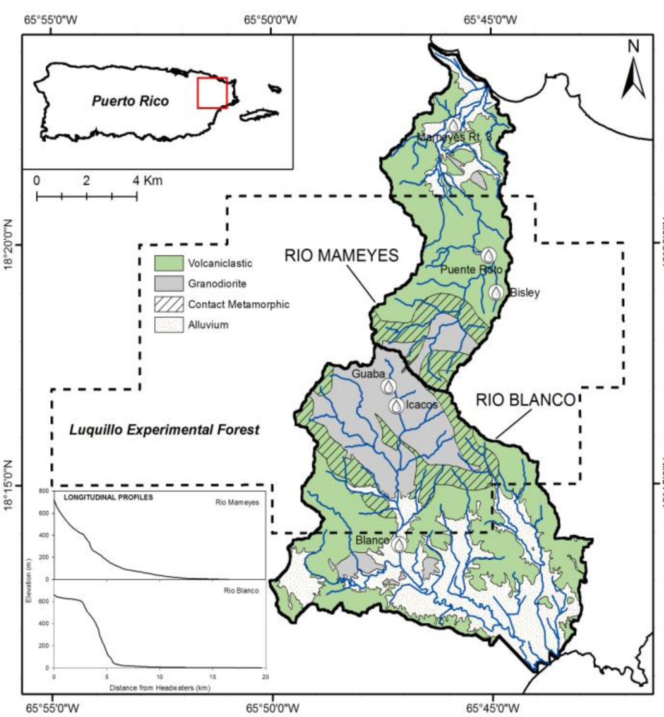
Luquillo Critical Zone Observatory
Overview
December 11, 2009

How critical zone processes, water balances, and mass fluxes differ in landscapes with contrasting lithology but similar climatic and environmental histories is the overarching focus of the Luquillo Critical Zone Observatory (LCZO). Although bedrock lithology and chemistry have been considered primary state factors in landscape and soil development for over a century, the influences of lithology on denudation, hydrologic routing, and geochemical processing is poorly constrained in most studies. To address this challenge the LCZO will use the natural laboratory of the Luquillo Mountains to quantify and contrast how critical zone processes in watersheds underlain by granodiorite (GD) and volcaniclastic (VC) bedrock are coupled and decoupled with climatic conditions and hydrologic, geochemical and biogeochemical cycles (Figure 1). A set of interrelated hypothesis (Figure 2, Table 1), sampling sites (Table 2) and a unified data management system will allow critical zone processes to be contrasted by bedrock (GD, VC), landscape position (ridge, hillslope, riparian), depth (surface to bedrock), forest type (Tabonuco, Colorado, Cloud) and location (upland to coastal).

Figure 1; Luquillo Critical Zone focus watersheds



Short term responses (e.g. days to seasons) to be investigated include the influence of lithology on biogeochemical responses to storms and droughts, and the influence of lithology on hydrologic routing and watershed scale hydrologic budgets. Recent research indicates there are greater seasonal variations in the chemistry of atmospheric inputs and soils processes than previously expected (Heartsill et al 2007, Shanley 2008, Scholl in press). These responses will be quantified using an improved network of weather stations, nested stream gages and multi-investigator event sampling campaigns. Basin responses at intermediate time scales (e.g. decades to centuries) will be evaluated by quantifying stream channel dynamics and the depositional records in floodplains and coastal zones. The long-term influences of lithology on sediment generation, hillslope and landscape development will be evaluated in studies of bedrock weathering rates and rates of saprolite and soil formation.

Figure 2: Conceptual framework and relationships between the hypothesis and sampling nodes for the Luquillo Critical Zone Observatory. Infrastructure is in red while hypothesis are in green.

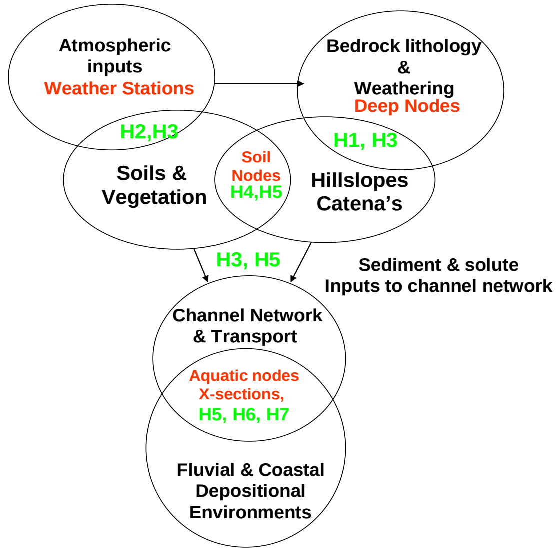


Table 1: Guiding Hypothesis for the Luquillo Critical Zone Observatory

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 CO_2 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).

