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

April 2015
Union College, Schenectady, NY

Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convener
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2015

Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA 91711

Christina Kelly
Proceedings Layout & Design
Scripps College

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

2014-2015 PROJECTS

RESILIENCE OF ENDANGERED ACROPORA SP. CORALS IN BELIZE. WHY IS CORAL GARDENS REEF THRIVING?:
Faculty: LISA GREER, Washington & Lee University, HALARD LESCINSKY, Otterbein University, KARL WIRTH, Macalester College
Students: ZEBULON MARTIN, Otterbein University, JAMES BUSCH, Washington & Lee University, SHANNON DILLON, Colgate University, SARAH HOLMES, Beloit College, GABRIELA GARCIA, Oberlin College, SARAH BENDER, The College of Wooster, ERIN PEELING, Pennsylvania State University, GREGORY MAK, Trinity University, THOMAS HEROLD, The College of Wooster, ADELE IRWIN, Washington & Lee University, ILLIAN DECORTE, Macalester College

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE, SOUTH CENTRAL ALASKA:
Faculty: CAM DAVIDSON, Carleton College, JOHN GARVER Union College
Students: KAITLYN SUAREZ, Union College, WILLIAM GRIMM, Carleton College, RANIER LEMPERT, Amherst College, ELAINE YOUNG, Ohio Wesleyan University, FRANK MOLINEK, Carleton College, EILEEN ALEJOS, Union College

EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SW MONTANA: METASUPRACRUSTAL ROCKS OF THE RUBY RANGE
Faculty: TEKLA HARMS, Amherst College, JULIE BALDWIN, University of Montana
Students: BRIANNA BERG, University of Montana, AMAR MUKUNDA, Amherst College, REBECCA BLAND, Mt. Holyoke College, JACOB HUGHES, Western Kentucky University, LUIS RODRIGUEZ, Universidad de Puerto Rico-Mayaguez , MARIAH ARMENTA, University of Arizona, CLEMENTINE HAMELIN, Smith College

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1358987
ExxonMobil Corporation

GEOMORPHOLOGIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA:
Faculty: KELLY MACGREGOR, Macalester College, AMY MYRBO, LabCore, University of Minnesota
Students: ERIC STEPHENS, Macalester College, KARLY CLIPPINGER, Beloit College, ASHLEIGH, COVARRUBIAS, California State University-San Bernardino, GRAYSON CARLILE, Whitman College, MADISON ANDRES, Colorado College, EMILY DIENER, Macalester College

ANTARCTIC PLIOCENE AND LOWER PLEISTOCENE (GELASIAN) PALEOCLIMATE RECONSTRUCTED FROM OCEAN DRILLING PROGRAM WEDDELL SEA CORES:
Faculty: SUZANNE O'CONNELL, Wesleyan University
Students: JAMES HALL, Wesleyan University, CASSANDRE STIRPE, Vassar College, HALI ENGLERT, Macalester College

HOLOCENE CLIMATIC CHANGE AND ACTIVE TECTONICS IN THE PERUVIAN ANDES: IMPACTS ON GLACIERS AND LAKES:
Faculty: DON RODBELL & DAVID GILLIKIN, Union College
Students: NICHOLAS WEIDHAAS, Union College, ALIA PAYNE, Macalester College, JULIE DANIELS, Northern Illinois University

GEOLOGICAL HAZARDS, CLIMATE CHANGE, AND HUMAN/ECOSYSTEMS RESILIENCE IN THE ISLANDS OF THE FOUR MOUNTAINS, ALASKA
Faculty: KIRSTEN NICOLAYSEN, Whitman College
Students: LYDIA LOOPESKO, Whitman College, ANNE FULTON, Pomona College, THOMAS BARTLETT, Colgate University

CALIBRATING NATURAL BASALTIC LAVA FLOWS WITH LARGE-SCALE LAVA EXPERIMENTS:
Faculty: JEFF KARSON, Syracuse University, RICK HAZLETT, Pomona College
Students: MARY BROMFIELD, Syracuse University, NICHOLAS BROWNE, Pomona College, NELL DAVIS, Williams College, KELSA WARNER, The University of the South, CHRISTOPHER PELLAND, Lafayette College, WILLA ROWEN, Oberlin College

FIRE AND CATASTROPHIC FLOODING, FOURMILE CATCHMENT, FRONT RANGE, COLORADO:
Faculty: DAVID DETHIER, Williams College, WILLIAM. B. OUIMET, University of Connecticut, WILLIAM KASTE, The College of William and Mary
Students: GREGORY HARRIS, University of Connecticut, EDWARD ABRAHAMS, The College of William & Mary, CHARLES KAUFMAN, Carleton College, VICTOR MAJOR, Williams College, RACHEL SAMUELS, Washington & Lee University, MANEH KOTIKIAN, Mt. Holyoke College, WILL WICHERSKI, Williams College

