KECK GEOLOGY CONSORTIUM

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

April 2009
Franklin & Marshall College, Lancaster PA.

Dr. Andrew P. de Wet, Editor
Keck Geology Consortium Director
Franklin & Marshall College

Dr. Stan Mertzman
Symposium Convenor
Franklin & Marshall College

Kelly Erb
Keck Consortium Administrative Assistant

Diane Kadyk
Academic Department Coordinator
Department of Earth & Environment
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster PA 17604-3003
717 291-4132 keckgeology.org

ISSN # 1528-7491

The Consortium Colleges National Science Foundation

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

ISSN# 1528-7491

April 2009

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

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

Stan Mertzman
Symposium Convenor
Franklin & Marshall C.

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

---

2008-2009 PROJECTS

THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS (GRENVILLE PROVINCE, NEW YORK)

Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University
Students*: JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College*; STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College*; ROBERT NOWAK*: The College of Wooster*; SEAN REGAN*: St. Lawrence University*; ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

PALEOECOLOGY & PALEOENVIRONMENT OF EARLY TERTIARY ALASKAN FORESTS, MATANUSKA VALLEY, AL.

Faculty: *DAVID SUNDERLIN*: Lafayette College, *CHRISTOPHER J. WILLIAMS*: Franklin & Marshall College
Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

SEAFLOOR VOLCANIC AND HYDROTHERMAL PROCESSES PRESERVED IN THE ABITIBI GREENSTONE BELT OF ONTARIO AND QUEBEC, CANADA

Faculty: *LISA A. GILBERT,* Williams College and Williams-Mystic and NEIL R. BANERJEE, U. of Western Ontario
Students: *LAUREN D. ANDERSON*: Lehigh University; *STEFANIE GUGOLZ*: Beloit College; *HENRY E. KERNAN*: Williams College; *ADRIENNE LOVE*: Trinity University; *LISA SMITH:* Amherst College; *KAREN TEKVERK*: Haverford College

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

Faculty: *DAVID P. DETHIER*: Williams College and *MATTHIAS LEOPOLD*: Technical University of Munich
Students: *EVEY GANNAWAY*: The U. of the South; *KENNETH NELSON*: Macalester College; *MIGUEL RODRIGUEZ*: Colgate University

GEOARCHAEOLOGY OF THE PODERE FUNGHI, MUGELLO VALLEY ARCHAEOLOGICAL PROJECT, ITALY

Faculty: *ROB STERNBERG*: Franklin & Marshall College and *SARA BON-HARPER*: Monticello Department of Archaeology
Students: *AVERY R. COTA*: Minnesota State University Moorhead; *JANE DIDALEUSKY*: Smith College; *ROWAN HILL*: Colorado College; *ANNA PENDLEY*: Washington and Lee University; *MAIJA SIPOLA*: Carleton College; *STACEY SOSENKO*: Franklin and Marshall College

GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI

Faculty: *NICHOLAS E. BADER and ROBERT J. CARSON*: Whitman College; *A. BAYASGALAN*: Mongolian University of Science and Technology; *KURT L. FRANKEL*: Georgia Institute of Technology; *KARL W. WEGMANN*: North Carolina State University
Students: *ELIZABETH BROWN*: Occidental College; *GIA MATZINGER, ANDREA SEYMOUR, RYAN J. LEARY*, *KELLY DUNDON* and *CHELSEA C. DURFEY*: Whitman College; *BRITTANY GAUDETTE*: Mount Holyoke College; *KATHRYN LADIG*: Gustavus Adolphus College; *GREG MORTKA*: Lehigh U.; *JODI SPRAJCAR*: The College of Wooster; *KRISTIN E. SWEENEY*: Carleton College.

BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL CHANGE

Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University
Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET and CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

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

Keck Geology Consortium: Projects 2008-2009
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 CONTROL OF GLACIAL EROSION WITHIN GREEN LAKES VALLEY, FRONT RANGE, COLORADO

EVEY GANNAWAY: The University of the South
Research Advisor: Martin Knoll

CHARACTERIZATION AND COMPARISON OF WEATHERING PROFILES WITHIN BETASSO CATCHMENT, FRONT RANGE, COLORADO

KENNETH NELSON: Macalester College
Research Advisor: Raymond Rogers

APATITE IN THE SOILS OF BETASSO PRESERVE, COLORADO

***MIGUEL RODRIGUEZ*: Colgate University**
Research Advisor: Dr. Richard April

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

FRACTURE CONTROL OF GLACIAL EROSION WITHIN GREEN LAKES VALLEY, FRONT RANGE, COLORADO

EVEY GANNAWAY: The University of the South
Research Advisor: Martin Knoll

INTRODUCTION

The critical zone has been defined as the region that supports life or more accurately, everything from the bedrock contact to the top of the canopy (Anderson et al 2007). By considering fractures as assistants to erosion, they can be seen as the lowermost extension of the critical zone. It is through such erosion that the critical zone boundary is able to propagate downwards. In regions of glacial activity, the critical zone has often been stripped bare by glacial quarrying, thus exposing the bedrock underneath to the effects of erosion and weathering. Green Lakes Valley is a glacially carved valley in the Front Range of the Rocky Mountains. Sitting near 3570m, the valley serves as the watershed for the City of Boulder, Colorado to the east.

At the head of the valley is the small remnant of the once massive Arikaree Glacier that carved into the Front Range during the Pinedale Glaciation, the last glacial maximum of 20,000 years ago. The long-valley profile of the Green Lakes Valley displays a series of topographic steps with five shallow lakes that serve as the headwaters of North Boulder Creek (Fig. 1). The Pinedale glacial activity exposed a complex fracture system in the bedrock of Green Lakes Valley, which is composed of various rock types. Fracture data allows us to interpret the influence of rock fracturing on various geomorphic processes including the difficulty of glacial quarrying, groundwater movement through bedrock, and nutrient supply to vegetation. Fracture density and orientation were measured in order to interpret the history of step cutting and profile development in the valley.

METHODS

In order to characterize fracturing, I surveyed a total of 30 transects in an area of roughly 0.50 km^2 that exposed four different rock types. Transects were

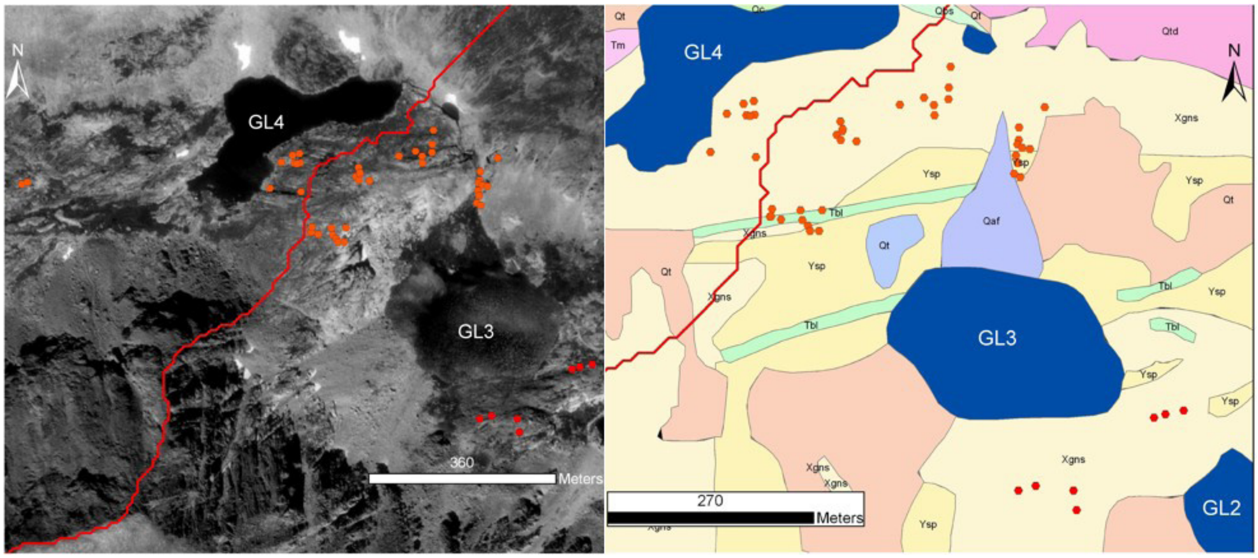

Figure 1. A) Aerial view of the topographic step between Green Lakes 3 and 4 indicating transect locations. B) Geologic map of the same area.

