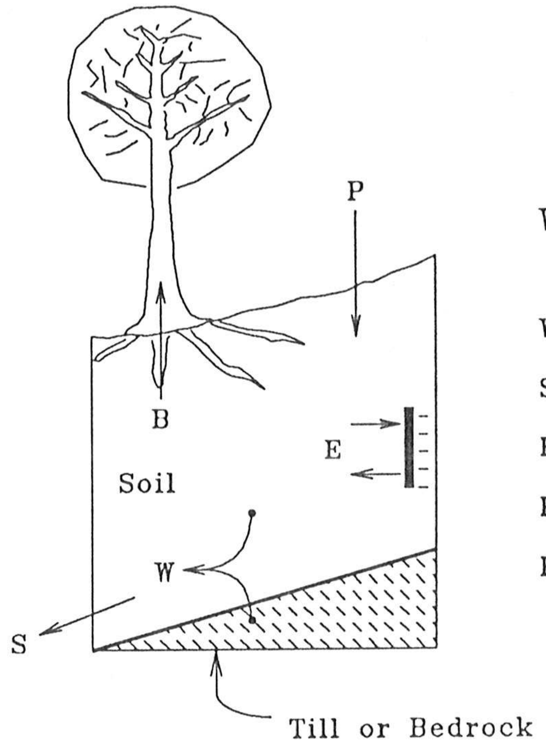
Estimation of Chemical Weathering Rates

- Chemical weathering is not readily measurable.
  - Very slow rate…
  - …integrated over the total mineral surface area in soils and parent material in a watershed…
  - …results in relatively large fluxes of Ca, Na, K, Mg, Si, etc.

→We need to use indirect methods to estimate fluxes of solutes from chemical weathering.

Catchment-Based Estimation of Chemical Weathering

- Watershed mass balances can be constructed for ions produced by chemical weathering:



$$W = S + B - P \pm E$$

W = Weathering

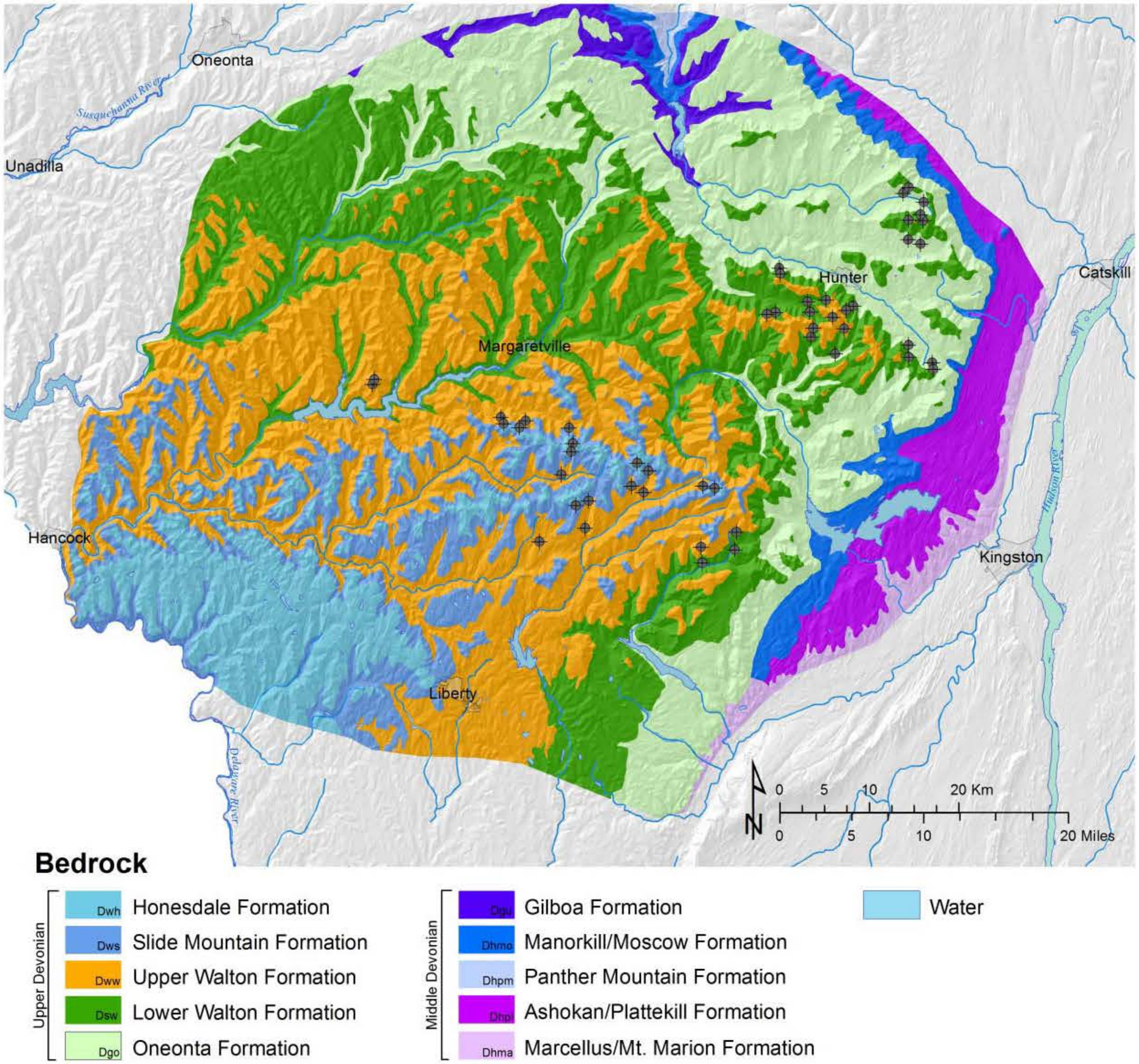
S = Stream Export

B = Net Biomass Uptake

P = Atmospheric Deposition

E = Net Cation Exchange

Catchment-Based Estimation of Chemical Weathering



Candidate Watersheds

(Ver Straeten, 2013)

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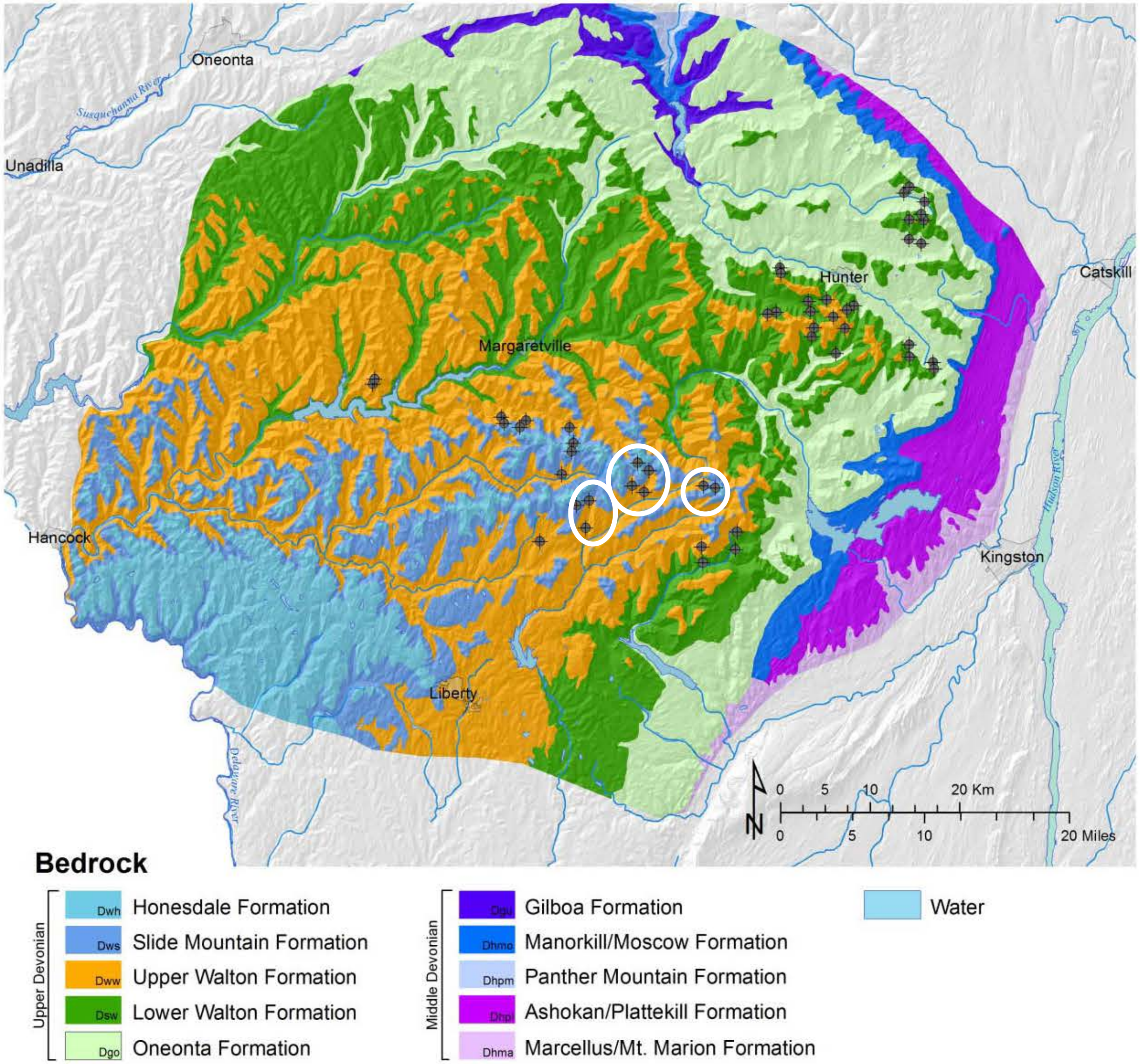
Catchment-Based Estimation of Chemical Weathering