SOPHOMORE PROJECT: **AQUATIC BIOGEOCHEMISTRY: TRACKING POLLUTION IN RIVER SYSTEMS**
Faculty: ANOUK VERHEYDEN-GILLIKIN, Union College
Students: CELINA BRIEVA, Mt. Holyoke College, SARA GUTIERREZ, University of California-Berkeley, ALESIA HUNTER, Beloit College, ANNY KELLY SAINVIL, Smith College, LARENZ STOREY, Union College, ANGEL TATE, Oberlin College

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1358987
ExxonMobil Corporation

Keck Geology Consortium: Projects 2014-2015
Short Contributions— Fire and Catastrophic Flooding, CO Project

FIRE AND CATASTROPHIC FLOODING, FOURMILE CATCHMENT, FRONT RANGE, COLORADO:
DAVID DETHIER, Williams College
WILLIAM. B. OUIMET, University of Connecticut
WILLIAM KASTE, The College of William and Mary

INVESTIGATING THE USE OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) AS PROXIES FOR HOLOCENE FOREST FIRES ON THE COLORADO FRONT RANGE
GREGORY HARRIS, University of Connecticut
Research Advisors: Michael Hren, University of Connecticut, Will Ouimet, University of Connecticut

POST-FIRE HILLSLOPE ASPECT CONTROLS ON EROSIONAL PROCESSES TRACED BY FALLOUT RADIONUCLIDES IN FOURMILE CANYON, COLORADO
EDWARD ABRAHAMS, College of William and Mary
Research Advisor: Jim Kaste

BURN SEVERITY EFFECTS ON HILL-SLOPE SOIL CHARACTERISTICS AND LOCAL VARIATION FOUR YEARS AFTER THE FOURMILE FIRE, BOULDER COUNTY, CO
OMAR KAUFMAN,Carleton College
Research Advisor: Mary Savina

CONNECTING SURFICIAL GEOLOGY AND HYDROLOGIC FLUX IN LEAKY, SNOWMELT-DOMINATED CATCHMENTS, NIWOT RIDGE, CO
VICTOR W. MAJOR, Williams College
Research Advisor: David P. Dethier

CHARACTERIZATION OF LEGACY MINE WASTE CONTRIBUTIONS TO FOURMILE CANYON, COLORADO
RACHEL SAMUELS, Washington and Lee
Research Advisors: Dave Harbor and Paul Low

RECONSTRUCTING THE HOLOCENE AND ANTHROPOCENE STRATIGRAPHIC HISTORY OF FOURMILE CANYON
MANEH KOTIKIAN, Mount Holyoke College
Research Advisor: Alan Werner
MANEH KOTIKIAN, Mt. Holyoke College

ANALYZING GEOMORPHIC EFFECTS OF THE SEPTEMBER 2013 FLOOD IN FOURMILE CANYON, COLORADO, USING LIDAR AND FIELD STUDIES
WILL WICHERSKI, Williams College Department of Geosciences
Research Advisor: David P. Dethier

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1358987
ExxonMobil Corporation

KECK Geology Consortium

Learning Science Through Research

Published by Keck Geology Consortium

Short Contributions
28th Annual Symposium Volume
25th April, 2015
ISBN: 1528-7491

RECONSTRUCTING THE HOLOCENE AND ANTHROPOCENE STRATIGRAPHIC HISTORY OF FOURMILE CANYON

MANEH KOTIKIAN, Mount Holyoke College
Research Advisor: Alan Werner

INTRODUCTION

In 2010, a wildfire burned through parts of Fourmile Canyon in the Front Range of Colorado. Three years later in 2013, a 50-year flood event caused extensive erosion in the canyon exposing the canyon-fill stratigraphy. The exposed cut banks along Fourmile creek reveal the geomorphologic history of different parts of the canyon and are useful for understanding the different period of environmental change, past events such as floods and wildfires, and human impacts that have occurred in the canyon. This study documents the exposed Holocene and Anthropocene canyon stratigraphy and provides an interpretation of its origin and age.

