PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

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KECK GEOLOGY CONSORTIUM
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Keck Geology Consortium: Projects 2012-2013
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Research Advisor: Sue Swanson

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KECK COLORADO PROJECT: INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO

DAVID P. DETHIER, Williams College
WILL OUIMET, University of Connecticut

INTRODUCTION

Processes in the *critical zone*, the life-sustaining surficial mantle of the earth, involve the interactions of weathered geologic materials, water, and the biosphere, mediated by atmospheric processes that are controlled by changing climate. Field and laboratory studies provide valuable data about processes in the critical zone and the physical basis for their integration into models of short and long-term geomorphic, hydrologic and biochemical response. The Keck Colorado Project has worked in cooperation with a large interdisciplinary study of the critical zone (*Boulder Creek Critical Zone Observatory: Weathered profile development in a rocky environment and its influence on watershed hydrology and biogeochemistry*— Suzanne Anderson, PI, Institute for Arctic and Alpine Studies, University of Colorado). The observatory (CZO) comprises several study areas including the 26 km^2 Fourmile burn and 3 small, instrumented catchments in the Boulder Creek basin, Colorado Front Range: (1) Green Lakes Valley (GLV; el. 3400 m)--a steep, glacially scoured alpine area in the City of Boulder watershed; (2) Gordon Gulch (el. 2600 m)--a forested, montane catchment that exposes isolated bedrock remnants (tors) developed on a surface of low relief; and (3) Betasso gulch (el. 1950 m)--a steep, thinly forested basin that preserves thick regolith in the upper catchment and exposes extensive bedrock outcrops at lower elevations (Fig. 1).

The glaciated GLV, low relief surface, and bedrock canyons such as Boulder and Fourmile Creek are developed in granitic and gneissic rocks and are influenced by the strong W-E gradients in elevation, climate and vegetation. Variation in critical-zone development in these different environments has allowed Keck Colorado Project students to study rock strength, weathering and regolith generation, soil chemistry, sediment transport, slope evolution, and surface-water hydrology in a variety of field settings. Land-use, vegetation and hydrologic response in each CZO catchment also reflect changes produced by local activities such as mining, timber harvest and fire, as well as global effects related to air pollution and to warming temperatures over the past 150 years. Our field studies have focused on using a variety of techniques to map and characterize spatial relations of near-surface geologic materials and their physical, hydrologic and geochemical properties in each of the study catchments.

SETTING

The Middle Boulder Creek catchment, which includes the Fourmile drainage, extends from the glaciated alpine zone of the Continental Divide east to the semi-arid western edge of the Great Plains. The high-relief zone of cirques and deep, U-shaped valleys in the GLV become shallower eastward through a zone of low relief and relatively low slopes. To the east, valleys deepen into steep, narrow bedrock canyons as they pass knickzones, and flatten to lower channel slopes near the piedmont margin. Small glaciers and late-persisting snowfields (Martinelli; Saddle) dot the glaciated zone in the GLV, which exposes bedrock and relatively thin deposits related to the latest Pleistocene Pinedale glaciation and to Holocene erosion. The forested zone of low relief is developed on local areas of thick (characteristically 3 to 8 m) regolith, including saprolite and oxidized bedrock, but the weathered mantle is thin in other areas and