established using a 30-meter tape or laser rangefinder. Transect lengths ranged from 8.0 to 59.5 m, and were placed both parallel and normal to foliation where possible to allow for maximum data collection. Transects were concentrated near the topographic step between Greens Lakes 3 and 4 (Fig. 1) including regions above, within, and below the step. Once transects were surveyed, I measured the distance between fractures. These measurements allowed me to calculate the density of fractures based on rock type, as well as location in the valley. Width, length, and nature of the individual fractures were recorded for fractures that extended at least one meter to either side of the 30m tape. Fractures were categorized as either major, minor, or trace. Field data was then grouped by transect, rock type, and location. Fracture densities were calculated for each individual transects and for the four separate rock types: biotite gneiss/metasediments, granite, latite dike, and monzonite. Fractures were also classified by location above, within, or below the topographic step.

Additionally, the orientations of the fractures were measured along 22 of the 30 transects using a Brunton compass to help determine if certain fracture patterns favored glacial quarrying in the step area. The orientations were plotted on individual stereo nets and rose diagrams for each transect, which allowed for a three-dimensional visualization of the fracture systems. The orientations of dominant fracture sets were then compiled to create a single rose diagram illustrating the intersecting nature of the dominant fractures.

RESULTS

Fracture attributes of the individual transects are highlighted by location and rock type in Table 1. These attributes include the strike or direction of the dominant fracture sets and spacing of the fractures. Additional qualitative analyses of the fractures will be detailed below.

Transects EGC-1A and EGC-1B are parallel to the

Transect	Location	Rock Type	Dominant Direction	Fracture Spacing
1A	Just above the step between Green Lakes 3 and 4	Biotite Gneiss/Metaseds		Primarily 0.00-1.50m
1B		Biotite Gneiss/Metaseds		Primarily 0.00-1.00m
2		Biotite Gneiss/Metaseds		Few fractures (up to 6.00m)
3		Biotite Gneiss/Metaseds		Primarily 0.00-1.00m
4		Biotite Gneiss/Metaseds		Primarily 0.00-1.00m
5	Above the step near the edge of Green Lakes 4	Biotite Gneiss/Metaseds		Primarily 0.55-1.00m
6		Biotite Gneiss/Metaseds		Primarily 0.00-1.50m
7		Biotite Gneiss/Metaseds		Primarily 0.00-1.00m
8		Biotite Gneiss/Metaseds	45°, 298°	Primarily 0.00-1.50m
9		Biotite Gneiss/Metaseds	61°, 351°	Primarily 0.00-0.50m
10	On the lip of the step between Green Lakes 3 and 4	Silver Plume Granite	48°, 64°	Primarily 0.00-1.00m
11		Silver Plume Granite & Biotite Gneiss/Metaseds	280°, 352°	Primarily 0.00-1.00m
12		Silver Plume Granite & Latite Dike	84°, 351°	Primarily 0.00-1.00m
13		Silver Plume Granite	46°	Primarily 1.00-1.50m
14		Silver Plume Granite	290°, 313°	Few fractures (up to 3.20m)
15	Within the step between Green Lakes 3 and 4	Biotite Gneiss/Metaseds	31°	Primarily 0.00-1.00m
16		Silver Plume Granite	82°	Almost entirely 0.00-0.50m
17		Silver Plume Granite	8°	Almost entirely 0.00-0.50m
18		Silver Plume Granite	63°	Almost entirely 0.00-0.50m
19		Silver Plume Granite & Biotite Gneiss/Metaseds	82°, 60°	Almost entirely 0.00-0.50m
20	To the west of Green Lakes 4	Monzonite	79°	Primarily 0.00-0.50m
21		Biotite Gneiss/Metaseds	47°	Primarily 0.00-0.50m
22	Below Green Lakes 3	Biotite Gneiss/Metaseds	354°	Primarily 0.00-0.50m
23		Biotite Gneiss/Metaseds	337°, 352°, 12°	Primarily 0.00-0.50m
24	Step at Green Lakes 3 and 4	Biotite Gneiss/Metaseds	315°	Primarily 0.00-1.00m
25		Biotite Gneiss/Metaseds		Primarily 0.00-1.00m
26	To the west of Green Lakes 3	Silver Plume Granite	67°	Primarily 0.00-0.50m
27		Silver Plume Granite	64°	Primarily 0.00-1.00m
28		Silver Plume Granite	63°	Few fractures (up to 3.6m)
29		Silver Plume Granite	25°	Primarily 1.00-1.50m
30		Silver Plume Granite	29°	Primarily 0.00-1.00m (up to 7.90m)