BACKGROUND

Setting

Fourmile Creek (65 km^2) begins at Niwot Ridge near the Continental Divide and discharges into Middle Boulder Creek at the junction of Country Road 118 and State Highway119. The canyon is characterized by steep slopes and discharge is heavily influenced by seasonal snowmelt and intense summer thunderstorms. The Front Range, where Fourmile Canyon is located, formed during the Laramide orogeny (Dickinson et al., 1988). Canyon slopes are comprised of oxidized granitic rock, saprolite, syenite, schist, felsic intrusive rocks, thin soils and grus (Dethier and Bove, 2011; Kellogg et al., 2008). Following deglaciation 21000-18000 yr BP, the Front Range was warmer and dryer during the Holocene climatic optimum until Neoglaciation between 5000 yr BP and 3000 yr BP (Benedict, 1973). Colder climate, glacial advance and greater snow cover occurred in the region 1505 yr BP to 955 yr BP, followed by high river discharges (Benedict, 1973).

Historical Record

Placer gold mining in Fourmile Canyon began during 1859 and marked a sharp transition of human impact and landscape change associated with the Anthropocene. The shift to vein-hosted gold mining resulted in over 200 companies building mills to processes ore (BCPOS, 2012). The impact from the mining history can be seen today with large mine shafts, exploration pits and waste piles dotting the hillslopes of the Fourmile watershed and tailings pond sediment at historic mill sites along Fourmile Creek. Multiple times between 1870 and 1920, a canyon railroad existed within Fourmile valley to transport recovered ore. The railroad was built on top of a distinctive road-bed fill to flatten the railway surface adjacent to Fourmile Creek.

Wildfires are common along the semi-arid Front Range. Fourmile Canyon experienced a large fire in September 2010, which burned a total of 16.5 km^2 (23% of the Fourmile watershed). A major five-day rainfall event occurred in September 2013 causing a 50-year flood. This rain event caused 1,138 debris flows in the Front Range in a 3,430 km^2 area and heavy erosion in the canyons, one of which was Fourmile (Coe et al., 2014).

METHODS

Field Methods

Exposures: Exposures were located along Fourmile Creek using a 1-m resolution Digital Elevation Model from LiDAR data (light detection and ranging) or by hiking the canyon. The LiDAR used was taken after the 2013 flood (Anderson et al., 2012). The location of each exposure was recorded using a GPS (Fig. 1) and each exposure was cleared with shovels and trowels to freshly expose the stratigraphy. The stratigraphy was then photographed, sketched to document the major stratigraphic units, described, and measured.

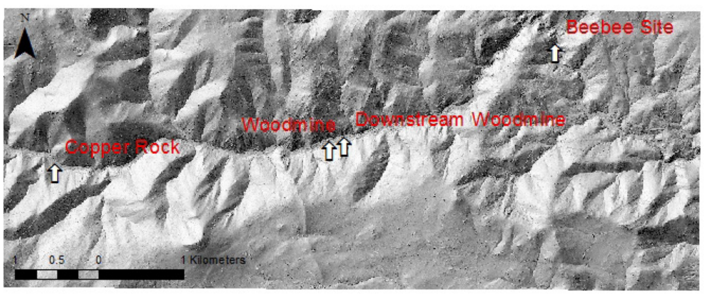

Figure 1. Field map showing sites discussed in text on a 1-m LiDAR hillshade (Anderson et al., 2012).

Field classification of stratigraphy: Exposures containing sediment from mine tailing ponds exhibited characteristic orange, gray and white layers of fine sand, silt or clay. Placer mine gravel deposits exhibited large rounded clasts placed in piles with little sand or gravel. Informally referred to as the "railroad layer," a thick deposit (typically greater than 10 cm) rich in coal, charcoal and soot covered sediment, accumulated while the railroad was in use. Meanwhile, railroad fill, typically occurred below the railroad layer and was characterized by having large angular blocks stacked to fill depressions during the railroad construction. Both the railroad layer and railroad fill were consistently found in proximity to the railroad grade, which was easily identified in the field and in LiDAR data. Slope deposits, associated with side-valley colluvial and alluvial processes, typically contained thin charcoal layers and layers with angular rocks and sediment. In contrast, fluvial deposits, representing canyon channel and floodplain deposition, contained imbricated clasts and a matrix that was better sorted, less angular and more compositionally mature.

Sampling of exposures: Samples were collected at the exposures for subsequent lab analysis and dating. Layers containing charcoal were sampled in order to provide age control for the associated stratigraphies and to estimate wild fire recurrence intervals. The main stratigraphic units were sampled to determine depositional environments. In layers containing large cobbles and boulders, only the matrix was sampled. Samples of the charcoal were collected for radiocarbon dating therefore the emphasis was on collecting the largest pieces of charcoal, not the matrix.

