

**KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491**

April 2010

Andrew P. de Wet
Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

Lara Heister
Symposium Convenor
ExxonMobil Corp.

Keck Geology Consortium Member Institutions:

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College
Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University
Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.

Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)

Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.

Faculty: David Dethier (Williams) Students: Elizabeth Dengler, Evan Riddle, James Trotta

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.

Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)

Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.

Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)

Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.

Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)

Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA

Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)

Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.

Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)

Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.

Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)

Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

**Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)
and ExxonMobil**

**Keck Geology Consortium: Projects 2009-2010
Short Contributions – COLORADO**

**INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK
CATCHMENT, FRONT RANGE, COLORADO**

Project Director: *DAVID P. DETHIER*: Williams College
Project Faculty: *MATTHIAS LEOPOLD*: Technical University of Munich

**FRACTURE DISTRIBUTION AND CHARACTERIZATION IN BETASSO
GULCH, CO**

ELIZABETH DENGLER
Bates College
Research advisor: Dykstra Eusden

**TALUS STRUCTURE AND EVOLUTION: A COMPARISON BETWEEN TALUS
NEAR GREEN LAKE 3 AND AT BUMMER'S ROCK, COLORADO**

EVAN RIDDLE
North Carolina State University
Research Advisor: Karl Wegmann

**THE DISTRIBUTION OF TORS IN GORDON GULCH, FRONT RANGE,
COLORADO**

JAMES TROTTA
Williams College
Research Advisor: David P. Dethier

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

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

DAVID P. DETHIER

Williams College

INTRODUCTION

Processes in the critical zone, the life-sustaining surficial mantle of the earth, involve weathered geologic materials, water, and the biosphere, mediated by atmospheric processes that are controlled by changing climate. Field studies that investigate hydrologic and geochemical components of the critical zone provide valuable information about processes and the physical basis for integrating those data into models of short and long-term geomorphic, hydrologic and biochemical response. The Keck Colorado Project is working in cooperation with a large interdisciplinary study (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) of the critical zone. The “observatory” (CZO) consists of 3 small, instrumented catchments in the Boulder Creek basin, Colorado Front Range:

(1) Green Lakes Valley--a steep, glacially scoured alpine area in the Boulder City watershed; (2) Gordon Gulch--a forested, mid-elevation catchment that exposes isolated bedrock remnants (tors) developed on a surface of low relief; and (3) Betasso gulch--a steep, lower-elevation basin where surficial deposits are of variable thickness and numerous fractures cut exposed bedrock (Fig. 1).

The glaciated Green Lakes Valley, low relief surface, and bedrock canyons are developed in granitic or gneissic rocks and influenced by the strong gradient in elevation, climate and vegetation from west to east. Variation in critical-zone development in these different environments allows us to test models of weathering and regolith generation, slope evolution and sediment transport in an accessible field setting. Land-use, vegetation and perhaps hydrologic response in each CZO catchment also reflect changes produced by anthropogenic activities over the past 150 years. Keck Colorado studies focus on using a

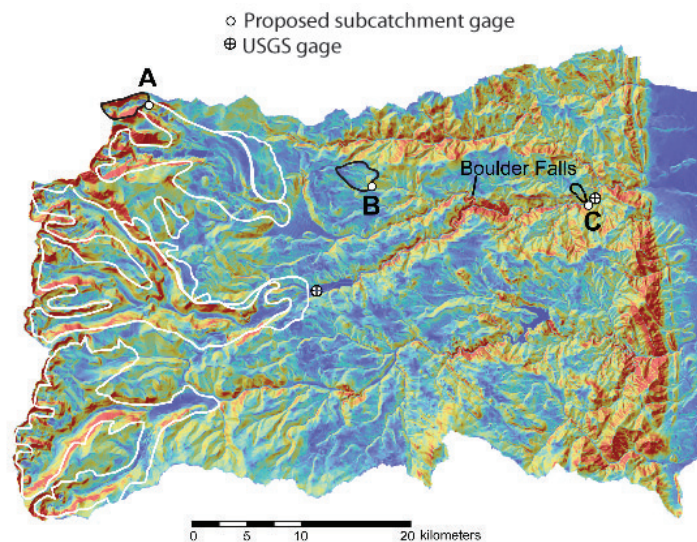


Figure 1. Shaded relief and slope map of upland Boulder Creek. Steepest slopes shaded red; shallowest slopes are blue. Study catchments include: A- Green Lakes Valley; B- Gordon Gulch and C- Betasso gulch. Pleistocene glacial limits (white), and two existing USGS gages are shown. Boulder Falls is a knickpoint on N. Boulder Creek; steep-walled canyons mark similar knickzones.

