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Seeing the bedrock through the trees

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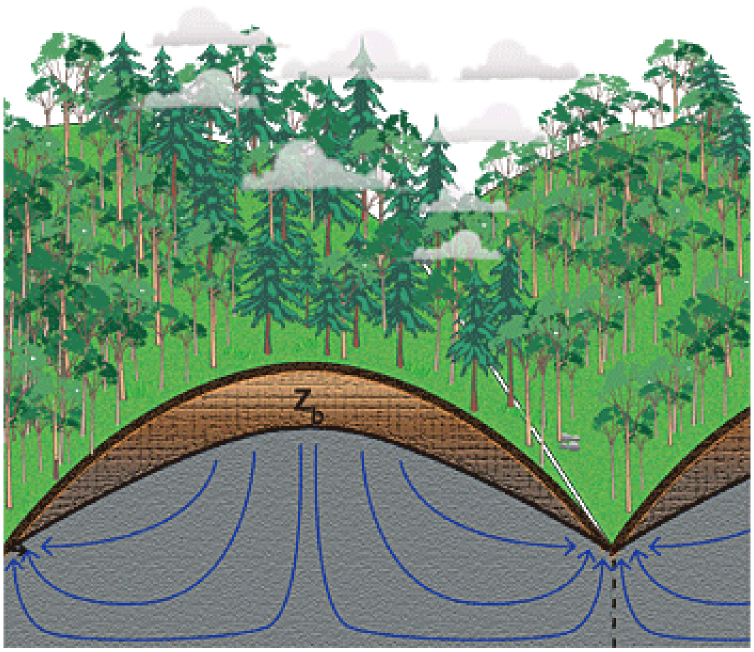

Weathered rock (light brown), an often thick layer of fractured rock underlying the thin veneer of soil (dark brown) and just above the impermeable bedrock (gray), can hold more water than soil and plays a major role in determining runoff, landslides and the evolution of mountainous or hilly terrain. Berkeley geologists argue that the rate at which water drains from bedrock (blue arrows) determines the thickness of weathered rock.

University of California, Berkeley, geologist William Dietrich pioneered the application of airborne LIDAR – light detection and ranging – to map mountainous terrain, stripping away the vegetation to see the underlying ground surface.

But that didn't take him deep enough. He still couldn't see what was under the surface: the depth of the soil, the underlying weathered rock and the deep bedrock.

He and geology graduate student Daniella Rempe have now proposed a method to determine these underground details without drilling, potentially providing a more precise way to predict water runoff, the moisture available to plants, landslides and how these will respond to climate change.

The technique, which will help improve climate models that today take into account only the soil layer, was published online last week in the Early Edition of the journal *Proceedings of the National Academy of Sciences*.

A major challenge to including groundwater in climate models, said Rempe, is determining the thickness of weathered bedrock, which can hold most of the water on hillsides, especially during California's dry summers. Their model proposes that the thickness of weathered bedrock under hillslopes is controlled from the bottom up, as opposed to the current view that water from above drives weathering of the bedrock.

"By understanding how water is routed within hillslopes, we can improve predictions of how vegetation and stream flow will respond to climate and land use changes," she said. "But a critical input to hydrologic and climate models is the thickness of soil and weathered bedrock. This model provides, for the first time, a simple theory based on groundwater drainage to predict this thickness across landscapes."

Erosion from the bottom up

The UC Berkeley model emerged from decades of study at various sites where the ground surface is actively eroding, primarily the University of

California's Angelo Coast Range Reserve near Laytonville, Calif., and a similar steep, forested area near Coos Bay, Ore. The results apply to mountainous topography across the world, including the Appalachians and Sierra Nevada in the United States.

Soil – a mix of organic material and weathered rock – is traditionally thought of as the key to the landscape, the place where plant roots obtain water and nutrients, the source of runoff into streams, and the material that erodes and occasionally slides. But in recent years, geologists have come to realize that the often thicker layer of weathered bedrock that lies under the soil – and is in the process of becoming soil – often plays a larger role for plants and the watershed. Roots often penetrate though soil to the weathered rock, and research by Rempe and Dietrich reveals that rock can store water far longer than soil.

Daniella Rempe collecting Douglas fir samples in the tree canopy at Angelo reserve to measure the stable isotope concentration, which is used to identify the source of the water the tree is using. William Dietrich photo.

"The soil is often a thin veneer on the landscape, but it may not be where the hydrologic action is taking place," Rempe said, noting that the soil at the Angelo site may be less than two feet thick, but the weathered bedrock layer is up to 80 feet thick. "The 100-foot-tall Douglas firs are not getting all of their water from the soil. It is just too thin."

Dietrich and Rempe propose in their model that the thickness of the weathered rock is determined primarily by the rate at which water drains from the solid but water-saturated bedrock beneath. This water can be hundreds of thousands of years old and moves through the rock extremely slowly, sometimes less than a millimeter per year. As the bedrock is uplifted by tectonic forces, water drains from the top, leaving dry rock subject to fracturing and chemical weathering. Fracturing allows water, gases, and plant roots to penetrate from above and easily transform the rock through weathering processes.

Bedrock doesn't drain, however, unless stream channels cut into the rock and provide a place to drain. To predict the thickness of weathered bedrock, their model needs only the rate at which channels incise and the rate at which the bedrock drains, determined by the porosity and permeability of the rock.

Focus on rock moisture

"This is a first step towards calculating the thickness of weathered bedrock across the landscape, a zone where we have documented 'rock moisture' dynamics, something we think is missing from current climate models," said Dietrich, a professor of earth and planetary science. "This rock moisture can be used by trees and may contribute to sustained base flow in streams as it slowly drains, yet it is virtually unknown."

One prediction of the model that is consistent with observations is that the weathered rock layer thickens towards the ridges that divide hillslopes.

"We are attempting to explain why some landscapes are covered with soil and deep weathered bedrock while others have bare fresh bedrock exposed at the surface," Rempe added. "Our hypothesis is that the primary control is the relative rate of surface erosion versus drainage of underlying fresh bedrock."

Dietrich and Rempe hope to drill at ridge tops to measure the thickness of weathered rock in order to test their model and confirm the key role played by drainage of fresh bedrock in setting the thickness of weathered bedrock across hilly and mountainous landscapes.

More information: A bottom-up control on fresh-bedrock topography under landscapes, *PNAS Early Edition*, 2014. www.pnas.org/content/early/201 … /1404763111.abstract

Provided by University of California - Berkeley