Lab Methods

Grain size analysis and characterization: Grain size analysis was done by dry sieving using a Ro-Tap shaker. The sieve sizes used include 16 mm, 4mm, 2mm, 1.18mm, 0.5mm, 0.25mm, 0.063mm and less than 0.063 mm and were chosen to represent the primary grain size boundaries (Folk, 1980). A representative amount (200g to 600 g) of each sample was weighed and sieved for 10 minutes. The samples collected by each sieve were weighed and recorded. Samples containing charcoal fragments in the matrix were run without separating charcoal out. A dissecting microscope was used to characterize the angularity and composition of each collected sample. Clast sphericity and angularity were classified using a particle shape chart (Miller and Henderson, 2010).

Particle size statistics: Particle size statistics were calculated using GRADISTAT version 8.0 (Blott and Pye, 2001). Grainsize distribution, mean, sorting, skewness, and kurtosis values were calculated for each sample and all samples were plotted on a gravel-sand-mud diagram using GRADISTAT.

Carbon-14 dating: Two exposures exhibited charcoal for Carbon-14 dating (Woodmine and Beebee). Charcoal from six samples was picked using tweezers to be dated at Woods Hole Oceanographic Institute using AMS carbon dating. Prior to dating, the outer surface of the charcoal was cleaned and then leached in heated acid-base-acid leaches to ensure no additional carbon or organic material remained.

Carbon dioxide was produced from the charcoal sample and reacted with a Fe-catalyst to form graphite which was then pressed onto targets that were analyzed using accelerator mass spectrometry. The samples' calibrated calendar ages were obtained using the Fairbanks0107 conversion (NOSAMS, 2014)**.**

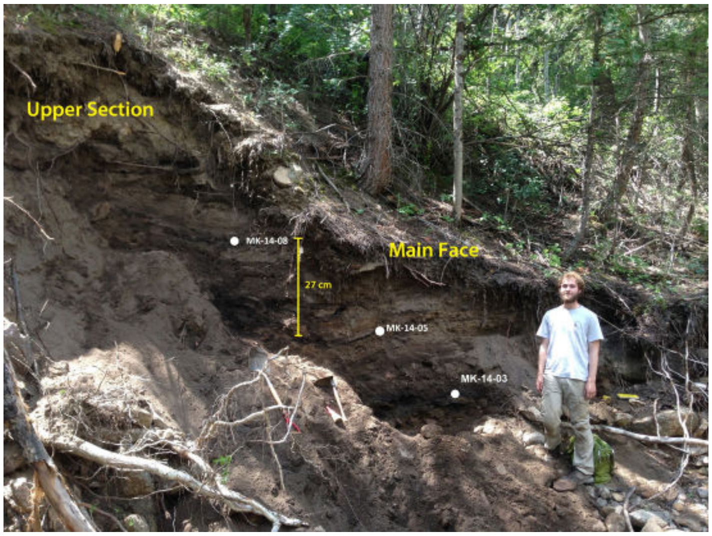

Figure 2. Photograph of Woodmine exposure showing the main face and the upper section with respect to dated stratigraphy.

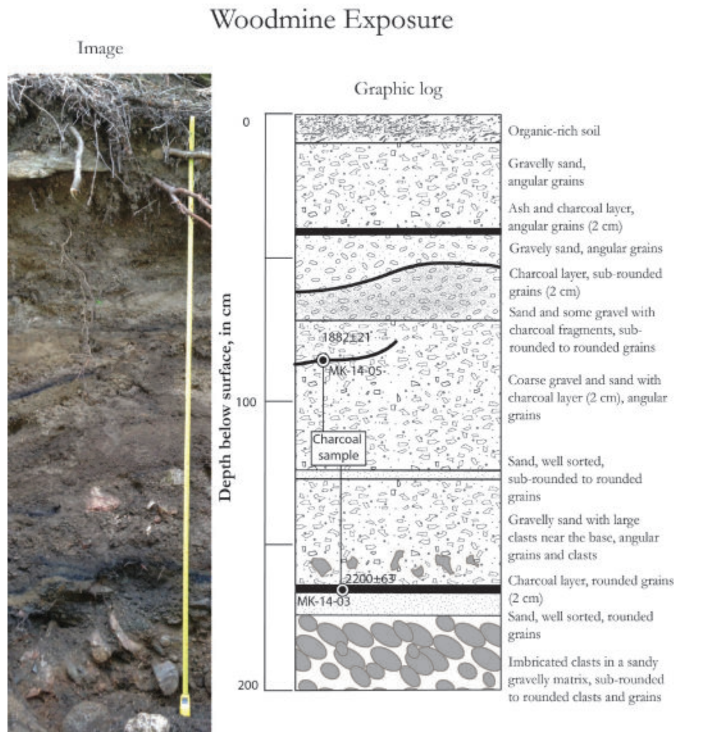

Figure 3. Photograph and graphic log of the Woodmine exposure with descriptions and known charcoal dates labeled with their corresponding sample name.

