How critical zone processes, water balances, and mass fluxes differ in landscapes with contrasting lithology but similar climatic and environmental histories

How to “Critical Zone Processes” Vary with Bedrock Lithology?

7 General Hypothesis
saprolite --- surface soils --- hillslopes/riparian zones --- transport & fluvial processes
How Critical Zone Processes vary with bedrock lithology?

4 Lithologies X 4 Forest Types

Rainfall

Runoff

r² = 0.90

r² = 0.77

How deep is the CZ?

How Critical Zone Processes vary with bedrock lithology?
“An end-member site”
In CZO network

Subtropical Dry to Wet life Zones

1000 mm/yr PET > Rainfall

5000 mm/yr Wetlands
“An end-member site”
In CZO network

Steepest Gradients
\( \frac{dh}{dl} \sim 1000 \text{ m over } 6\text{ km} \)
Rainfall \( \sim +235 \text{ mm/yr/100 m} \)
Runoff \( \sim +400 \text{ mm/yr/100 m} \)
Critical Zone Exploration Network

Biology
“Highest Woody Plant Diversity”

Disturbance
50 yr RI for direct hurricane impacts
Landslides RI ~ 1-2 years

Lithology
??

Time
Eocene, no glaciations, oldest surfaces ??
Long-term environmental records
“Old on the inside young on the outside”
Urban site with long environmental time series
Who we are…
USGS-WEBB + USFS-IITF + LUQ-LTER

• Executive Committee
  – Scatena-Brantley-Buss & White
  – Hypothesis leaders: Brantley, Silver, McDowell, Jerolmack, Shanley

• Advisory Committee
  – Larsen, Gaillardet, Lugo….

• Data Management Committee
  – McDowell, Scatena, UPenn employee

• Education Committee
  – Silver, Johnson, Shanley
Institutional Affiliations

- **USGS & USFS**
  - White, Buss, Shanley, Scholl, IITF…
- **Penn State**
  - Brantley, White, Fletcher
- **UPenn**
  - Scatena, Johnson, Jerolmack, Plante, Horton, Willenbring
- **UNH**: McDowell
- **UCB**: Silver
- **Collaborators**
  - Kurtz: BU
  - Heimsath: ASU..
  - Mayol: UPR
  - Porder: Brown
  - J. Pett-Ridge OSU
Institutional Links

• Other CZO’s
  – Brantley, Willenbring, Plante

• LTER
  – Scatena, Silver, McDowell

• NEON/STREON
  – IITF, Lugo, McDowell

• San Juan ULTRA
  – IITF, Lugo, Scatena
Hypothesis 1: The rate of saprolite advance varies with regolith thickness and landscape position and is fastest in GD valleys and slowest on VC ridges. Over large areas, the rate of saprolite advance will equal the rate of denudation and can be predicted from bedrock chemistry, porefluids, and physical rock properties (Brantley, Buss, White, Heimsath, Willenbring,).

Hypothesis 2: In surface soils, chemical transformations of atmospheric inputs are decoupled from bedrock lithology and influenced by soil carbon, surface redox, and plant nutrient cycling. Biotic influences on soil biogeochemistry decrease with storm intensity and soil depth and are greatest in surface soils of the VC during low intensity rainfalls (Johnson, Shanley, Silver, Scatena, UPR).

Hypothesis 3: The residence time and routing of water varies with bedrock lithology and will be longest in areas underlain by the GD and shortest in areas underlain by VC. However these differences will decrease with storm intensity and duration (Scholl, Scatena, Shanley, McDowell).

Hypothesis 4: Over seasonal time scales, iron reduction and related CO2 production will be greatest in VC surface soils and lowest at depth on stable GD ridge tops. Over large areas and longer time scales deep weathering rates and surface soils properties are closely linked to the frequency of low redox events and the magnitude of iron reduction (Silver, Brantley, Plante).

Hypothesis 5: The morphology, and soil biogeochemistry of riparian and colluvial deposits varies systematically with lithology and in a downstream direction, while their vegetation and soil organic matter chemistry varies systematically with rainfall and temperature (McDowell, Plante, Silver, Scatena, Jerolmack).

Hypothesis 6: Sediment supply and transport within the stream channel network is dominated by surface erosion associated with rainfalls of moderate intensity in the VC and landslides associated with high intensity events in the GD (Jerolmack, Horton, Willenbring, Scatena, Shanley).

Hypothesis 7: The depositional environments of coastal and fluvial sediments draining the GD will have a higher resolution record of climatic disturbances and land use changes than corresponding environments in the VC (Horton, Willenbring, Jerolmack, Heimsath, Scatena).
Sediment & solute inputs to channel network

Atmospheric inputs
Weather stations

Soils & Vegetation

Bedrock lithology & Weathering
Deep Nodes

Hillslopes Catena’s

H3, H5
Sediment & solute Inputs to channel network

Soil & Vegetation
Johnson, Silver
Plante, Silver
Scatena

Nutrient cycling
Kurtz, Johnson,
McDowell, Scatena, Silver

Channel Network & Transport

Aquatic nodes X-sections,
H5, H6

Fluvial & Coastal Depositional Environments

Streams;
Jerroloamack, McDowell,
Scatena, Shanley

Dating & Isotopes
Scholl, Willenbring,
Hemistath, Shroud

Atmospheric inputs
USFS & USGS,
Scholl, Shanley
Silver, Scatena
Mayol & UPR
J. Pett-Ridge OSU