Neversink Drainage:

- Winnisook
- Biscuit Brook
- Pigeon Brook
- Fall Brook

(Ver Straeten, 2013)

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Data Sources

- Precipitation Fluxes (P)
  - Biscuit Brook NADP site
    - For this analysis, no adjustments were made for elevation or aspect, though these are important (e.g., Weathers et al. 2000).
- Stream Fluxes (S)
  - Streamflow
    - USGS gages at Biscuit, Winnisook
    - Pigeon and Fall Brook estimated from Biscuit Brook data using watershed area ratio.
  - Monthly sampling for chemistry: 6/2010 - 7/2013
    - Flow-weighted average concentrations for July 1 – June 30 water years.

Input-Output Budgets: Biscuit Brook

Flux	Water Year		Si	Mg	Ca	Na	K	H
			---------------------------- mol/ha/yr ----------------------------					
Precip	2010-2011		0*	9	24	48	7.4	238
Stream			368	182	368	143	50	5.6
Biomass								
Exchange								
Net Release			**368**	**173**	**344**	**95**	**42**	-233
Flux	Water Year		Si	Mg	Ca	Na	K	H
			---------------------------- mol/ha/yr ----------------------------					
Precip	2011-2012		0*	9	27	36	5.2	205
Stream			336	157	260	135	45	6.5
Biomass								
Exchange								
Net Release			**336**	**148**	**233**	**99**	**40**	-198
Flux	Water Year		Si	Mg	Ca	Na	K	H
			---------------------------- mol/ha/yr ----------------------------					
Precip	2012-2013		0*	7	23	35	5.1	154
Stream			290	142	229	129	45	5.8
Biomass								
Exchange								
Net Release			**290**	**135**	**206**	**94**	**40**	-148

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Net Depletion from Soil Exchange Sites (E)

- Period: 1984-2001
  - O Horizon: Warby et al. (SSSAJ, 2009)
  - 0-10 cm Mineral: Tamargo & Johnson (unpublished data – Adirondack Region)
    - ΔCa = -43 mol ha^{-1} yr^{-1}
    - ΔMg = -9.5 mol ha^{-1} yr^{-1}
    - ΔK = +3.4 mol ha^{-1} yr^{-1}
    - ΔNa = 0