RESULTS

Summary of exposures

The exposures reveal different periods of time into the history of the canyon from the Holocene through the Anthropocene. The Woodmine exposure (Fig. 1) is located at the base of a hillslope and contains two main parts: the main face, and the upper section (Fig. 2). The main face has a height of 200cm and the upper section is 200cm taller than the main face. This exposure was revealed by the 2013 flood in Fourmile canyon. The railroad grade is in close proximity to the outcrop but the exposure does not have railroad coal or other man-made materials in the stratigraphy indicating no Anthropocene related sediment deposition. The base of this outcrop has large clasts that are imbricated with a thin layer of sand on top as well as multiple charcoal rich layers (Fig. 3).

The Beebee site lies behind an abandoned house next to the property of Mr. Robert Beebee and is located at the base of a hillslope and was exposed by the 2013 flood (Fig. 1). The exposure is a slope deposit with multiple charcoal layers and shows no signs of fluvial interactions however coal pieces were found at the top indicating some Anthropocene modified deposits (Fig. 4A).

The Copper Rock site is surrounded by slopes but is located in a flattened area of the canyon (Fig. 1). The 2013 flood uncovered this exposure revealing the railroad fill with preserved stratigraphy below. Beneath the railroad fill was a mud-rich deposit 40cm thick that was dark in color from the organics it contained (sample MK-14-22).

The Downstream Woodmine exposure (Fig. 1) was indicative of the effect of the Anthropocene related activity in the region. It contained both placer mine tailings as well as sediment from a tailings pond. 30 cm beneath the mine tailings pond deposit was a gray, mud-rich charcoal deposit (MK-14-13) on top of a terrace with large imbricated clasts (Fig. 4B). Placer mine tailings continue behind the exposure and further back towards the base of the slope is the railroad graded surface.