Weathering;
Brantley, White,
Buss, Fletcher
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<tr>
<th>Node</th>
<th>Infrastructure and Measurements</th>
<th>Volcaniclastic (Bisley/Mameyes)</th>
<th>Granodiorite (Guaba/Blanco)</th>
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<td><strong>Soil and Deep Weathering Nodes (Terrestrial Nodes)</strong></td>
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<td>Deep Weathering (Brantley)</td>
<td>Surface to bedrock lysimeters, tensiometers, &amp; gas samplers. Periodic &amp; event sampling, XRF, mineralogy, archived soils</td>
<td>Bisley Ridge (N1) Bisley Slope (N2) Bisley Riparian (N3)</td>
<td>Guaba Ridge (U1) Guaba Slope (U2) Icacos (N2)</td>
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<tr>
<td>Soil &amp; Redox (Johnson) (Silver)</td>
<td>Quantitative pits &amp; bore holes. SOM, total and extractable nutrients, X-ray, grainsize, hydrologic properties. Surface to bedrock Apogee oxygen sensors, trace gas, H2O content, samplers, Multiple quantitative soil pits at the intensive research sites and throughout the Luquillo Mountains, stratified by climate, bedrock, and land cover (N1-5)</td>
<td>Bisley Ridge (N1) Bisley Slope (N2) Bisley Riparian (N3)</td>
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<td><strong>Aquatic Sampling Nodes</strong></td>
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<td>Fluvial (Jerlomack, Scatena McDowell Shanley)</td>
<td>Upgrade gages with permanent cross-sections (U1,2), bedload transport estimates (U1-3), Be10 denudation rates (N2-5) expand water sampling (U1), sensors for conductivity &amp; temp (N1,2)</td>
<td>USGS 655 (U1) USGS 660 (E) USGS 670 (E)</td>
<td>Icacos USGS 750 Guaba USGS 749 Rio Blanco USGS</td>
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<tr>
<td>Riparian (McDowell)</td>
<td>Piezometers, tensiometers, lysimeters &amp; gas samplers, Periodic &amp; event sampling</td>
<td>Bisley (U1,2) Multiple sites along R. Mameyes</td>
<td>Icacos (U1,2) Multiple sites along R. Blanco</td>
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<tr>
<td>Coastal (Horton)</td>
<td>Short cores and surface samples</td>
<td>Mameyes estuary and coastal zone</td>
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<td><strong>Atmospheric Sampling Nodes</strong></td>
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<tr>
<td>Atmospheric Climate Stations (E) (Shanley, Scholl, UPR)</td>
<td>Hourly &amp; daily climate (precip, temp., radiation, RH, wind, soil moisture etc.) Periodic &amp; event sampling of chemistry, stable isotopes</td>
<td>Upgrade and standardize existing network supported by USGS WEBB, USFS IITF, and UCB at Icacos, Bisley and Sabana. Isotope samplers will be established as needed.</td>
<td></td>
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</tbody>
</table>
Time Line

• **Annual Meetings in Late May**
  – Jan/10 meeting
  – Web seminars; multi-institutional courses
  – AGU, Goldschmidt, Luq-LTER meetings

• **Nodes**
  – Year 1 & 2; upgrades & integrations, deep well

• **Data & synthesis**
  – Joint synthesis publication in Y5
What will be Transformative??

ideas, discoveries, or tools that radically change our understanding
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ideas, discoveries, or tools that radically change our understanding

• Bedrock is important
  – Nutrient cycling, forest distributions
  – Bedrock vs dust vs biology
What will be Transformative ??

ideas, discoveries, or tools that radically change our understanding

• Bedrock is important
• Boulders are important!
What will be Transformative ??

ideas, discoveries, or tools that radically change our understanding

• Bedrock is important
• Boulders are important..
• Dating and landscape and landform age
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• Sample design
What will be Transformative ??

ideas, discoveries, or tools that radically change our understanding

• Bedrock is important
• Boulders are important..
• Dating and landscape and landform age
• Sample design
• It’s not just hurricanes!
SOM

Hurricane
Dominated
110 yr

Gap and slide
Dominated
40 yr

Stable Ridge Tops – Dynamic valleys
Landslide and uproots everywhere
Rapid turnover in top 50-100 cm

TPI  ~ 39%
TPI + Age + Depth ~ 60%
Vegetation type  ~ 8%

Surface
Saprolite
Bedrock

Saprolite thickness // channel

Bisley Soils
Luquillo Critical Zone Observatory
Upper & lower limits to Cumulus cloud formation
500m to 2000 m

2000 m ~ upper Cumulus limit

1000 m

~ 500 m ~ lower Cumulus limit
Cation Flux in Rainfall and Throughfall
Elevation and CZEN Processes
Forest Types, NPP, Decomposition & SOM, Landslides, bioturbation...

SOC

Earthworms

Elevation

Cloud

Coast

Forest types