How weather and climate shape Earth's life sustaining surface

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Credit: University of Colorado at Boulder

We know less about the ground beneath our feet than we do about the surface of Mars, but new research by University of Colorado Boulder geoscientists shines a light on this hidden world from ridgetops to valley floors and shows how rainfall shapes the part of our planet that is just beyond where we can see.

Earth is popularly known as the "third rock from the sun," yet hard rock is rare at the ground surface. Scientists have dubbed the vegetation, soil and water-storing debris that hides Earth's rocky interior from view the "critical zone." The name honors the fact that this zone is simultaneously essential to life and is shaped by living organisms. The character of the critical zone—particularly its depth—controls how groundwater is stored and released to streams.

Groundwater provides the water supplies that are the lifeblood of agriculture and industry in the nation, and indeed around the world. But groundwater itself is not passive. It reacts with the rock along its path, and in so doing both chemically transforms the rock and picks up dissolved minerals and nutrients.

The researchers were inspired to study the fundamental differences between two National Science Foundation-supported Critical Zone Observatories (CZOs). In the Boulder Creek CZO in the Colorado Front Range, fresh rock can be found beneath a thin layer of soil and broken rock that evenly mantles hillsides. In the Calhoun CZO in the South Carolina piedmont, fresh rock is far below the surface, and the critical zone billows thickly under ridge crests and thins under valley bottoms. And the soils of Colorado are gray-brown and rocky, in contrast to the red clays of South Carolina.

The CU Boulder researchers set out to understand why this life-sustaining and water-storing blanket of soil and the underlying weathered rock vary so much from one place to another. Co-authors included Distinguished Professor Robert S. Anderson of CU Boulder's Department of Geological Sciences, President's Teaching Scholar Professor Harihar Rajaram of CU Boulder's Department of Civil, Environmental, and Architectural Engineering, and Professor Suzanne P. Anderson of CU Boulder's Department of Geography.

"Our goal was to create a model to explain why these differences occur," said Suzanne Anderson.

The researchers focused on one of the most obvious differences between the two sites: the weather. They built a numerical model to test whether the much greater rainfall in the southeast could explain the great differences in the depth of weathering. In the model, rainwater is tracked as it seeps through the landscape, and causes rock minerals to weather (or transform) into clay. Because weathering processes are slow, it was necessary to include soil formation and erosion as well.

"Weathering of bedrock may be the most important geologic process, since it produces the soil we depend on for our existence," says Richard Yuretich, director of the NSF Critical Zone Observatories program, which funded the research.

The results, published today in a special issue of the journal *Hydrological Processes* devoted to the role of water in the critical zone, show that a shallow Colorado-type critical zone forms under dry conditions, while a thick, undulating South Carolina-type critical zone forms in wet conditions.

In other words, the model succeeds in explaining the drastic differences in these landscapes. The connectivity of the system captivated the research team.

"It's fascinating how simple patterns in critical zone thickness respond to climate, to erosion, and undoubtedly to processes that we haven't considered yet," said Suzanne Anderson, who is also a fellow of CU Boulder's Institute of Arctic and Alpine Research (INSTAAR). "Being able to predict these patterns of weathering puts us in a position to understand things we care about, from water supplies to maintaining healthy soils."

"Soil resources are precious," said Robert Anderson, also an INSTAAR fellow. "One of the aspects of the landscape that we had to embrace in this modeling effort is that it takes thousands of years to generate the soil we have. If it is scraped away or misused, it's not going to be replaced in human timescales. Mismanagement means you will never get it back."

"But to me", he said, "it is interesting enough, and satisfying enough, to explain why you can dig a pit 20 feet deep with a shovel in South Carolina, and have to resort to a pick axe within 2 feet in Colorado. It's all about the weather."

More information: R.S. Anderson et al, Climate driven co-evolution of weathering profiles and hillslope topography generates dramatic differences in critical zone architecture, *Hydrological Processes* (2018). DOI: 10.1002/hyp.13307

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