Table 1. Transects classified by location, rock type, and fracture attributes.

foliation in the gneiss. Several fractures had substantial width and were significantly weathered. In two locations along transect EGC-1A, a block was detached from the outcrop due to intersecting fractures. Transect EGC-2 is perpendicular to foliation, and thus roughly normal to EGC-1A and EGC-1B. Transect EGC-3 is also perpendicular to foliation. Transect EGC-4 is along an extensive outcrop running parallel to foliation.

Transects EGC-5, EGC-6, and EGC-7 are a set trending parallel and perpendicular to the foliation of the gneiss. Transects EGC-8 and EGC-9 also follow the trend of foliation in the gneiss and metasediments. Qualitative analysis of these transects indicates an even distribution of major and minor fractures.

Transects EGC-10 through EGC-14 are a series of transects mainly in the Silver Plume Granite. There was a rough balance between fractures classified as major and minor, with a low number of trace fractures described as well.

Transects EGC-15 through EGC-19 are within the metasediments and Silver Plume Granite; EGC-19 includes the contact between the two lithologies. These transects crossed several sets of closely fractured, roughly parallel joint sets.

Transect EGC-20 is within a monzonite and is at the base of a more minor step between Green Lakes 4 and 5. EGC-21 trends parallel to the foliation of the metasediments and is found within this step. There appears to be a balance between major and minor fractures along both transects.

Transects EGC-22 and EGC-23 cross metasediments and minimal gneisses and are located below Green Lakes 3 within a very gradual step in the valley profile down to Green Lakes 2. Along both of these transects, minor fractures are more common than major fractures.

Transects EGC-24 through EGC-30 are a series of transects that were established from the base of Kiowa Peak to the south of the valley north towards Niwot Ridge. Transects cross both gneisses and metasediments and the Silver Plume Granite. EGC-24 and EGC-25, both entirely within the metasediments, run parallel and perpendicular to foliation, respectively. EGC-26 through EGC-30 are within the Silver Plume Granite.

The spacing of fractures along all 30 transects indicates a high frequency of closely spaced fractures between 0.00 to 0.50m and 0.55 to 1.00m. As the distance between fractures increases beyond 1.00m, the frequency decreases gradually along most transects (Fig. 2). However, two locations within Green Lakes Valley demonstrate a slightly different pattern (Fig. 3). The transects found within the topographic step between Green Lakes 3 and 4 include EGC-15 through EGC-19. Along these transects were several visibly heavily fractured outcrops, which featured fracture spacing of almost only 0.00 to 0.50m. The transects found on the lip of the step between Green Lakes 3 and 4 include EGC-13 and EGC-14 and have distinctly wider fracture spacing. Fracture spacing along these transects was primarily 1.00 to 1.50m, but significantly wider in several locations. An additional feature of these transects was a general lack of extensive or major fractures.

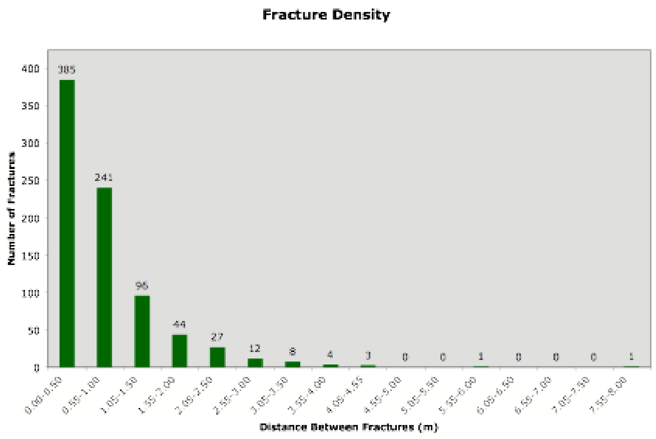

Figure 2. Fracture density of the 30 total transects (822 measurements were collected).