variety of techniques to map and characterize near-surface geologic materials and their properties in each of the study catchments.

SETTING

The middle Boulder Creek catchment (Fig. 1) extends from the glaciated alpine zone of the Continental Divide east to the semi-arid western edge of the Great Plains. Deep, U-shaped valleys in the glaciated areas become shallower eastward through a zone of low relief and relatively low slopes, 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 dot the alpine zone, which exposes bedrock and relatively thin deposits related to the latest Pleistocene Pinedale glaciation and Holocene erosion. The forested zone of low relief exposes areas of thick (characteristically 3 to 8 m) regolith, saprolite and oxidized bedrock, but the weathered mantle is thin in other areas. In the vicinity of knickzones and in downstream areas such as Betasso gulch, slopes near channels are steep with shallow, fresh bedrock whereas more distant areas retain a thicker weathered mantle.

APPROACH

In this second project year, we used field mapping and sampling, supplemented by geophysical measurements, in all three CZO catchments, in order to provide basic data about the shallow geology and erosional history of the critical zone and to help guide the location of future studies. Keck students learned geophysical techniques and initial data reduction, processing and visualization methods in these settings. Students chose from a variety of potential projects in the study catchments. In 2009 project topical areas included:

1. Fracture distribution and bedrock geology, Betasso catchment
2. Talus structure and evolution, Green Lakes and Betasso catchments
3. The distribution of tors, Gordon Gulch catchment
4. Regolith stirring by biologic processes,

Gordon Gulch

We ran ground-penetrating radar and resistivity lines in Gordon Gulch and in the Green Lakes Valley and worked in cooperation with investigators from the University of Colorado, who ran seismic-refraction lines in Gordon Gulch.

STUDENT PROJECTS

Three Keck students (Liz Dengler from Bates, Evan Riddle from North Carolina State, and JT Trotta from Williams) joined Bex Gilbert (Williams), who was supported by NSF funding. David Dethier supervised students on a daily basis and field teams frequently joined investigators and graduate students from the University of Colorado. Matthias Leopold (Technical University of Munich) worked with Keck students for about a week in the field. Keck students were among the only undergraduates to present preliminary results of their field research at the 2nd annual Boulder Creek CZO meeting on 11 August 2009. Keck Colorado research spread across the three Boulder CZO study catchments and students worked in pairs on a daily basis and sometimes as geophysical support teams (Fig. 2). Geophysical data provided important background data for Trotta's work and for Riddle's talus studies.



Figure 2. Resistivity measurements on stabilized talus, Green Lakes Valley.

Liz Dengler mapped the fracture distribution and bedrock geology of the Betasso catchment and nearby Bummers Rock (Fig. 3), which are underlain by rocks of the Boulder Creek batholith (Gable, 1980). Fractures produced by tectonism (Molnar et al., 2007) and local stresses (Selby, 1980) play a central role in weathering, in preparing rock for erosion and in groundwater recharge and flow, but regolith masks fractures in most of the CZO.



Figure 3. Talus survey below Bummers Rock, Betasso Gulch area.