Observatory infrastructure and sampling design

The LCZO infrastructure, sampling strategy, and integrated data management system are designed to provide a platform whereby collaborators can put geochemistry and biogeochemistry into a geomorphic and hydrologic perspective. The basic infrastructure of the LCZO will be an integrated set of sampling sites (e.g. nodes in Table 2). These sampling sites will build upon existing study sites that have long-term and ongoing records of rainfall, throughfall, litterfall, and streamflow (Schellekens et al 2004, Peters et al 2006, Heartsill et al 2007, Wei et al 2007). Atmospheric sampling nodes will consist of 8 weather stations and an additional 8 rain gages that will monitor climatic and geochemical inputs to the different lithologies and forest types across a precipitation gradient that ranges from 1000 mm/yr to 5000 mm/yr. Atmospheric inputs will be monitored at existing climate stations that are maintained by the USGS, the USFS, and UC Berkeley. Although these stations cover the entire matrix of elevation, lithology, and forest types, most of these stations were established with previous funding that no longer exists. Furthermore, while most of the sites have been partly maintained on a volunteer basis they are outdated and do not collect a full array of comparable data. LCZO will take advantage of this disarray by upgrading and standardizing the stations and integrating them into a common data management system. When these stations are upgraded, calibrated, and integrated into a network, the LCZO will be able, for the first time, to constrain variations in precipitation along the elevation gradient and thereby greatly improve water budgets for the individual study basins.

Soil and deep weathering nodes will consist of monitored hillslope catena's underlain by VC and GD lithologies (Table 2). Soil and regolith water and gas samples will be sampled using suction samplers installed according to our previous studies and CZEN standards (see http://www.sas.upenn.edu/lczo/ and CZEN.ORG). Quantitative soil pits will be sampled at each of the intensive sampling sites and across lithologic, climatic and vegetation gradients. Analysis of C02 gas fluxes by W. Silver of UC Berkeley, and analysis of soil carbon stability by A. Plante of UPenn will also allow us to develop complete watershed level carbon budgets for the first time. This integrated sampling design combined with reactive transport modeling, isotope tracer studies, and cosmosgenic dating will allow us to place these weathering and pedologic studies into a geomorphological and ecological framework.

Aquatic nodes of the observatory will focus on quantifying the fluxes of water, sediment, and solutes from the basin and how they are transformed as they move from pore spaces in the lithologic matrix to the coastal zone. These nodes will include 8 stream gages and numerous georeferenced cross-sections and riparian sampling sites. A major limitation to previous studies has been the ability to monitor storm events and temporal variations in exports. To overcome this limitation, the LCZO will add sensors to the existing stream gages to obtain continuous records of conductivity, and temperature. LCZO housing facilities for researchers will also facilitate coordinated sampling campaigns and allow for event based studies that are not currently possible.

Water chemistry will be sampled weekly and on a campaign basis and will be processed at the USGS WEBB laboratories and at the University of New Hampshire. While the water chemistry at most of the proposed aquatic sampling nodes has been sampled before, sampling frequency has been erratic and the actual data is stored in different ways and at different institutions. The LCZO will ameliorate this situation by providing a centralized data management archive where researchers can access existing data and share the new data they collect.

The pasture work proposed in the original proposal will be postponed indefinitely and replaced by a project that will compare the coastal zone response of the two basins to storms and recent environmental change. Although the environmental and land use history of the Luquillo Mountain is well known (Scatena et al in press, Wei et al 2007), the environmental history recorded in coastal sediments and floodplains is not. Dr. B. Horton of UPENN has been asked to address this information gap and link this effort to his existing research in the coastal zones of the Caribbean and the mid-Atlantic. This effort will quantify how coastal sediments from the 2 basins have recorded and responded to storms and environmental change. The research will use micro-fossil and stratigraphic indicators from shallow sediment cores taken in the coastal zones of both rivers. The environmental histories developed in the coastal zone will then be compared to the historical record and the geologic recorded in upland floodplains and landscapes.

Site Management:

The LCZO will be managed via subcontracts administered through the University of Pennsylvania. While PI's will be responsible for their own research component, daily management will be the responsibility of F.N. Scatena and a local site manager employed by UPenn. The hiring of a full time data manager based at UPENN, and a site manager/field technician who will be based in Puerto Rico will begin immediately.

Technical and administrative oversight will be provided by an Executive Management Team (Scatena, Brantley, White). This committee will have monthly conference calls and met as needed to review annual reports of the Co-PI's, evaluate staff performance, plan annual meetings, and work to insure the group is progressing and integrating. Each hypothesis also has a leader (marked in bold in Table 1) who is responsible for organizing synthesis activities and reporting on the progress of the hypothesis. An Education and Outreach committee (Silver, Plante, and others) and Data Management Committee (Scatena, Miller, McDowell, Data and web manager) will oversee those components of the project.

The LCZO will hold annual meetings in Puerto Rico during the first week of June where researchers will report on their progress and archive data and samples collected in the previous year. An External Advisory Committee will be invited to these meetings to critique our progress and provide technical advice. These senior-level individuals (Larsen, Gaillardet, Lugo) have worked in the area and/or on similar problems and have agreed to advise the group. Funds have also been allocated to allow potential collaborators and outreach groups to participate in these annual meetings. The first face-to-face meeting is planned for early January 2010 where sampling, data management protocols and synthesis activities will be refined.