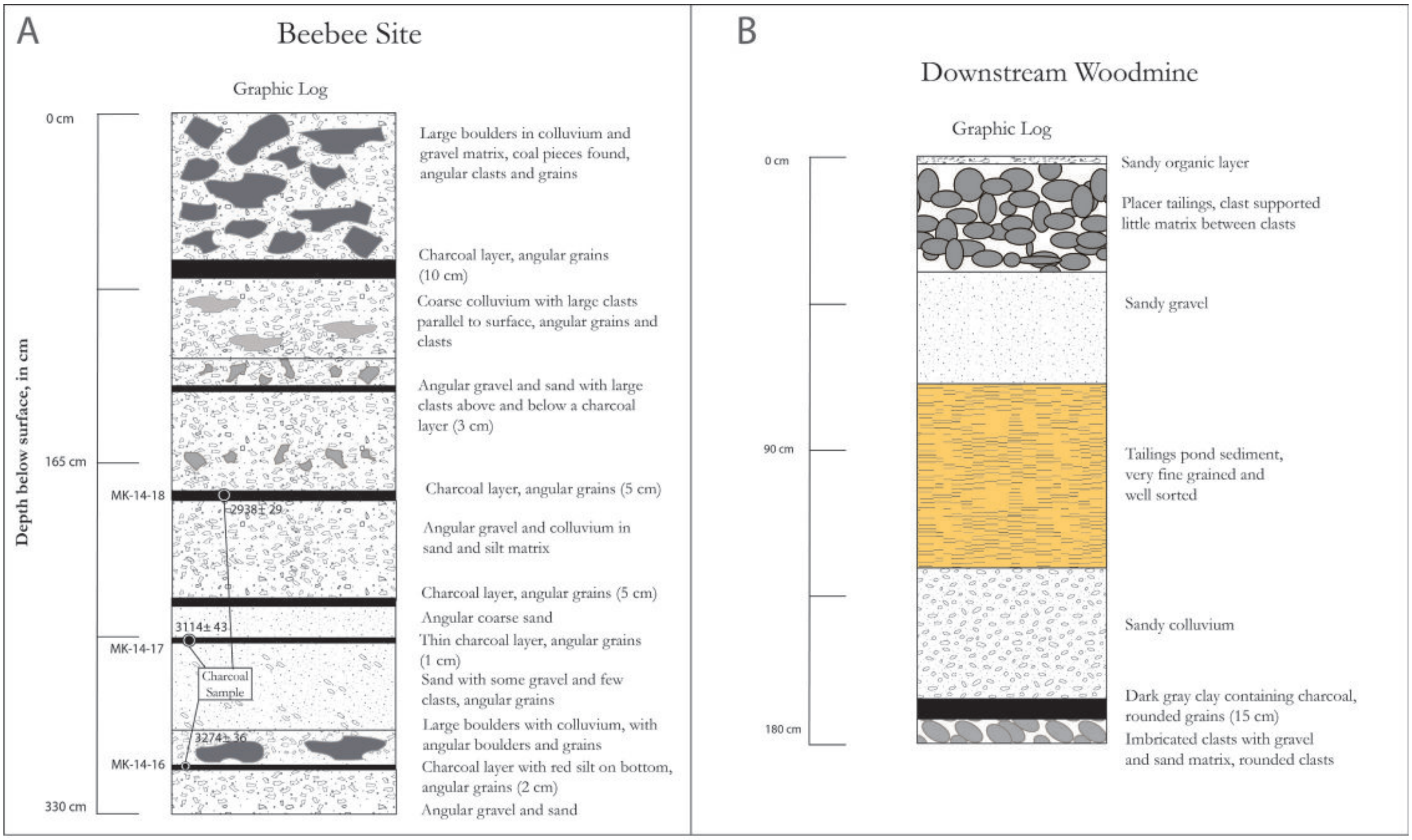

Figure 4. Graphic log of Beebee (A) and Downstream Woodmine (B) with descriptions and known charcoal dates labeled with their corresponding sample names.

Grain Size, Shape, and Maturity Analysis

The grain size analysis showed that all samples had relatively low silt/clay contents with only one apparent clustering of data points, Cluster A (Fig. 5). This cluster contains samples with a higher sand content based on the sand to gravel ratio. Analysis of samples from the Woodmine, Downstream Woodmine, and Copper Rock sites found in Cluster A suggests that all of these samples were fluvial due to their rounded to sub-rounded grains. At Woodmine, some layers contained rounded grains and had less gravel (Fig. 5) while other layers at the same locality contained only angular grains. These results are shown with the associated stratigraphic column at Woodmine (Fig. 3). At the Beebee site, all samples had angular clasts of a similar texture (Fig. 4A).

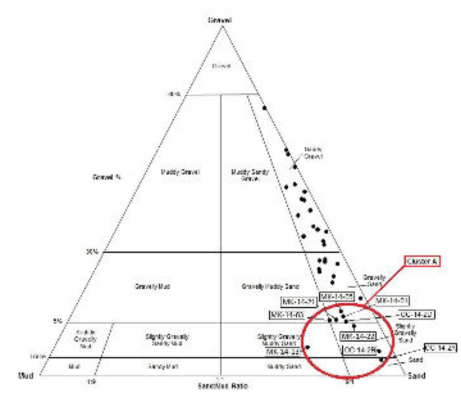

Figure 5. Gravel-sand-mud ternary diagram made by GRADISTAT (Blott and Pye, 2001). Cluster A is labeled with samples MK-14-01, -03 and -05 and OC-14-2A, -2B and -2D from Woodmine, sample MK-14-13 from Downstream Woodmine, and samples MK-14-21 and -22 from Copper Rock.

Charcoal Dates

Age control for the exposed stratigraphy at Woodmine and the Beebee site is provided by charcoal dates that ranged from 3274 yr BP to 475 yr BP (Table 1). Samples MK-14-03, 05, and 08 are from the Woodmine exposure and their ages are in stratigraphic order with the oldest, 2200 yr BP, at the bottom of the exposure (Fig. 3). Samples MK-14-16, 17 and 18 are from the Beebee site had charcoal ages come back in

Charcoal Dates in Years B.P.

Sample Name	14 C Age	Age Error	Calibrated Calendar Age			Δ13 C	Δ14 C
			Age	Standard Deviation	Calibration Version		
MK-14-3	2180	20	2200	63	Fairbanks0107	-23.79	-243.4
MK-14-5	1940	20	1882	21	Fairbanks0107	-26.31	-220.83
MK-14-8	390	15	475	25	Fairbanks0107	-21.88	-54.76
MK-14-16	3050	20	3274	36	Fairbanks0107	-23.6	-321.52
MK-14-17	2950	20	3114	43	Fairbanks0107	-21.77	-312.67
MK-14-18	2840	20	2938	29	Fairbanks0107	-23.34	-303.19

Table 1. Table of charcoal samples and corresponding carbon-14 dates.

stratigraphic order with the oldest, dating to 3274 yr BP, at the base of the exposure (Fig. 4A).