By measuring fracture orientation and mapping bedrock at 284 sites (Fig. 4), Liz was able to demonstrate that Betasso granodiorite and quartz monzonite are cut by two predominant fracture sets that likely record Laramide reactivation of Precambrian structures. She showed that fracture orientations define a conjugate N-NW set (Pair A) parallel to a hematite-rich fault zone mapped in Betasso Gulch and an E-NE set (Pair B). Field evidence suggests that faults and zones of hydrothermal alteration parallel to Pair B are also present. Regional evidence (Kellogg et al., 2008) suggests that Pair A and Pair B are Laramide or late Laramide structures and that the hydrothermal alteration and mineralization are

related to the Colorado Mineral Belt (Lovering and Tweto, 1953). Local field relations do not clearly define the relative age relationship between Pair A and B.



Figure 4. Liz Dengler measuring fractures in Boulder Creek Granodiorite on Bummers Rock.

Most fractures dip steeply to the east or northeast. Fracture spacing has a mean value between about 0.5 and 1.0 m ($n=143$) and local spacing varies from less than 10 cm to ~7 m. (Fig. 5). Rocks appear to be more densely fractured near major faults and more widely fractured in local areas near the top of Bummers Rock, perhaps accounting for its persistence in an erosional landscape.

Evan Riddle studied the deposition and morphology of talus below Bummers Rock (Betasso catchment) and above Green Lake 3 (Fig. 6), where deposits have accumulated in an area that was deglaciated at about 12 ka. Working with Matthias Leopold, Evan used GPR (Fig. 7) to estimate the thickness of talus along several transects near the lake. Combining thickness measurements and estimates allowed him

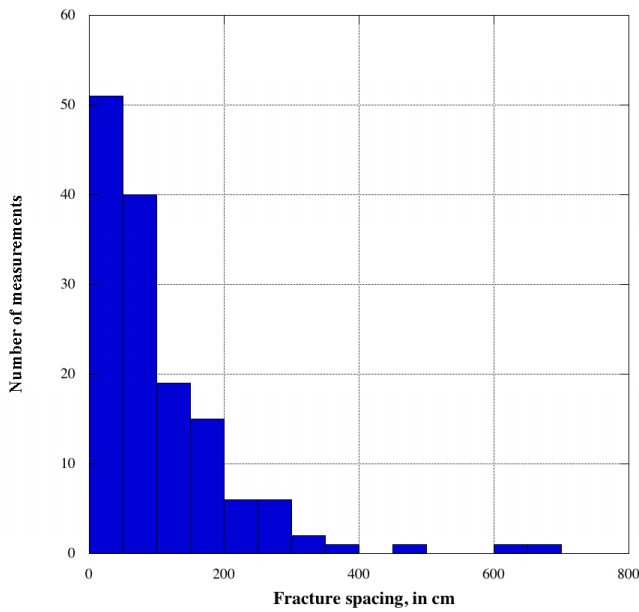


Figure 5. Fracture-spacing frequency diagram, Betasso Gulch area (E. Dengler data).



Figure 6. Oblique view of south-facing talus slope and talus cone studied by Evan Riddle. Light colored outcrops are Silver Plume granite. Green Lake 3 in foreground.

to estimate talus volume. Evan's research shows that talus blocks at the alpine site are unstable, subangular and relatively unweathered and that their size distribution mirrors fracture spacing in their source area. In contrast, talus below Bummars Rock (Fig. 3) consists of more rounded, partially weathered blocks that only partially cover the slope below their source area. Evan postulated that the release of talus blocks at Bummars Rock requires weathering and rounding of blocks bounded by joint surfaces, followed by eventual sliding or toppling. To characterize block rounding, Evan constructed a gauge (Fig. 8)



Figure 7. Evan Riddle using ground-penetrating radar on a talus cone, Green Lakes Valley area.

and used it to estimate the amount of material lost from fresh, partly weathered and weathered joint intersections. His preliminary results are promising, but will have more meaning when surface exposure ages from Bummars Rock are available and can be applied to local rates of cliff retreat.



Figure 8. Evan Riddle demonstrates use of block-rounding gauge to estimate the amount of material removed by weathering, Bummars Rock area.

Evan's preliminary work by Green Lakes 3 suggests that talus accumulation rates integrated over the past 12,000 yrs average $\sim 2 \text{ m}^3 \text{ yr}^{-1}$, equivalent to $< 0.1 \text{ mm}$ of cliff retreat per year. These rates are relatively low, but are generally consistent with values reported by Caine (1986) from the upper Green Lakes Basin.