The average orientations of dominant fracture sets along each transect are detailed in Figure 4. After plotting each transect on an individual stereo net,

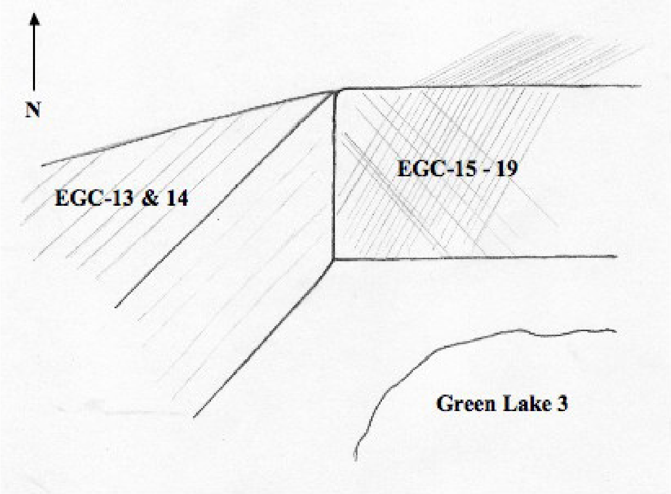

Figure 3. Sketch demonstrates the fracture spacing differences within the step (EGC-15 through 19) and at the lip of the step (EGC-13 and 14) between Green Lakes 3 and 4.

rose diagrams were also created. The dominant fracture sets were then compiled in a single rose diagram, which featured strikes of 63° and 80° for the majority of fractures within Green Lakes Valley (Fig. 4). The extensive intersecting nature of these fractures is indicated by the range in strike from 8° to 354°. Groupings in the rose diagram were done in 18° increments and a total of 520 readings were used to create the stereo nets and rose diagrams.

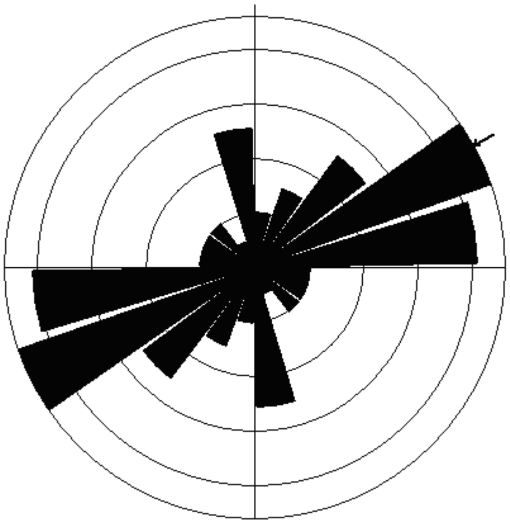

Figure 4. Overall rose diagram detailing the dominant intersecting fracture sets. 230 of the 520 total fractures were included to determine only the dominant fracture patterns in Green Lakes Valley.

DISCUSSION

The complex fracture system as seen in the bedrock of Green Lakes Valley has served, and will continue to serve, as a control on the erosion of the valley profile. Fracturing of the bedrock by tectonism involved with the Laramide Orogeny that uplifted the Rocky Mountains has assisted with the glacial erosion of Green Lakes Valley. More recent removal of material during glacial quarrying has resulted in additional sheet jointing, as well. Not only did the fractures assist with past erosion, they will also have a profound effect on the present and future erosion of the region (Molnar et al., 2007).

Tectonism that fractures the bedrock is essentially a method of disintegration of the rock that serves to accelerate the rates of erosion along those planes. The fragmented nature of the bedrock in the Front Range of the Rocky Mountains has persisted for roughly 50 million years. When the most recent period of glaciation on the North American continent ended 10,000 years before present, a stepped topography of Green Lakes Valley was exposed. The fractures allowed the glacier to effectively extract bedrock by quarrying processes. Even a geomorphic agent as powerful as a glacier has difficulty eroding a zone that has wide fracture spacing (Molnar et al, 2007).