In addition to the annual meeting, web-based organizational conferences will begin as soon as funds are available. Monthly web seminars will also be held throughout the academic year where Co-PI's and students will be required to share their results. These seminars are currently being held as part of the LCZO seed money project and have been attended by approximately 10 individuals per seminar. In the later years of the project, it is expected that these web seminars will be incorporated into courses and seminars at the various institutions. Additional hypothesis-based meetings and meetings at AGU and similar conferences will also be held when needed and convenient.

Data and Information Management:

The information management system of the LCZO will be dedicated to preserving and distributing high quality data that can be used in cross-site comparisons and predictive modeling. Our data management philosophy is also based on the premise that the best form of data management involves data that has been synthesized in peer reviewed journals and made widely available online. To accomplish this, a full time data manager will be hired and a central LCZO website will be maintained at UPenn. This site will be a central portal for the site and will be link to the National CZO Portal. The primary focus of the LCZO data manager, who will be supervised directly by Scatena, will be to establish a central data system to archive and manage Luquillo CZO data, compile existing data, and develop a quality control system that evaluates and manages the data collected from terrestrial, aquatic, and atmospheric sensors.

Synthesis and cross-site activities:

A major goal of the LCZO will be to promote synthesis within the geosciences and between the various institutions and students involved with the project. While the focus and study areas of the LCZO are distinct to that of the Luquillo LTER and Puerto Rico NEON site, there will be ample opportunities to collaborate with those groups. Likewise, LCZO members already have unfunded and informal collaborations with the proposed Delaware CZO and various LTER sites in the study of carbon dynamics and quality (Plante, Silver, McDowell, Stroud Water Resource Center and others) and with the coastal site Delaware (Horton) as well as with an investigation of granite weathering with C. Rasmussen (Arizona CZO). The fact that part of the Luquillo site is also underlain by granodiorite thus provides opportunities for geochemical comparisons between existing and proposed CZO sites.

Contact Information:

Luquillo-CZO@sas.upenn.edu
Luquillo Critical Zone Observatory
Department of Earth and Environmental Science
University of Pennsylvania
http://www.sas.upenn.edu/lczo

Table 2. Planned location of infrastructure and measurements proposed for the Luquillo Critical Zone Observatory. Ex = existing, no upgrade required, Ux = upgrade of existing infrastructure required, Nx = new installations, x = year of planned upgrade or installation.

Sampling Node (Principal)	**Infrastructure and Measurements**	**Volcaniclastic** (Bisley/Mameyes)	**Granodiorite** (Guaba/Icacos/Rio Blanco)
Soil and Deep Weathering Nodes			
Deep Weathering (Brantley)	Surface to bedrock lysimeters, tensiometers, & gas samplers. Periodic & event sampling, XRF, mineralogy, archived soils	Bisley Ridge (N1) Bisley Slope (N2) Bisley Riparian (N3)	Guaba Ridge (U1) Guaba Slope (U2) Icacos Riparian (N2)
Redox (Silver)	Surface to bedrock Apogee oxygen sensors, trace gas, H_20 content, samplers,	Bisley Ridge (N1) Bisley Slope (N2) Bisley Riparian (N3)	Guaba Ridge (U1) Guaba Slope (U1) Icacos Riparian (N2)
Soil (Johnson)	Quantitative pits & bore holes, SOM, total and extractable nutrients, X-ray, grainsize, hydrologic properties	Multiple quantitative soil pits at the intensive research sites and throughout the Luquillo Mountains, stratified by climate, bedrock, and land cover (N1-5)	
Aquatic Sampling Nodes			
Fluvial (Jerlomack, Scatena McDowell Shanley)	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 & temp (N1,2)	USGS 655 (U1) Bisley Q1-3 (U2) USGS 660 (E) USGS 670 (E)	Icacos USGS 750 (U1) Guaba USGS 749 (U2) Rio Blanco USGS (E)
Riparian (McDowell)	Piezometers, tensiometers, lysimeters & gas samplers, Periodic & event sampling	Bisley (U1,2) Multiple sites along R. Mameyes	Icacos (U1,2) Multiple sites along R. Blanco
Coastal (Horton)	Short cores and surface samples	Mameyes estuary and coastal zone	Rio Blanco estuary and coastal zone
Atmospheric Sampling Nodes			
Atmospheric Climate Stations (E) (Shanley, Scholl, UPR)	Hourly & daily climate (precip, temp., radiation, RH, wind, soil moisture etc,) Periodic & event sampling of chemistry, stable isotopes	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. 8 stations and 8 rain gages will be operational	
Data Management (Scatena)	Web site at UPENN (http://www.sas.upenn.edu/lczo/) will provide the portal to all LCZO activities. Data will be managed by an integrated data management system that is linked to National CZO portal.		

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