UW Researchers Advance Understanding of Mountain Watersheds

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James St. Clair, a UW doctoral student, is the lead author on a Science paper that discovers the distribution of porosity in the subsurface of mountain watersheds can be determined by looking at the state of stress in the earth's crust. (Steve Holbrook Photo)

University of Wyoming geoscientists have discovered that the underground water-holding capacity of mountain watersheds may be controlled by stresses in the earth's crust. The results, which may have important ramifications for understanding streamflow and aquifer systems in upland watersheds, appears Oct. 30 in Science, one of the world's leading scientific journals.

The scientists conducted geophysical surveys to estimate the volume of open pore space in the subsurface at three sites around the country. Computer models of the state of stress at those sites showed remarkable agreement with the geophysical images. The surprising implication, says Steve Holbrook, a UW professor in the Department of Geology and Geophysics (http://www.uwyo.edu/geolgeophys/), is that scientists may be able to predict the distribution of pore space in the subsurface of mountain watersheds by looking at the state of stress in the earth's crust. That state of stress controls where subsurface fractures are opening up -- which, in turn, creates the space for water to reside in the subsurface, he says.

"I think this paper is important because it proposes a new theoretical framework for understanding the large-scale porosity structure of watersheds, especially in areas with crystalline bedrock (such as granite or gneiss)," Holbrook says. "This has important implications for understanding runoff in streams, aquifer recharge and the long-term evolution of landscapes."

James St. Clair, a UW doctoral student, is lead author of the paper, titled "Geophysical Imaging Reveals Topographic Stress Control of Bedrock Weathering." Holbrook, Cliff Riebe, a UW associate professor of geology and geophysics; and Brad Carr, a research scientist in geology and geophysics; are co-authors of the paper.

Researchers from MIT, UCLA, the University of Hawaii, Johns Hopkins University, Duke University and the Colorado School of Mines also contributed.

Weathered bedrock and soil together make up the life-sustaining layer at Earth's surface commonly referred to as the "critical zone." Two of the three study sites were part of the national Critical Zone Observatory (CZO) network -- Gordon Gulch in Boulder Creek, Colo., and Calhoun Experimental Forest, S.C. The third study site was Pond Branch, Md., near Baltimore.

"The paper provides a new framework for understanding the distribution of permeable fractures in the critical zone (CZ). This is important because it provides a means for predicting where in the subsurface there are likely to be fractures capable of storing water and/or supporting groundwater flow," St. Clair says. "Since we cannot see into the subsurface without drilling holes or performing geophysical surveys, our results provide the means for making first order predictions about CZ structure as a function of the local topography and knowledge (or an estimate) of the regional tectonic stress conditions."

The research included a combination of geophysical imaging of the subsurface -- conducted by UW's Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG (http://www.uwyo.edu/epscor/wycehg/)) -- and numerical models of the stress distribution in the subsurface, work that was done at MIT and the University of Hawaii, Holbrook says.

The team performed seismic refraction and electrical resistivity surveys to determine the depth of bedrock at the three sites, which were chosen due to varying topography and ambient tectonic stress. At the two East Coast sites, the bedrock showed a surprising mirror-image relationship to topography; at the Rocky Mountain site, the bedrock was parallel to topography. In each case, the stress models successfully predicted the bedrock pattern.

"We found a remarkable agreement between the predictions of those stress models and the images of the porosity in the subsurface with geophysics at a large scale, at the landscape scale," Holbrook says. "It's the first time anyone's really looked at this at the landscape scale."

St. Clair says he was fortunate to work with a talented group of scientists with an extensive amount of research experience. He adds the experience improved his ability to work with a group of people with diverse backgrounds and improve his writing.

"Our results may be important to hydrologists, geomorphologists and geophysicists," St. Clair says. "Hydrologists, because it provides a means for identifying where water may be stored or where the flow rates are likely to be high; geomorphologists, because our results predict where chemical weathering rates are likely to be accelerated due to increased fluid flow along permeable fractures; and geophysicists, because it points out the potential influence of shallow stress fields on the seismic response of the CZ."

Despite the discovery, Holbrook says there is still much work to be done to test this model in different environments.

"But, now we have a theoretical framework to guide that work, as well as unique geophysical data to suggest that the hypothesis has merit," he says.

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