Critical research

Professor Donald L Sparks and **Drs Anthony Aufdenkampe** and **Lou Kaplan** reveal the progress their cutting-edge project is making on understanding the complex interactions within the Earth's critical zone

Firstly, could you offer an insight into the background of this project and its overall goals?

The Christina River Basin – Critical Zone Observatory (CRB-CZO) is one of six environmental observatories supported by the U.S. National Science Foundation focusing on how water, atmosphere, ecosystems and soils interact and shape the Earth's surface. The critical zone is the Earth's porous near-surface layer, and incorporates everything from the tops of the trees to the deepest groundwater.

The CRB-CZO has the overarching goal of 'integrating the feedbacks between the water cycle, the mineral cycle and the carbon cycle as materials are transported across geophysical boundaries from soils to sea'. We ask whether:

- Processes that mix minerals and carbon are rate limiting to watershed-scale carbon sequestration, chemical weathering and soil production?
- Humans accelerate rates of carbon-mineral mixing and does this result in anthropogenic carbon sequestration significant to local, regional and global budgets?

The Christina River Basin has been studied extensively in the past. How does your research extend beyond work already carried out in this region?

We are performing scientific investigations with a level of disciplinary integration that goes well beyond anything previously carried out. We are bringing cutting-edge, innovative methodologies from each of the individual scientific disciplines involved to bear on our research questions, exploiting recent advances in open source sensor networking hardware to vastly extend the temporal and spatial coverage of our investigations, and using new cyber infrastructure to share data at an unprecedented level.

In what ways is this Critical Zone Observatory (CZO) and associated research unique from the other five CZOs that form the National Critical Zone Observatory Program?

Humans have emerged as a major geological force on the Earth's surface. The CRB-CZO is the only CZO with an explicit focus on anthropogenic alterations of the critical zone. Other strengths of the CRB-CZO, although not necessarily unique, include a connection to the coastal zone, a focus on watershed-scale greenhouse gas budgets, and active development of a wireless sensor network based on powerful, low-cost and easy to use open source electronics.

Have you forged relationships with these other CZOs and/or those CZOs beyond U.S. borders?

Absolutely – we participate in monthly discussions with principal investigators from all of the CZOs; moreover, the CZOs have an annual meeting that brings together all researchers to discuss their scientific progress, and many individuals on our team have developed research collaborations with scientists from other CZOs. We were also quite excited to recently co-host critical zone scientists from around the world for a workshop on the Design of International CZO Networks in collaboration with SoilTrEC, a European-based effort similar to the CZOs.

How has the project benefited from its collaboration with the University of Delaware (UD) and the Stroud Water Research Center (SWRC)?

Both institutions have greatly benefited from partnering on the CRB-CZO, and we expect these benefits to increase. Many scientists from other institutions have already approached us to collaborate because they see substantial added value to performing their research within the field sites and activities of a CZO. The vision that each CZO would serve as a national and international focal point and resource for integrated Earth surface sciences is already materialising.

The project is still in the first half of its funding period. Are you satisfied with its progress to date? What have been the highlights during these first two years of CRB-CZO's existence?

We are making excellent progress on our project. During the first half of the project we have hired some outstanding graduate students and postdocs and forged some exciting and meaningful collaborations. A strong network of team members is in place, we have identified excellent field sites, installed an extensive sensor network that is continuing to expand, added important sampling infrastructure, and established an effective data gathering and management plan.

Are there plans for making the project's results available to policy makers and the public?

We frequently present to, and conduct interviews with, various groups including state agencies, nature conservancies, nature centres, retired faculty and various layperson groups. Specifically, we are building collaborations between research scientists and members of the Christina River Basin Task Force, who are overseeing efforts to preserve the watershed and its water quality for the c. 1 million people who rely on it for drinking water. We are also developing a self-explanatory web portal for the public to visualise our data and models, to understand our results and to share their observations and thoughts (www.wikiwatershed.org).

Original **observations**

The Christina River Basin – Critical Zone Observatory is leading U.S. research into the effects of human impact upon the mineral cycle and its possible effects on carbon sequestration in the Earth's critical zone

THE EARTH'S CRITICAL zone is the area situated between the lithosphere and the atmosphere; a living, constantly evolving boundary layer where water, atmosphere, ecosystems, and soils interact. It is essential to life on our planet; the complex interactions in the critical zone regulate the natural habitat and determine the availability of life sustaining resources, including food production and water quality.