Soil Base Cation Depletion is a Small, but Meaningful, Flux

Biscuit Brook: 992 ha						
Flux	Si	Mg	Ca	Na	K	H
	---------------------------- mol/ha/yr ------------------------------					
Precip	0*	8.2	25	40	5.9	199
Stream	331	160	286	136	47	6.0
Biomass						
Exchange		-10	-43	0	3.4	
Weathering	**331**	**143**	**218**	**96**	**44**	-193

Fall Brook: 1263 ha						
Flux	Si	Mg	Ca	Na	K	H
	---------------------------- mol/ha/yr ------------------------------					
Precip	0*	8.2	25	40	5.9	199
Stream	374	191	496	225	71	8.1
Biomass						
Exchange		-10	-43	0	3.4	
Weathering	**374**	**174**	**428**	**185**	**68**	-191

Pigeon Brook: 706 ha						
Flux	Si	Mg	Ca	Na	K	H
	---------------------------- mol/ha/yr ------------------------------					
Precip	0*	8.2	25	40	5.9	199
Stream	336	150	377	135	46	4.5
Biomass						
Exchange		-10	-43	0	3.4	
Weathering	**336**	**132**	**309**	**95**	**44**	-195

Winnisook: 230 ha						
Flux	Si	Mg	Ca	Na	K	H
	---------------------------- mol/ha/yr ------------------------------					
Precip	0*	8.2	25	40	5.9	199
Stream	387	144	152	134	50	215
Biomass						
Exchange		-10	-43	0	3.4	
Weathering	**387**	**126**	**84**	**94**	**48**	16

Net Uptake/Release from Biomass (B)

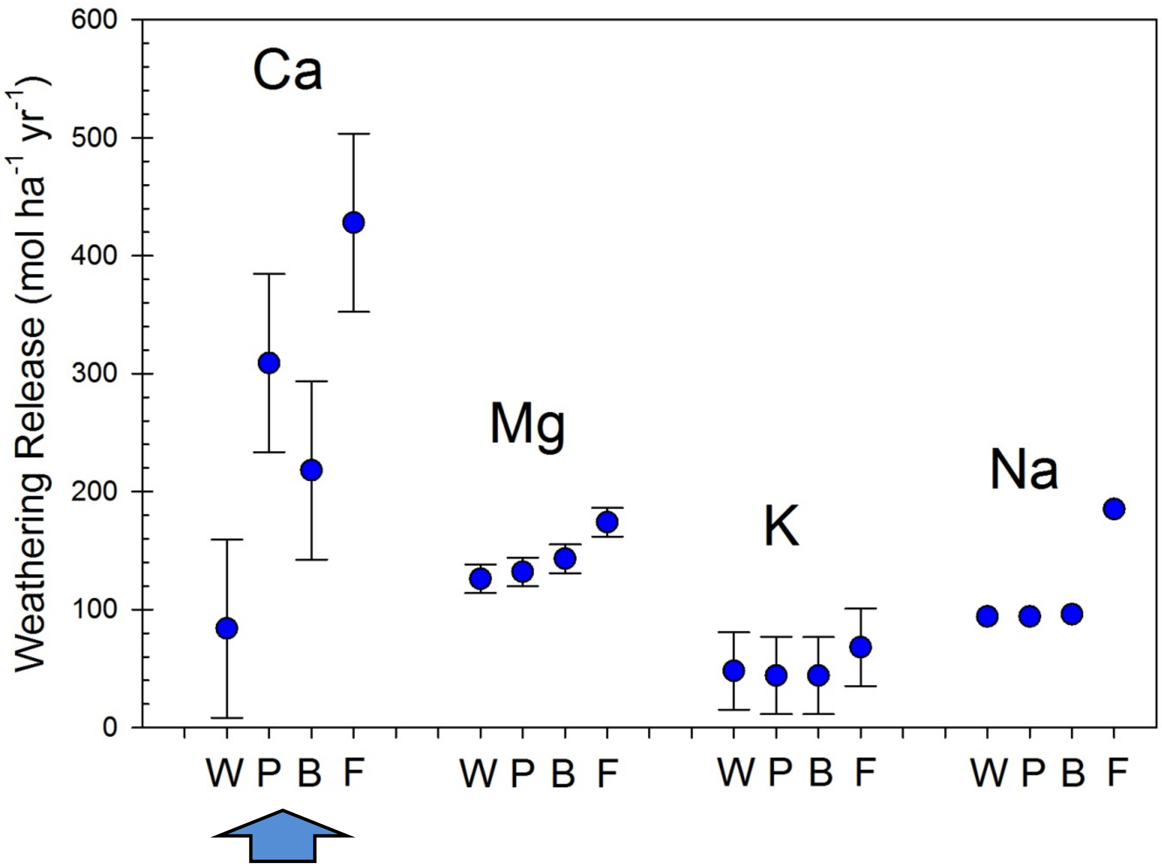
- FIA biomass estimates for Sullivan + Ulster + Greene:
  - -0.45% per year
- Layton abstract (this conference):
  - Most plots increased in diameter, basal area, volume between 2002/03 and 2012/13