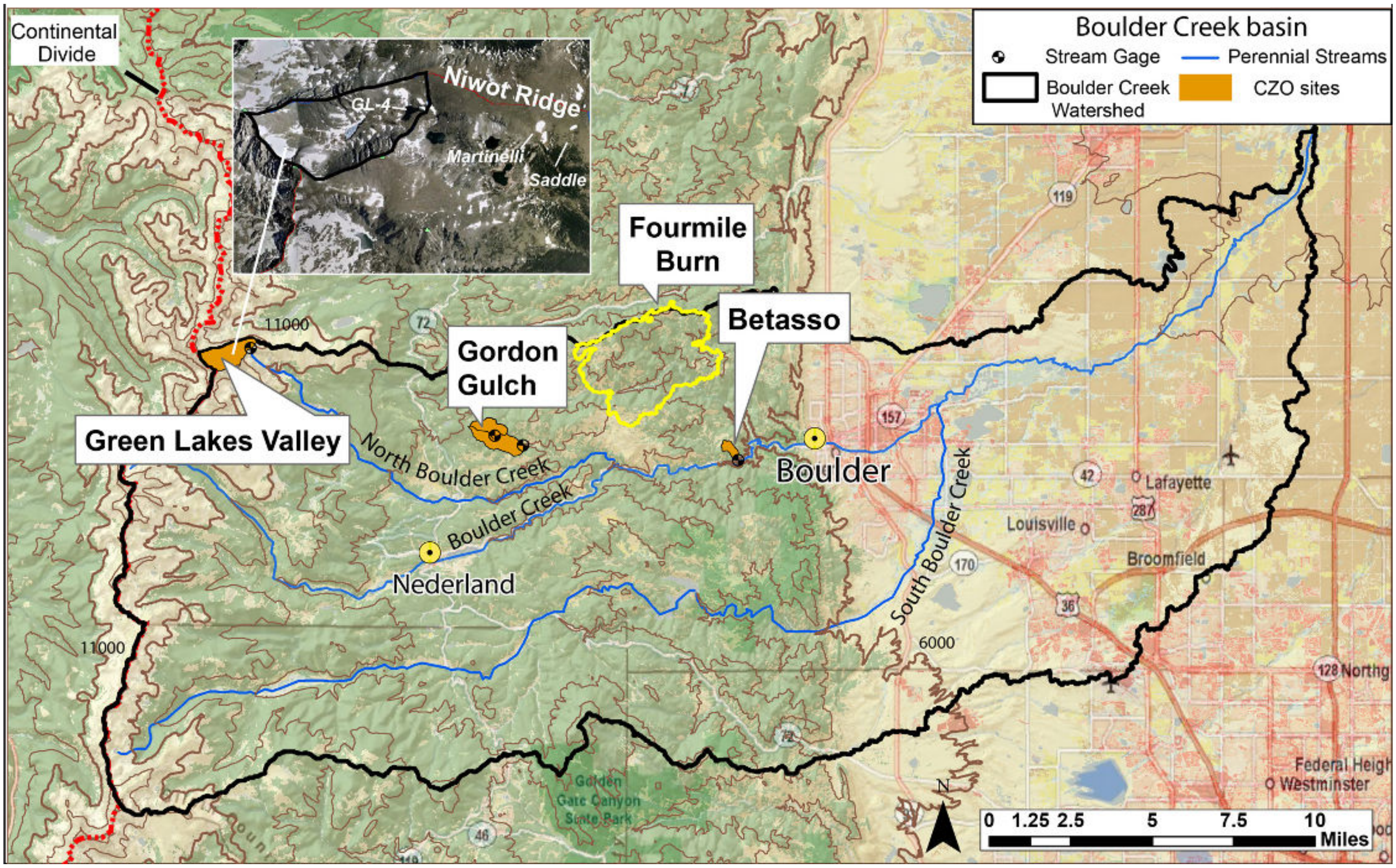

Figure 1. Map showing the Boulder Creek basin, Colorado, and study areas discussed in the text. Inset shows Niwot Ridge area and the location of the Saddle, Martinelli and GL-4 basins.

bedrock crops out at the surface as isolated outcrops termed tors. Low terraces and alluvial fans as thick as 4 m locally line channels. In the vicinity of knickzones and in downstream areas such as Betasso gulch, slopes near channels are steep and fresh bedrock is exposed, whereas areas more distant from channels retain a thicker weathered mantle.

APPROACH

In our fifth project year, we used field mapping and sampling in all three CZO catchments and adjacent areas in order to provide basic data about alpine hydrology and geochemistry, bedrock weathering, hillslope evolution and the effects of the Fourmile fire on sediment transport and soil chemistry. Students supported by the Keck Geology Consortium learned field mapping and sampling techniques and initial data reduction, processing and visualization methods in these settings. Students chose from a variety of potential projects in the study catchments; 2012 topical areas included:

Alpine hydrology, geochemistry and permafrost in GLV and on Niwot Ridge

Mapping deposits from the 13.5 ka Lake Devlin outburst flood, North Branch of Boulder Creek

Measuring fracturing in fresh and weathered bedrock in the three CZO catchments

Assessing the effects of the Fourmile fire and rainfall events on sediment transport (in cooperation with the U.S. Geological Survey) and Mn cycling

Applying ^{137}Cs and ^{210}Pb and ^{226}Ra concentrations in soil profiles to measure rates of sediment transport on hillslopes

We continued our mapping of surficial deposits (Fig. 2) and mobile regolith studies in Gordon Gulch, begun in 2009 by James Trotta, continued in 2010 by James McCarthy and Cianna Wyshnytzky, and in 2011 and 2012 by Neil Shea (University of Connecticut M.S.

