Critical Zone Observatories: Building a network to advance interdisciplinary study of Earth surface processes

S. A. Anderson1,*, R. C. Bales2 AND C. J. Duffy3

1 Institute of Arctic and Alpine Research and Department of Geography, University of Colorado, UCB-450, Boulder, CO 80309 USA
2 Sierra Nevada Research Institute and School of Engineering, University of California, PO Box 2039, Merced, CA 95344 USA
3 Department of Civil and Environmental Engineering, The Pennsylvania State University, 212 Sackett Building, University Park, PA 16802-1408 USA

ABSTRACT

We live at the dynamic interface between the solid Earth and its outer fluid envelopes. This interface, extending from the outer vegetation canopy to the base of active groundwater, was recently named the Critical Zone because it supports life and is increasingly impacted by human actions. Understanding the complex interactions between processes that operate in and shape the Critical Zone requires interdisciplinary approaches that span wide spatial and temporal scales. Tectonic processes, weathering, fluid transport, and biological processes control the function and structure of the Critical Zone. Three Critical Zone Observatories recently established by the U.S. National Science Foundation are designed to integrate studies of process interactions up to the watershed scale. A goal of the program is to build the three independently conceived observatories into a network from which broader understanding – larger spatial scales but also deeper insight – can emerge.

Introduction

The Earth’s surface is a dynamic zone in which the rock of the interior is permeated by gases and fluids of the atmosphere and hydrosphere. Biological systems extract nutrients and sometimes energy at the interfaces present in this zone: plants anchor in soil, microbes live on mineral surfaces, megafauna roam the surface. The dynamism of this so-called Critical Zone (National Research Council, 2001) derives from both internal energy supplied from the Earth’s interior manifested in the action of plate tectonics, and external radiation from the Sun that drives cycling of water and feeds living systems. Chemical processes spurred by contact of water and air with rock surfaces as well as nutrient- and energy-seeking biological activities at these interfaces in the Critical Zone drive cycling of chemical constituents across the Earth’s surface. Understanding the processes operating and shaping this dynamic environment is recognized as a problem that is fundamentally interdisciplinary in nature: by geochemists (Anderson et al., 2004), soil scientists (Wilding and Lin, 2006; Minasny et al., 2008), hydrologists (Kirchner, 2003; Lin et al., 2006), and geomorphologists (Bishop, 2007; Istanbulluoglu and Bras, 2005). Research communities are formulating strategies to cross disciplinary boundaries and embrace multifaceted approaches. One such strategy is to identify environmental gradients and conduct studies across many such gradients so the interactions that shape the Critical Zone can be understood (Brantley et al., 2007).

* E-mail: Suzanne.anderson@colorado.edu
DOI: 10.1180/minmag.2008.072.1.7

© 2008 The Mineralogical Society
**Critical Zone Observatories**

In 2007, the U.S. National Science Foundation conducted its first call for systems-based observatories for studying Earth-surface processes. The open competition for Critical Zone Observatory (CZO) proposals solicited watershed-scale studies that would advance our understanding of integration and coupling of Earth-surface processes. Three projects were funded (Fig. 1): Southern Sierra Critical Zone Observatory (University of California, Merced), Boulder Creek Critical Zone Observatory (University of Colorado), and Susquehanna-Shale Hills Critical Zone Observatory (Penn State University). Each of the funded CZO projects articulates overarching science questions that couple hydrology, geomorphology, and biogeochemical systems.

The Southern Sierra CZO is sited at the rain-snow transition in the foothills of the Sierra Nevada in California. Snowpack profoundly affects the timing and rates of water discharge, as well as rates of exchange with the atmosphere and rates of biogeochemical processes. In a warming climate, snowfall amounts and timing of melt change, shifting towards rain rather than snow as the primary form of precipitation. Hence, the primary goal of the Southern Sierra CZO is to understand hydrology and critical zone processes in snow-covered landscapes. Observations will be made to follow the processes that control fluxes and stores of water in both snow-dominated and rain-dominated areas. Particular foci include assessing differences in hydrologic and biogeochemical fluxes across the rain-snow transition, and the role of extreme hydrologic events.