Assumed range of ±0.45% yr^{-1}, Hubbard Brook, NH nutrient pools:

- ΔCa = ± 75.6 mol ha^{-1} yr^{-1}
- ΔMg = ± 12.1 mol ha^{-1} yr^{-1}
- ΔK = ± 32.8 mol ha^{-1} yr^{-1}
- ΔNa = 0

Effect of Vegetation Uptake on Weathering Estimates

Averages for 2010-2013 (3 Water Years)



Winnisook Pigeon Biscuit Fall Brook

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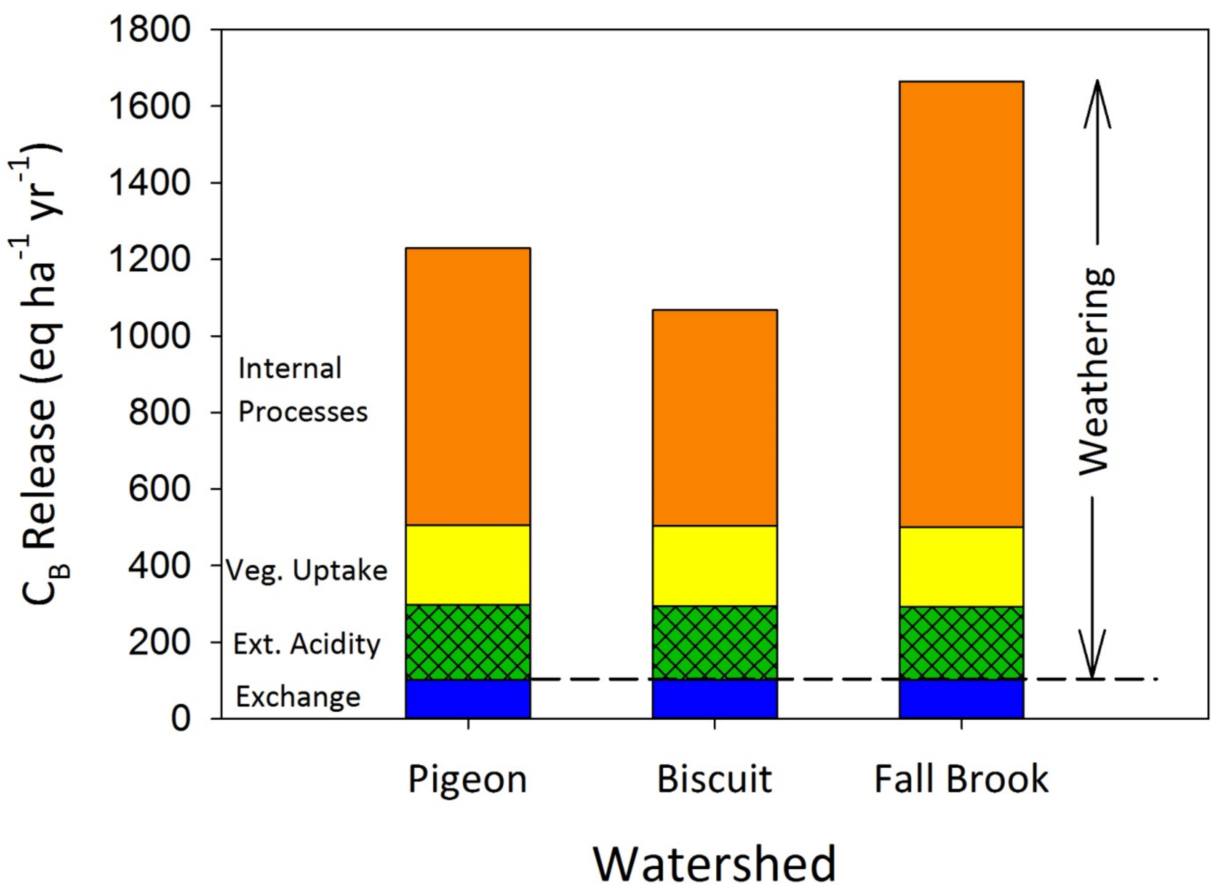
Mineral Sources