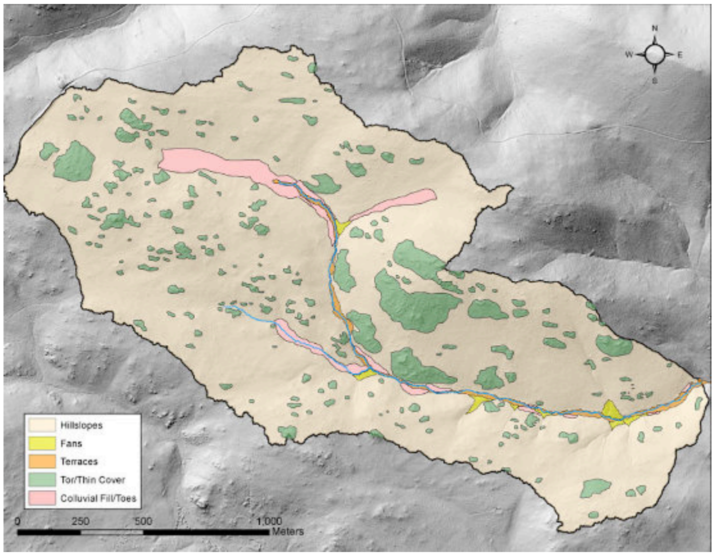

Figure 2. Map showing surficial deposits in Gordon Gulch, Boulder Creek basin. Lidar base from Anderson et al. (2012).

Figure 3. Keck Colorado students and Will Ouimet in Green Lakes Valley, 2012. View east across Green Lake 4 and 3.

candidate) and investigators from the University of Colorado. The mapping collectively shows that bedrock exposures (tors) comprise about 11% of the surface in Gordon Gulch, and that alluvial fans, stream valley terrace deposits and several areas of colluvial fill and thick toe slopes cover about 5% of the basin. The rest of the gulch exposes mobile regolith 0.4 to 0.5 m thick, which overlies gneissic and granitic saprolite. Nearby catchments appear to expose less bedrock and more mobile regolith. Meteoric ^{10}Be and soil chemistry suggest that weathering rates are relatively slow (Wyshnytzky and McCarthy, 2011; Dethier et al., 2012) and that Gordon Gulch soil and mobile regolith have a residence time on slopes of 1 to 4 x 10^4 yr, with lower portions of north facing slopes consistently displaying greater thicknesses of mobile regolith (>70 cm) and 1.5 - 3x more than other slope locations (Shea et al., 2013). The addition of short-lived radionuclide analysis (^{137}Cs and ^{210}Pb) this past year allows us to compare the short-term (<100-200 yr) behavior of CZO hillslopes to the longer time scale implied by the meteoric ^{10}Be analysis.

STUDENT PROJECTS

Six Keck students joined Gabe Lewis (Williams), Ian Nesbitt (Williams) and Neil Shea (M.S. student, University of Connecticut), who were supported directly by NSF funding, for field studies in all of the CZO catchments. David Dethier and Will Ouimet supervised students, and field teams worked with Joerg Voelkel and Matthias Leopold (Technical University of Munich) on geophysical studies, joined investigators and graduate students from the University of Colorado and worked with U.S. Geological Survey personnel in the Fourmile burn area. Keck Colorado students worked in pairs on a daily basis and sometimes as a group on field trips (Fig. 3) and when we needed to excavate or fill deep soil pits. Short papers elsewhere in this volume report results of the field and laboratory studies in some detail. We summarize and provide brief notes on this research here.

Tim Boateng (Amherst) used field studies and thin section analysis to examine bedrock fracturing in each of the study areas and in freshly burned and spalled rocks in the Fourmile burn (Fig. 4). Most fractures do not appear to have been initiated by weathering, but weathering has widened, altered and connected fractured surfaces in areas to the east of the recently glaciated Green Lakes Valley.