JT Trotta mapped the mostly isolated bedrock outcrops (tors; Fig. 9) of Gordon Gulch, which is developed on a rolling surface of low relief, an area previously mapped as thick saprolite and well-developed soils (Birkeland et al., 2003). Work by Keck students and investigators from the University of Colorado, however, suggests that the weathered zone may be thin in many areas and the soils young. If this view of the landscape is correct, tor distribution may reflect relatively recent erosion. JT's mapping shows that bedrock exposures form the surface in $\sim 4.5\%$ of the catchment and that tors locally stand as high as 15 m above surrounding slopes. Tall tors appear to be less weathered at ground level than at 5 to 10 m above the ground, where gneissic layers locally display decimeters of local relief.



Figure 9. Tor developed in granitic rocks, Gordon Gulch.

Tors are unevenly distributed in the basin and are more common on steep, south-facing slopes than in adjacent areas with northern aspects (Fig. 10). Bedrock, which consists of sillimanite and garnet-bearing Proterozoic gneisses and 1.4 Ga granitic rocks, does not appear to control directly the size,

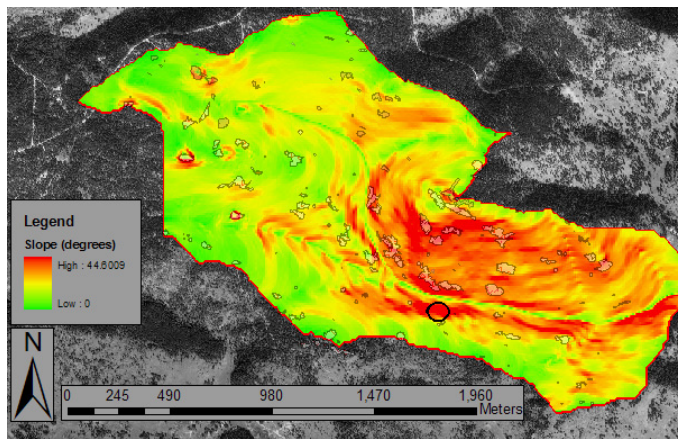


Figure 10. Outcrop map layer overlay on a DEM-based slope map of Gordon Gulch. The southeastern part of the catchment has the highest slope and the greatest number of outcrops. Black circle shows the location of Figure 11.

shape or location of tors. However, foliation, which strikes NW and dips NE, is mainly slope-parallel on north-facing slopes, where there are fewer bedrock exposures (Fig. 11). Tors are thought to be remnant features typical of deeply weathered landscapes (Street, 1971). The association of tors with steep areas in Gordon Gulch suggests that these features may record geologically recent erosion that stripped regolith and saprolite.



Figure 11. Image looking northwest along a steep part of Gordon Gulch that has almost no outcrops. The slope of the north-facing hill in this picture is approximately 35° . See Figure 10 for the location of this photo.

Rebecca (Bex) Gilbert studied soil stirring by biologic activity in Gordon Gulch, focusing on treethrow and on sediment moved by ants and by prospectors looking for gold, silver and tungsten. To help calibrate root and pit measurements made at some 150 uprooted trees, Bex and the Keck students pulled apart 15 recent rootballs and weighed the rocks and soil that had been disrupted by the treefalls (Fig. 12). Gilbert's results show that of the biologic agents studied in Gordon Gulch, prospectors disrupted the most area and volume (Fig. 13), over a period of a century. Treethrow lifts and mixes an average of $\sim 2 \text{ m}^3 \text{ km}^{-2}$ of regolith from depths of



Figure 12. Bex Gilbert (Williams College) and fresh rootball, Gordon Gulch

20 to 50 cm each year. Ants (*Formica* sp.) may be the most effective mixers of shallow regolith in Gordon Gulch, but additional work is needed to quantify how frequently anthills are constructed. The upper 50 cm of regolith creeps downslope under the influence of a suite of processes in areas like Gordon Gulch, but biological activity may be the most important.