Despite the critical zone's importance to terrestrial life, it remains poorly understood: questions remain surrounding how it functions, and how it will change in the future. More specifically, too little is known about how physical, chemical, and biological processes in the critical zone are related and at what spatial and temporal scales.

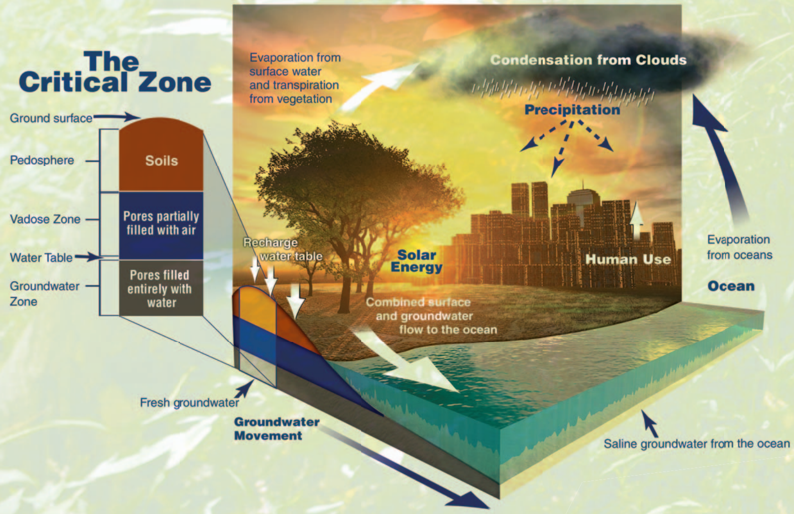
Humans have also had a major geological impact on the critical zone. Throughout much of the world, sub-soils are being exposed by aggressive suburban expansions and underground minerals are being excavated and mixed into this chemically and biologically reactive zone. Together with the increasing atmospheric CO_2 level, engineered soil landscapes present scientists with the largest Earth-scale experiment to date. Despite the increasing awareness from diverse disciplines that mineralogy and weathering have a significant bearing upon carbon cycle and storage, the impact of the human accelerated mineral cycle on the carbon flux between lands and the atmosphere remains virtually unknown.

CRITICAL ZONE OBSERVATORIES

In the U.S., six environmental laboratories called Critical Zone Observatories (CZOs) have been established to help determine how the critical zone operates and evolves – including a predictive ability for how it will respond to projected changes in climate and land use. Funded by the National Science Foundation, the CZOs work together on overarching shared goals, but each observatory also focuses on aspects of critical zone science that fit the strengths of its investigators and its physical setting. Each CZO consists of a series of field sites within a watershed-scale field area. The sites are instrumented for a variety of hydrogeochemical measurements as well as sampled for soil, canopy and bedrock materials.

The Christina River Basin Critical Zone Observatory (CRB-CZO) was established in 2009, specifically to study mineral and carbon cycles in order to quantify the human impact upon critical zone carbon sequestration. Led by Dr Donald L Sparks, the project team at the CRB-CZO is comprised of scientists from the University of Delaware and Stroud Water Research Center (SWRC), who specialise in a diverse range of disciplines: soil science, geochemistry, geomorphology, ecology, hydrology, ecohydrology, environmental engineering, microbiology, biogeochemistry, isotope geochemistry, GIS, and modelling.

CRB-CZO is situated within the 1,440 km^2 Christina River watershed in South East Pennsylvania and North Delaware. Located in unglaciated Piedmont, the human footprint within the region spans centuries and current land covers include second-growth forest, agriculture, suburbia, urban, commercial and industrial – providing an ideal natural laboratory to study the gradient of human impacts on critical zone processes.



THE CRB-CZO PRINCIPAL INVESTIGATORS

ORGANO-MINERAL COMPLEXATION

Traditionally considered independent, the two major processes governing inorganic and organic aspects of the critical zone – the mineral cycle (chemical weathering and mineralogical transformations, mixing into bioactive surface soils, natural versus anthropogenic erosion, colluvial and fluvial transport and burial) and carbon cycle (photosynthetic C-fixation, heterotrophic mineralisation of organic carbon to carbon dioxide and other greenhouse gasses, sequestration in biomass, soils and sediments) – are in fact united by organo-mineral complexation.