Claudia Corona (Williams) compared the geochemical variability of Martinelli and Saddle Streams, which drain two small (~0.25 km^2), adjacent catchments in GLV. Claudia's work builds on research carried out by Nel Caine (University of Colorado) as part of the Long-Term Ecological Research Program (LTER) and on studies initiated by James Winkler in 2011. Snowmelt runoff in 2012 was unusually low and July had near-record rainfall, in contrast to the late and voluminous snowmelt of 2011. Claudia's results

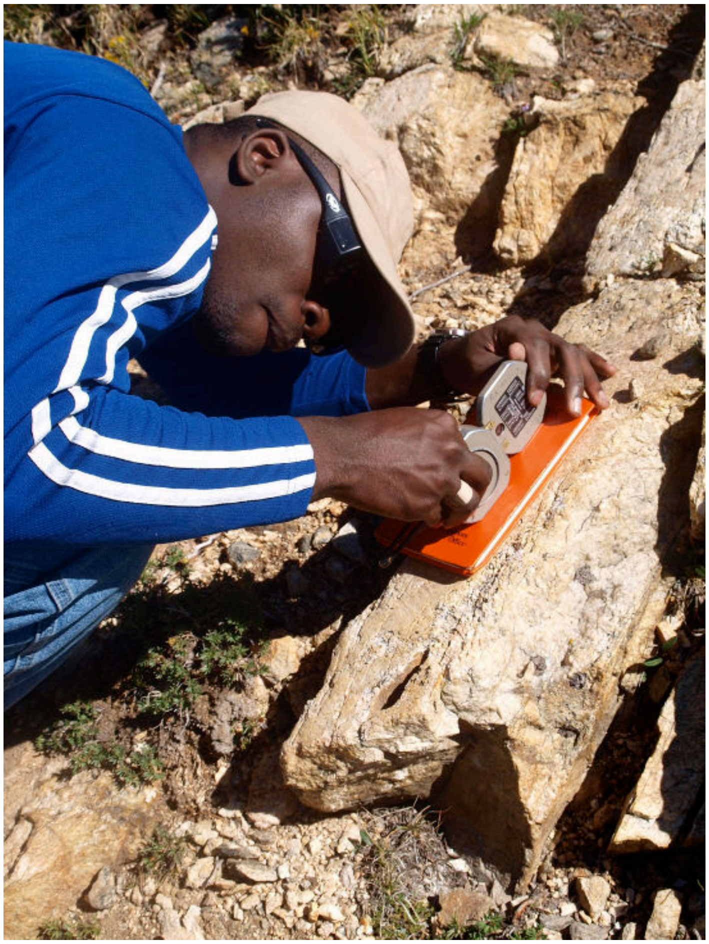

Figure 4. Tim Boateng measuring a polished, fractured surface, Green Lakes Valley.

Figure 5. Claudia Corona and Ian Nesbitt measuring discharge and sampling water chemistry, Saddle Stream, Green Lakes Valley.

demonstrate that Martinelli and Saddle surface waters have distinct geochemistries and that the spatial and temporal variability of stream chemistry decreases downstream in both catchments (Fig. 5.)

Chris Halcsik (Beloit) mapped an extensive debris fan deposited when Glacial Lake Devlin drained catastrophically through Caribou Creek and into the N. Branch Boulder Creek valley at about 13 ka (Madole, 1980). Bouldery deposits cover eroded till and outwash near Boulder Creek and extend downstream at least two km along Boulder Creek. Chris's mapping demonstrates that at least one smaller flood occurred along Caribou Creek in historic time, perhaps after the failure of a dam under construction by the City of Boulder.

Figure. 6. Chris Halcsik and Gabe Lewis (in soil pit) at the end of a geophysics line on S-facing slope of Niwot Ridge. Kiowa Peak (4048 m) in background.