INTERPRETATIONS

Woodmine

Fluvial deposits at Woodmine are interfingered with colluvial deposits in outcrop. This makes sense because the exposure is located in contact with the base of the slope and the creek. Mapped exposure at Woodmine is 200cm – the upper 70cm is dominantly colluvial and the bottom 50cm is dominantly fluvial with a 50cm thick section of interfingering when clear fluvial sand has clear colluvium directly above and below (Fig. 3). Variations in stratigraphy suggest a change in the pattern of deposition which could be caused by environmental change, such as climate or human interactions that change the way sediment naturally accumulates.

The charcoal dated at Woodmine was in stratigraphic order from distinct layers suggesting that the charcoal was not a result of slope processes but was probably created at that location or in close proximity to where the samples were collected. Radiocarbon dated wildfires occurred during 2200 yr BP, 1882 yr BP, and 475 yr BP (Table 1). Sample MK-14-08 was dated from the upper section of the Woodmine exposure adjacent to the main face in order to compare the ages of stratigraphic units to determine the cause of the change in shape between the main face and the upper section. MK-14-08 is only 475 yr BP whereas MK-14-05 (main face) was 1882 yr BP (Fig. 2). With a height difference of 27cm between these two samples, it is possible that the upper section is younger than the main face of the exposure indicating that the top of the main face was eroded away.

Copper Rock

The thick clay-rich deposit (MK-14-22) at Copper Rock beneath the railroad fill is interpreted to be a slack-water depositional setting because of the high organic matter content, the rounded clasts, and the thickness of the stratigraphic layer (30cm). It is likely that this represents ponding of water by a landslide, flood deposit, or beavers (Madole, 2012).

Beebee Site

The radiocarbon ages of the charcoal in the three layers' dates at the Beebee site are 3274 yr BP, 3144 yr BP, and 2938 yr BP, respectively. The charcoal samples at this site were all slope deposits based on the texture of the associated sediment. The charcoal layers must have occurred from fires in close proximity to the outcrop because of their concentration. Although coal is found in the top-most layer, the Anthropocene impact did not affect the aggradation pattern of the site.

Downstream Woodmine

The clay rich layer just above the imbricated clasts shows a low energy depositional setting following a high energy fluvial event. Based on the stratigraphy between the Woodmine exposure and Downstream Woodmine, it appears that imbricated clasts of this size are not commonly occurring deposits of Fourmile creek. The mine tailings in the stratigraphy at Downstream Woodmine indicate Anthropocene reworking of sediment. During 50 years that mining boomed in this region, 130cm of sediment has accumulated.

DISCUSSION

Fluvial aggradation occurs during waning flow conditions accumulating at the base of the creek raising the grade. When stream discharge is low, its capacity to carry a large load decreases resulting in sediment deposition (Bull, 1990). The same is true for slope deposits. When the system does not have enough energy to remove more than is being accumulated, there will be aggradation (Bull, 1990). Interfingering of slope deposits and fluvial deposits indicate times when both systems did not have enough energy to remove extra accumulation of sediment and deposited it as canyon-fill. The disappearance of glaciers after 3000 yr BP suggests less meltwater in the creek corresponding with fluvial aggradation. It is possible that periods of dryer climate led to the aggradation sediment which was followed by periods of wetter climate causing degradation of Fourmile Canyon. Samples in Cluster A (Fig. 3) are all interpreted to be of fluvial origin because of their rounded clasts and higher relative sand content. The missing sediment on the main face of the Woodmine exposure suggests that a large erosional event such as a flood or debris flow selectively wiped the top sediment away on that face leaving the upper section intact.

During 50 years that mining boomed in this region, Downstream Woodmine indicates that as much 130 cm of sediment (much of what the flood exposed) is directly associated with Anthropocene landscape change and human activity within the Fourmile floodplain. Closer to valley sides, such as expressed in Woodmine and Beebee, there is less indication of the Anthropocene. Overall, stratigraphic columns and descriptions show that railroad and mining related sediment associated with the human activity in the Anthropocene was deposited directly on top of older Holocene deposits and often consisted of reworking the older deposits (such as the placer deposits of Downstream Woodmine).