Natural organic matter and all the forms of carbon it contains are produced by plants above the soil surface. Fine minerals are weathered out of the bedrock and transported to the surface over time to form soils. The relatively thin soil layer where organic matter and minerals meet and mix supports the growth of most terrestrial and many freshwater ecosystems, including our agricultural systems. Soil surfaces are also where the carbon in a fallen leaf is either returned to the atmosphere as a greenhouse gas or preserved for long periods of time. Sediments provide a similar interface for aquatic systems.

Over the last decade, scientists studying the mechanisms of carbon preservation in soils and sediments have established that one of the most important factors determining the fate of organic carbon in the environment is whether it has been complexed to a mineral surface. It is this key process for stabilising carbon that Sparks' team is interested in: "We define organo-mineral complexation as the suite of chemical mechanisms that bind natural organic matter to minerals such that they are difficult or impossible to separate by physical means alone," Sparks explains. One of the project team's hypotheses is that organo-mineral complexation is limited by the supply of the mineral surface and the mixing of the minerals and organic matter in natural ecosystems.

DATA COLLECTION

A central component of the CRB-CZO project is establishing an environmental sensor network. Much of the team's efforts to date have centred on a single small watershed, which has served as a testbed for this larger network, which will be operational in 2012. To measure water fluxes and storage, the researchers have deployed dozens of pressure/depth transducers in streams and groundwater, as well as soil moisture sensors. To understand biological and geochemical processes, they have installed temperature, conductivity, redox, oxygen, and carbon dioxide probes in streams and soils. The project's most advanced sensors are submersible UV/Vis diode array spectrophotometers that they can use to quantify suspended solids, nitrate and dissolved organic carbon in streams.

Sparks' team is also using cutting-edge data communication techniques: "An innovative aspect of our sensor network is its foundation on the open source electronics 'Arduino' platform with ZigBee-based radio networking," states Dr Anthony K Aufdenkampe, Co-Lead PI. "With over half a million users worldwide, this approach is robust, easy-to-use and low-cost, all of which allows us to invest our effort and money on widespread deployment of highest quality sensors, rather than on data communication infrastructure."

In addition to the sensor network, the team is also collecting grab samples from streams using automated stream water samplers that can be activated via a mobile phone, together with soil cores, and borings through the soil into the bedrock. They are also using data collected by airborne LIDAR based on two flights over the basin, one under a full tree canopy and one under a bare canopy.

TRANSLATING FINDINGS, BENEFITING ALL

The CRB-CZO team is working hard to ensure its findings are widely disseminated and are benefiting the right people. External investigators may access their datasets through the cyber infrastructure the researchers have created. The SWRC retains two full-time staff to translate CRB-CZO's research into educational programmes for school children, teachers, and citizen and conservation groups. In addition, the University of Delaware has created its own Delaware Environmental Institute (www.udel.edu/denin), which will develop an outreach component.

Existing ties between the University of Delaware, SWRC, and state agencies are being reinforced by the sharing of environmental data. Graduate students conducting research at the CZO are benefiting from the help of the multidisciplinary team of scientists there. The observatory also plans to form a committee, which will evaluate their research activities and make recommendations for site access and the installation of additional field instruments.

The CRB-CZO is at the forefront of scientific research on understanding how human effects on mineral and carbon cycles might affect climate change, and Sparks is confident about what his team can achieve: "By making our measurements in watersheds that include land use and land cover from fully forested to row crop agriculture to active construction, we will be able to assess these effects in a rigorous scientific manner," he explains. "Also, because the CRB-CZO has an active coastal component, our ultimate goal is to provide an integrated understanding that extends from the headwaters to the estuary."

INTELLIGENCE

THE CHRISTINA RIVER BASIN CRITICAL ZONE OBSERVATORY

OBJECTIVES

To integrate knowledge of water, mineral and carbon cycles to quantify human impact on critical zone carbon sequestration – from uplands to coastal zone.

PARTNERS

University of Delaware, USA

Delaware Environmental Institute, USA

Stroud Water Research Center, USA

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