Gabe Lewis (Williams) worked with Matthias Leopold to map the shallow subsurface on Niwot Ridge and adjacent areas, using resistivity (ERT) techniques. On Niwot Ridge and in Gordon Gulch, ERT shows that

Figure 7. Hannah Mondrach and Annette Patton with a toeslope pit sampled for ^{137}Cs and Mn, Gordon Gulch.

in most areas, layered, mainly gravel-rich deposits as thick as 5 m cover bedrock (Fig. 6). There is no evidence that permafrost persists on Niwot Ridge, though it had been reported in the 1970s. Gabe's thermal models confirm that most of Niwot Ridge is too warm for permafrost at present, but show that a drop in mean annual temperature of 1°C would produce at least patchy permafrost.

Hannah Mondrach (University of Connecticut) sampled the upper 20 cm of soils throughout Gordon Gulch, Betasso Gulch and the Fourmile burn in order to measure concentrations of ^{137}Cs and ^{210}Pb, fallout radionuclides with short half lives that adhere to soil particles and can act of tracers of regolith mixing and movement. Her results indicate that the range of ^{210}Pb and ^{137}Cs inventories and concentration profiles with depth that exists in these soils is consistent with short-term (<100-200 yr) mobilization, deposition and erosion of hillslope sediment. Coupled with our meteoric ^{10}Be studies, Hannah's data provide a crucial link between the long and short-term behavior of CZO hillslopes.

Ian Nesbitt (Williams) studied the hydrology of Martinelli and Saddle Streams (Fig. 1) to help quantify short-term and annual water budgets for their catchments. His results suggest that the catchments are not watertight and that significant amounts of water may bypass the stream gages, flowing into shallow, subsurface gravel. Synoptic measurements of stream discharge and temperature show downstream changes consistent with significant local gains and losses of water through the channel.

Annette Patton (Whitman) sampled vegetation and soils throughout the Boulder Creek watershed, including the Fourmile burn, in order to measure concentrations of Mn, which appears to be mobilized in relatively high concentrations by forest fires. Her research suggests that needles contain 90-to 150 µg g^{-1} Mn and that shallow soil horizons have extractable Mn concentrations of 50-to 100 µg g^{-1}. Elevated concentrations of Mn measured in Fourmile Creek and in overbank sediment after the fire may result from erosion by overland flow that washed ash and soil into channels.

Ben Purinton (Wesleyan) used mapping, geochemical analysis and stream gage data to study the hydrologic, geochemical and geomorphic impacts of the 2010 Fourmile Canyon fire. His results indicate that the combination of vulnerable hillslopes and well-timed rain events led to two large flood pulses of fine grained, mining contaminated sediment being mobilized downstream and deposited overbank along Fourmile Creek (Fig. 8) within and downstream of the fire region. Burned hillslopes are largely re-vegetated today, but sand and gravel persists within Fourmile Creek, a sign of continued post-fire response in this landscape. Overall, Ben's study highlights how episodic erosion events drive landscape evolution in the region.

Figure 8. Ben Purinton takes notes on Fourmile Creek overbank deposits. Note charcoal- rich layer exposed in shallow trench.

CONCLUSIONS

"Piggybacking" the Keck Colorado Geology Project on the NSF-Boulder Creek Critical Zone Observatory has allowed Keck undergraduates to integrate their projects with the research of graduate and postdoctoral students from the University of Colorado, other research universities and the U. S. Geological Survey. Keck student research has benefitted from the personnel, monitoring efforts, and general level of scientific interest associated with the NSF project. The Boulder Creek CZO has gained from the focused field and laboratory research of the Keck students, their energy, and their collective demonstration of what can be accomplished by the best undergraduates.

ACKNOWLEDGMENTS

Field studies and measurements in the Boulder Creek area were performed in cooperation with the Boulder Creek CZO Project (National Science Foundation), the USDA Forest Service, and the City of Boulder Watershed and Parks and Recreation Departments. Nel Caine (University of Colorado) and Craig Skeie (City Watershed Manager) guided work in the Green Lakes Valley and Pete Birkeland (University of Colorado) taught us about soils. Suzanne Anderson and Bob Anderson (University of Colorado) shared their knowledge of the Critical Zone and how to study it. Jeff Writer (U.S. Geological Survey, Boulder) introduced us to the Fourmile fire area and Deborah Martin and John Moody, USGS, provided essential guidance in the field. We gratefully acknowledge the ongoing cooperation, cogent advice and digging ability of Joerg Voelkel and Matthias Leopold (Technical University of Munich). Hospitality of the Mountain Research Station made this project possible.

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