- Calcium: dolomite, smectite, (plagioclase?)
- Magnesium: chlorite, biotite, dolomite
- Potassium: muscovite, biotite, (oligoclase?)
- Sodium: ??? (plagioclase? ancient marine clays?)

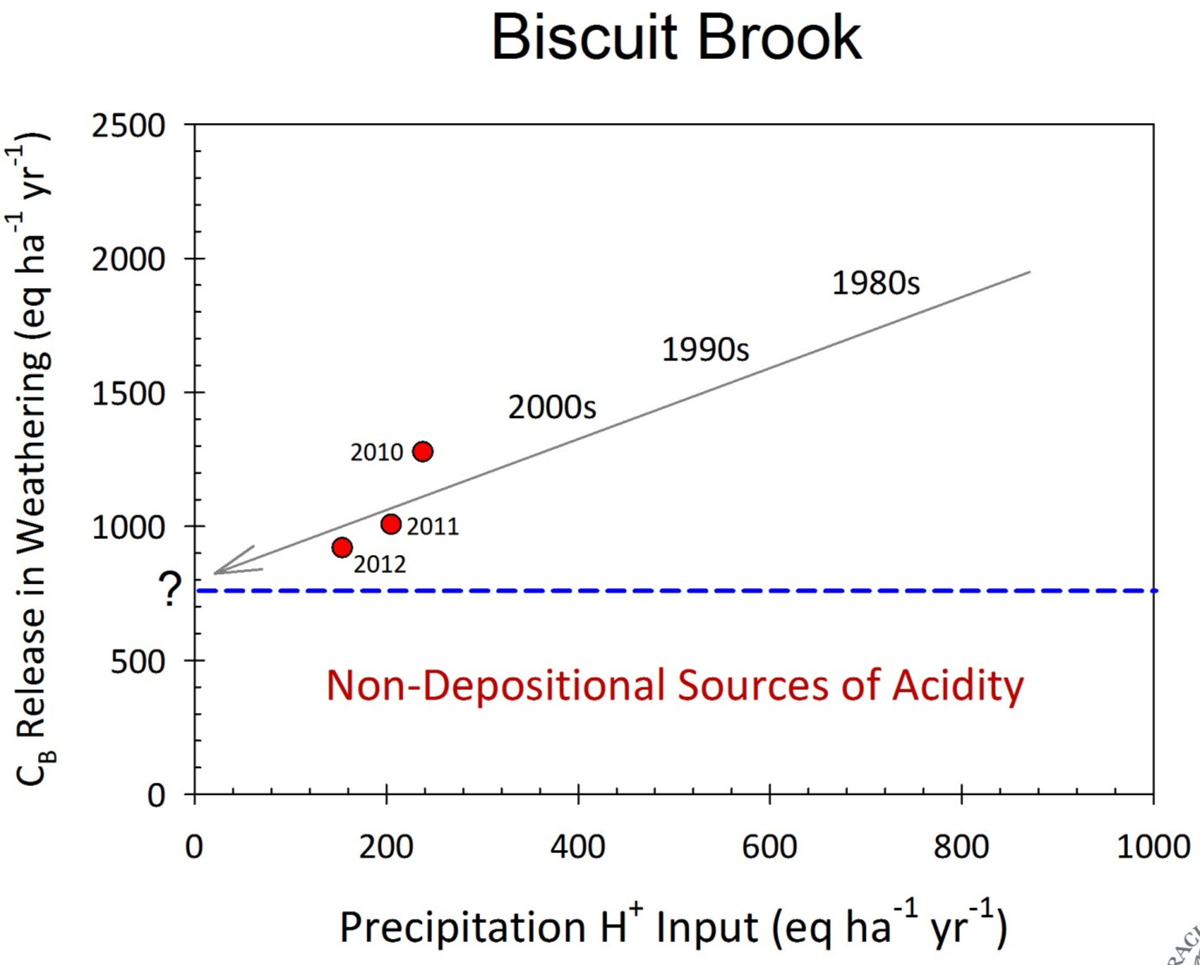
[Based on mineral chemistries in Ver Straeten, 2013]