Grouping transects first by location and then by lithology allowed for the varying fracture densities to be assessed in relation to the valley profile. The prominent closely spaced fracture system featured in transects EGC-15 through EGC-19, found within the step between Green Lakes 3 and 4, confirm the assumption that the closer the fractures, the weaker the rock strength and, thus the more susceptible the bedrock to erosion by a glacier (Selby, 1980). The more evenly balanced collection of narrowly, as well as widely spaced fractures (EGC-1A through EGC-14), corresponds to a lesser amount of glacial erosion, forming the broad bench where Green Lakes 4 is located. Transects EGC-24 through EGC-30 have a similar balanced fracture density that results in another broad bench where Green Lakes 3 is located.

A preliminary evaluation can be made of the importance of lithology in the fracturing of Green Lakes Valley. The fabric and foliation in certain rock types lend themselves to increased fracturing because of pre-existing weaknesses along those planes (Manda et al., 2007). Fracture density in the biotite gneiss and metasediments was consistently 0.00m-0.50m and 0.55m-1.00m, most likely attributable to the fabric and foliation of the host rock, but also featured zones of wider spaced fractures. In the Silver Plume Granite, however, the fracture spacing varied by location. Within the step between Green Lakes 3 and 4, fracture spacing is limited to primarily 0.00m-0.50m, but along the lip of that step, fracture spacing is generally much wider, up to 3.20m in some locations (Fig. 3). Because the Silver Plume Granite lacks a definitive and controlling foliation, it is unlikely that the fracture patterns are due to the host rock fabric. Fractures within the monzonite intrusion and latite dike were not studied extensively enough to determine their influence on fracturing.

The fractures found in the varying bedrock types were more than just an effective control of erosion during glacial activity. Even today, the fractures continue to provide sites for accelerated erosion due to a significant increase in surface area. Instead of purely being an assistant to mechanical erosion, the fractures also serve to enhance chemical erosion (Molnar et al., 2007). It is this currently occurring form of erosion that provides insight in to the nature of the critical zone in Green Lakes Valley. Following suit, these fractures will then provide a conduit for groundwater flow into the subsurface. Intersecting fracture systems, as seen in the variable fracture orientations, have created a complex interconnected bedrock aquifer for increased groundwater flow over time due to continued weathering and erosion of the critical zone. The fracture attributes recorded during this study, such as spacing, orientation, and width, allowed for an initial determination of the connectedness of the system (Manda et al., 2008). However, only additional study of the fracture attributes will allow a comprehensive statement to be made on groundwater flow pathways in the bedrock of Green Lakes Valley.

CONCLUSION

The glacially carved Green Lakes Valley in the Front Range of the Rocky Mountains is an extensively fractured region due to tectonism associated with the Laramide Orogeny. When the Arikaree Glacier retreated from this region beginning ~20,000 years ago, a significantly eroded, valley profile was exposed. The fractured and fragmented nature of the bedrock allowed for the formation of a series of topographic steps, which later became sites for the five shallow, glacier-fed Green Lakes. The significant region of closely spaced fractures that was easily eroded to form one of these steps is bounded above and below by regions featuring a wider variety in fracture density that suffered less erosion, and thus form a broad, flat valley profile. The present erosion along these fractures will continue the development of the critical zone in Green Lakes Valley.

REFERENCES

Anderson, P.A., von Blackenburg, F., and White, A.F., 2007, Physical and chemical controls on the critical zone: Elements, v. 3, p. 315-319.

Manda, A. K., S. B. Mabee, and D. U. Wise, 2008, Influence of rock fabric on fracture attribute distribution and implications for groundwater flow in the Nashoba Terrane, eastern Massachusetts: Journal of Structural Geology, v. 30, p. 464-477.

Molnar, P., R. S. Anderson, R. S., and S. P. Anderson, 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 Antartica and New Zealand: Zeitschrift für Geomorphologie v. 24, p. 31-51.