Future Keck studies will build on work by the 2009 Keck group and on the NSF-sponsored hydrology and treethrow studies of Eirik Buraas and Bex Gilbert, respectively, in Gordon Gulch. We hope to involve students in additional studies of rockfall and talus formation, in documenting the effects of anthropogenic influences on the Gordon Gulch and

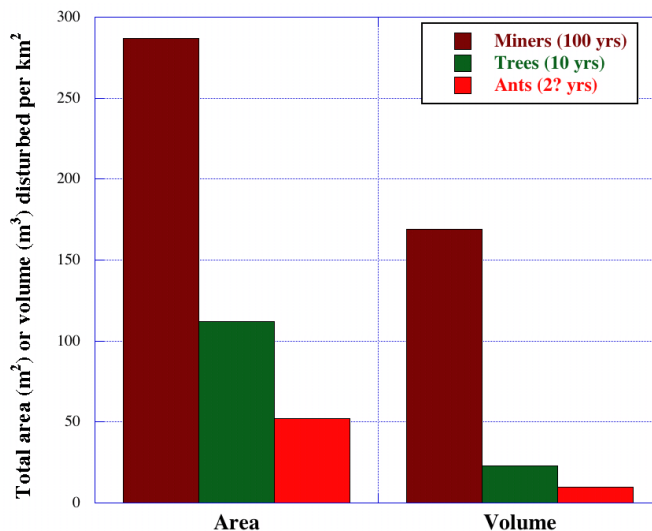


Figure 13. Surface area and volume of regolith disturbed by prospecting, treethrow and ant activity, Gordon Gulch.

Betasso catchments and in more detailed analyses of the effects of eolian deposition on soil development and catchment chemistry in the Boulder Creek CZO.

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 basin, Pete Birkeland (University of Colorado) taught us about soils and Suzanne Anderson and Anne Sheehan (both at University of Colorado) shared their knowledge of the Critical Zone and how to study it in many field “teaching moments”. Rory Cowie (University of Colorado) introduced us to the channels and slopes of Gordon Gulch. We gratefully acknowledge the ongoing cooperation and cogent advice of Joerg Voelkel and Matthias Leopold (Technical University of Munich) and the hospitality of the Mountain Research Station.

REFERENCES

- Birkeland, P.W., Shroba, R.R., Burns, S.F., Price, A.B., Tonkin, P.J., 2003, Integrating soils and geomorphology in mountains—an example from the Front Range of Colorado: *Geomorphology*, v. 55, p. 329–344.
- Caine, T.N., 1986, Sediment movement and storage on alpine slopes in the Colorado Rocky Mountains, in Abrahams, A., *Hillslope Processes*: Boston: Allen & Unwin, p. 115–37.
- Gable, Dolores J., 1980, The Boulder Creek Batholith, Front Range, Colorado: Geological Survey Professional Paper 1101, 88 p.
- Kellogg, K.S., Shroba, R.R., Bryant, Bruce and Premo, W.R., 2008, Geologic map of the Denver West 30' x 60' quadrangle, north-central Colorado: U.S. Geological Survey Scientific Investigations Map 3000, scale 1:100,000, 48-p. pamphlet.
- Lovering, T.S., and Tweto, Ogden, 1953, *Geology and ore deposits of the Boulder County tungsten district, Colorado*: U.S. Geological Survey Professional Paper 245, 199 p.
- Molnar, P., Anderson, R. S., and Anderson, S. P. 2007, Tectonics, fracturing of rock, and erosion: *Journal of Geophysical Research*, 112, F0312, doi:10. 1029/2005JF000433.
- Selby, M. J., 1980, A rock mass strength classification for geomorphic purposes: with tests from Antarctica and New Zealand: *Zeitschrift für Geomorphologie* v. 24, p. 31-51.
- Street, F.A., 1971, A study of tors in the Front Range of the Rocky Mountains in Colorado, with special reference to their value as an indicator of non-glaciation: M. S. thesis, University of Colorado, Boulder, 242 p.