Sources of Acidity for Weathering

Averages for 2010-2013 (3 Water Years)
(Aggrading Forest)



Towards Critical Loads



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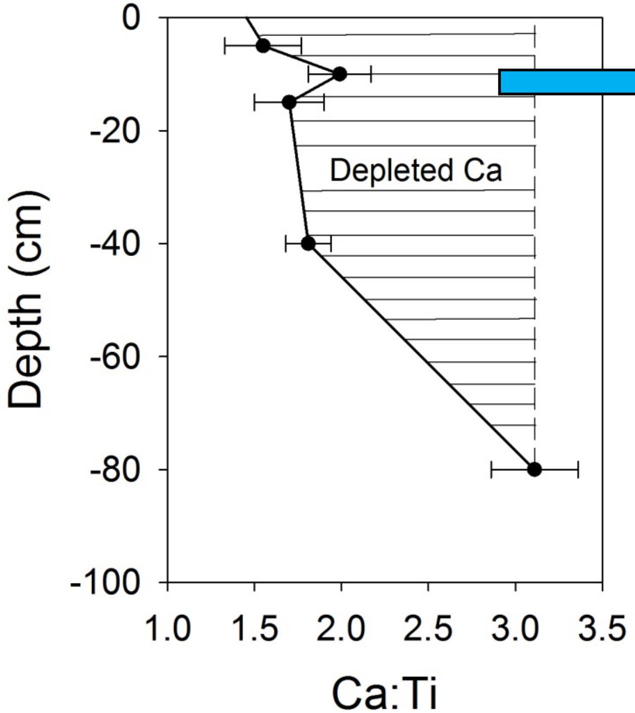
Other Approaches

- Modeling
  - PROFILE (and its offspring)
    - Requires bulk soil/parent material chemistry, climate data, precipitation chemistry.
    - Successfully applied in Europe, Canada, USA
    - Used for setting critical loads targets in Europe
- Element Depletion
  - Estimate loss of weathering products relative to an immobile element (e.g., Zr, Ti)

Element Depletion Analysis



ΔCa (g/kg) × ρ_b (kg/m^3) × Depth (m)

+ Unit Conversions

+ Adjustment for stone content

Summed for all layers/horizons:

1100 kg Ca/ha

Divided by time of soil formation (14 kyr):

80 g Ca/ha/yr

Unpublished data from Hubbard Brook, NH

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Conclusions/Data Gaps

- Net release of base cations in Catskills headwater catchments far exceeds external acid inputs.
- Depletion of cations from soil exchange sites and uptake by vegetation are potentially significant fluxes in the computation of weathering rates by mass balance analysis.
- Internal sources of acidity (e.g., CO_2 uptake, plant growth, nitrification, weathering of sulfides) account for most of the H^+ required to explain base cation release in weathering.
- Key Data Gaps:
  - Forest biomass/growth data
  - Tissue chemistry of predominant tree species
  - Mineralogic composition of soil and till
  - Bulk chemistry of complete soil profiles (incl. 'immobile' elements)

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