The Boulder Creek CZO extends from the peaks of the continental divide in the Front Range of the Rocky Mountains to the plains (Murphy, 2006). In this watershed, three different erosion histories have produced widely varying Critical Zone architectures. Pleistocene glaciers have carved U-shaped troughs at the continental divide, the last major glaciers leaving the landscape about 14 ka ago. As ice sculpted the headwaters over the last few million years, rivers on the plains draining the Front Range switched from alluvial to incising, and have lowered the plains by hundreds of metres. As a result, Boulder Creek has carved a canyon with a steep knick zone presently several km upstream from the mountain front. Downstream of the knick zone, hillslopes and tributary drainages are responding to this base-level lowering with steepened slopes and reduced regolith thicknesses. A third erosional regime is found in the region upstream of the knick zone, and downstream of the glacial limit. This is a landscape of low relief, relatively deep weathering, and tectonic quiescence since the Laramide orogeny (~50 Ma). The overarching goal of the Boulder Creek CZO is to understand how erosion and weathering conspire to produce the different Critical Zone architectures, and how these different architectures control the biological and hydrological function of the Critical Zone.

The Susquehanna Shale Hills CZO is based in a small catchment carved in shale bedrock in the Valley and Ridge province of the Appalachian Mountains in Pennsylvania. The focus of this CZO is to develop a quantitative and predictive understanding of the formation, evolution and structure of regolith, the weathered rock material.

---

**Fig. 1.** Shaded relief map showing locations of Critical Zone Observatories. SS = Southern Sierra CZO; BC = Boulder Creek CZO; SH = Susquehanna Shale Hills CZO. Base DEM from the National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/topo/globega2.html).
of the Critical Zone. The field site is a forested, temperate-climate catchment developed on homogeneous shale bedrock. This CZO will also incorporate a number of satellite sites developed in shale bedrock along a climatic gradient along the eastern seaboard.

Can a network be more than its parts?

Ideally, the three Critical Zone Observatories will form the nucleus of a network that advances interdisciplinary understanding of the environment that sustains life. While each CZO was selected for funding based on its individual merits, we are taking steps to foster links between the CZOs. These steps are designed to build links between the researchers directly engaged in the three CZOs and their projects, as well as to engage researchers from the Earth-surface science community at large.

Data access portal

The three CZOs have pledged to build a single portal that will provide community access to the data from all CZO sites.

Scientific Steering Committee

A national Steering Committee is being formed to provide guidance to the CZOs. Part of their charge is to make recommendations on networking and synthesis activities.

Annual science meeting

Representatives from each CZO will attend an annual science meeting so that we visit each field site and share knowledge. The Steering Committee will participate as well.

Community participation

All CZOs are committed to being community resources in terms of data and field access. These points illustrate concrete steps we are taking to integrate the science across observatories. Ultimately, however, success depends on many scientists embracing the idea of linking their individual efforts and ideas to those of others. This linkage can take many forms, such as data mining, site comparison, cataloguing and compiling observations, experiments, and modeling. The most important step is having network and interdisciplinary thinking. Insights and research directions unimagined in the planning for the individual CZOs may emerge from using these observatories as a network.

Conclusions

Three Critical Zone Observatories have been established to advance our understanding of the complex interactions that operate in Earth surface environments. A single site is not sufficient to develop and test ideas about how interactions between tectonics, fluid transport, weathering and biological processes shape the Earth’s surface. Instead, we must network data, ideas, models and tools (Brantley et al., 2007) to build the integrated understanding we hope to achieve.

Acknowledgements

The authors are the Principal Investigators of Critical Zone Observatories, and acknowledge support from the National Science Foundation, as follows: SPA — Boulder Creek — NSF0724960; RCB — Southern Sierra — NSF0725097; CJD — Susquehanna Shale Hills — NSF0725019. We thank Sue Brantley and Robert Anderson for comments on a draft of this paper.

References


