Linking geomorphology, weathering and soil cations in the Luquillo Mountains of Puerto Rico

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Almost always, the approach has been to isolate the effects of one by minimizing variation in the others.
What controls nutrient availability in the tropical forests of the Luquillo Mountains?

Nutrient availability = \( f (\text{Cl} \quad O \quad R \quad P \quad T) \)

We investigated the relative importance of several state factors at once.
What controls nutrient availability in the tropical forests of the Luquillo Mountains?

Sampling Design

24 Sub-watersheds

- 2 Parent Materials: quartz diorite (QD) and volcaniclastic (VC) (N=8)
- Three Forest Types: Colorado, Tabonuco, Palm (N = 8)
- Elevation 300-800 m
- 4 of each forest type at 500-700 m
- In each sub-watershed - 3 soil pits per ridge, slope and valley positions.
- 216 Soil Pits (3 depths/pit)
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Carbon stocks: Forest Type (even controlled for elevation)
   Soil C:N: Elevation (high elevation -> higher C:N)
   Soil $\delta^{15}N$ - Elevation (lower $\delta^{15}N$ at high elevation)

Labile P - Topographic position (higher down slope)
   Total P - Rock type (higher on VC)
   Topo position (higher downslope)

Mage and Porder, 2013, Johnson et al, in prep

C, N are driven by community/climate.
P by geology and geomorphology
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

H1: Like P, cations will be controlled by geology/geomorph

H2: rapid weathering means no differences across landscape

A great deal has been done on deep weathering and streams, but little work has been done on cations in soils
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Weathering is rapid on QD (White et al, 1995, Brown et al, 1885).

Most weathering on QD occurs at rock/saprolite interface (White 1995, Buss 2013) or around corestones (Fletcher + Brantley, 2010).

Regolith formation 30x faster on VC (Dosseto et 2012).

Solute fluxes from VC watersheds not 30x higher (Stallard, 2012).

Most of the landscape is not in equilibrium (Stallard, 2012).

Does this matter for the cation status of soils?
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

We missed a key landscape parameter in our sampling design.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

A regional knickpoint drives differences in denudation on QD.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Denudation rates vary by 2–4x across the knickpoint.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

We only have a few sites below the knickpoint.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Below the knickpoint, QD soils contain 16±4% feldspar.

Above the knickpoint, and on VC, feldspar near 0.

$^{87}\text{Sr}/^{86}\text{Sr} = 0.7065$ below the knickpoint (more rock Sr).

$^{87}\text{Sr}/^{86}\text{Sr} = 0.7085$ above the knickpoint (more atm. Sr).

Primary minerals are in soils below the knickpoint, not above or on VC.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Exch Ca Stocks (g m$^{-2}$, 0–80cm)

All Sites
- $n = 72$
- $Ca = 260 \pm 19$

VC, QD Above
- $n = 51$
- $Ca = 192 \pm 10$

QD Below
- $n = 21$
- $Ca = 430 \pm 43$

Colorado, Palm
- $n = 39$
- $Ca = 175 \pm 10$

Tabonuco
- $n = 12$
- $Ca = 247 \pm 23$

Denudation is the biggest driver of Ca Stocks
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Exch K Stocks (g m^{-2}, 0–80 cm)

All Sites
n = 72
K = 74 ± 19

39%

Colorado, Palm
n = 47
Ca = 53 ± 1.3

3%

Volcaniclastic
n = 39
Ca = 175 ± 10

Quartz Diorite
n = 12
Ca = 247 ± 23

Tabonuco
n = 24
Ca = 74 ± 2.8

Forest type is the biggest driver of K stocks
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Exch. cation stocks depend on the supply of primary minerals.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Cation loss relative to parent material (0-80cm)

All Sites
n = 48
\( T_{Ca}, T_{Mg}, T_{K} = -0.94, -0.86, -0.82 \)
SE = ± 0.12, 0.03, 0.03

33,49,36%

VC
n = 27
\( T_{Ca}, T_{Mg}, T_{K} = -1, -0.97, -0.92 \)
SE = ± 0.00, 0.01, 0.02

18,10,17%

QD
n = 21
\( T_{Ca}, T_{Mg}, T_{K} = -0.86, -0.71, -0.68 \)
SE = ± 0.14, 0.04,

A
Below Knickpoint
n = 12
\( T_{Ca}, T_{Mg}, T_{K} = -0.80, -0.64, -0.56 \)
SE = ± 0.05, 0.06, 0.08

B
Above Knickpoint
n = 9
\( T_{Ca}, T_{Mg}, T_{K} = -0.95, -0.81, -0.83 \)
SE = ± 0.02, 0.05, 0.03

Denudation (and maybe lithology) controls depletion of soil elements relative to parent rock.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Our study was not built around differences in denudation... but maybe it should have been.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Control for rock type, forest type, elevation. Vary denudation rate.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Control for rock type, forest type, elevation.
Vary denudation rate.
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Control for rock type, forest type, elevation. Vary denudation rate (width for now).
What controls soil cation stocks and loss in the tropical forests of the Luquillo Mountains?

Soil element loss varies with denudation rate. Nutrients do not.
What controls nutrient availability in the tropical forests of the Luquillo Mountains?

Rapid weathering EYNF does not result in universally weathered soils.

Geomorphic disequilibrium drives difference in weathering and in nutrients at the landscape scale.

Geomorphic disequilibrium may drive weathering and ecosystem differences in many tropical landscapes.

Conclusions
What controls nutrient availability in the tropical forests of the Luquillo Mountains?

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