The oldest charcoal samples dated at Woodmine and at the Beebee site show that the accessible canyon-fill at Fourmile Canyon is young, dating exclusively to the late Holocene. Overall, during the late Holocene, sediment was aggrading in Fourmile Canyon. This is significant because during the Holocene, aggradation was not occurring at the rate it accumulated at during the Anthropocene. By understanding the Anthropocene impact in Fourmile Canyon, it is possible to further investigate the impact humans have on the erosion of slopes, the likehood of more frequent fires and the severity of floods from increased run-off.

CONCLUSION

The stratigraphy exposed by the Fourmile Canyon Flood in 2013 provides evidence of past forest fires, periods of fluvial aggradation and slope deposition during the Holocene and the effects of human activity in the Anthropocene. The canyon fill contains interbedded charcoal and fluvial and slope deposits that can be differentiated confidently based on angularity and sand to gravel ratios. The dates on charcoal record times of localized forest fires and provide an age control for the canyon stratigraphy while giving an idea of fire occurrence intervals. The charcoal dates showed that the canyon fill dates to the late Holocene. The canyon-fill is young and may represent a time of canyon aggradation during an interval of increased aridity. The stratigraphy gives an insight on Holocene patterns of sediment accumulation as well as patterns of sediment accumulation during the Anthropocene and the changes in accumulation rates, forest fire occurrence intervals and the frequency of large erosional events.

ACKNOWLEDGEMENTS

I would like to thank the Keck Geology Consortium and NSF for giving me this opportunity and for funding my research. Partial funding for carbon-14 analysis was provided by NSF Geomorphology and Land Use Dynamics (NSF EAR-1401260). I would also like to thank David Dethier and Will Ouimet for their continued assistance and advice from the beginning of my project to the end, and Al Werner for his guidance once I was back at Mount Holyoke. Finally, I would like to thank the rest of my Keck group for their support.

REFERENCES

Anderson, S.P., Qinghua, G., and Parrish, E. G., 2012, Snow-on and snow-off LiDAR point cloud data and digital elevation models for study of topography, snow, ecosystems and environmental change at Boulder Creek Critical Zone Observatory, Colorado: Boulder Creek CZO, INSTAAR, University of Colorado, Boulder, digital media.

BCPOS (Boulder County Parks and Open Space). Fourmile Canyon Historical and Architectural Survey, 2012-2013. By Mary Therese Anstey and Adam Thomas. Compiled by HISTORITECTURE, L.L.C. Report no. Project CO-12-018. N.p.: n.p., 2013.

Benedict JB (1973) Chronology of cirque glaciation, Colorado Front Range. Quaternary Research 3: 584–600.

Blott, S. J., and Pye, K. “GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments.” Earth surface processes and Landforms 26, no. 11 (2001): 1237-1248.

Bull, W. B. “Stream-terrace genesis: implications for soil development. “Geomorphology 3, no. 3 (1990): 351-367.

Coe, J. A., Kean, J.W., Godt, J.W., Baum, R.L., Jones, E.S., Gochis, D.J., and Anderson, G.S., 2014, New insights into debris-flow hazards from an extraordinary event in the Colorado Front Range. *GSA Today* 24, no. 10.

Dickinson, W.R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, M.A., McKittrick, M.A., and Olivares, M.D., 1988, Paleogeographic and paleotectonic setting of the Laramide sedimentary basins in the central Rocky Mountain region: *Geological Society of America Bulletin*, v. 100, p. 1023–1039, doi: 10.1130/0016-7606(1988)100<1023:PAPSOL>2.3.CO;2

Dethier, D.P. and Bove, D.J., 2011, Mineralogic and Geochemical Changes from Alteration of Granitic Rocks, Boulder Creek Catchment, Colorado. *Vadose Zone Journal* 10: 858-866. DOI: 10.2136/vzj2010.0106

Folk, R. L., 1980, Petrology of Sedimentary Rocks. Austin, TX: Hemphill Publishing Company.

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.

Leopold, M., and Völkel, J., 2007, Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. *Quaternary International* 162,133-140.

Madole, R.F., 2012, Holocene alluvial stratigraphy and response to climate change in the Roaring River valley, Front Range, Colorado, USA., *Quaternary research* 78, no. 2 (2012): 197-208.

Miller, N. A., and Henderson, J. J., 2010, Quantifying sand particle shape complexity using a dynamic, digital imaging technique.” *Agronomy journal* 102, no. 5, 1407-1414.

NOSAMS. “Radiocarbon Data and Calculations.” National Ocean Sciences Accelerator Mass Spectrometry. Last modified November 4, 2014. Accessed March 6, 2015. http://www.whoi.edu/nosams/page.do?pid=40146.