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

April 2014
Mt. Holyoke College, South Hadley, MA

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

Dr. Michelle Markley
Symposium Convener
Mt. Holyoke 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-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2014

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

2013-2014 PROJECTS

MAGNETIC AND GEOCHEMICAL CHARACTERIZATION OF IN SITU OBSIDIAN, NEW MEXICO*:*
Faculty: *ROB STERNBERG*, Franklin & Marshall College, *JOSHUA FEINBERG*, Univ. Minnesota, *STEVEN SHACKLEY,* Univ. California, Berkeley, *ANASTASIA STEFFEN*, Valles Caldera Trust, and Dept. of Anthropology, University of New Mexico
Students: *ALEXANDRA FREEMAN*, Colorado College, *ANDREW GREGOVICH*, Colorado College, *CAROLINE HACKETT*, Smith College, *MICHAEL HARRISON,* California State Univ.-Chico, *MICHAELA KIM*, Mt. Holyoke College, *ZACHARY OSBORNE*, St. Norbert College, *AUDRUANNA POLLEN*, Occidental College, *MARGO REGIER*, Beloit College, *KAREN ROTH*, Washington & Lee University

TECTONIC EVOLUTION OF THE FLYSCH OF THE CHUGACH TERRANE ON BARANOF ISLAND, ALASKA*:*
Faculty: *JOHN GARVER*, Union College, *CAMERON DAVIDSON*, Carleton College
Students: *BRIAN FRETT*, Carleton College, *KATE KAMINSKI*, Union College, *BRIANNA RICK*, Carleton College, *MEGHAN RIEHL*, Union College, *CLAUDIA ROIG*, Univ. of Puerto Rico, Mayagüez Campus, *ADRIAN WACKETT*, Trinity University,

EVALUATING EXTREME WEATHER RESPONSE IN CONNECTICUT RIVER FLOODPLAIN ENVIRONMENT*:*
Faculty: *ROBERT NEWTON*, Smith College, *ANNA MARTINI*, Amherst College, *JON WOODRUFF*, Univ. Massachusetts, Amherst, BRIAN YELLEN, University of Massachusetts
Students: *LUCY ANDREWS*, Macalester College, *AMY DELBECQ*, Beloit College, *SAMANTHA DOW*, Univ. Connecticut, *CATHERINE DUNN*, Oberlin College, *WESLEY JOHNSON*, Univ. Massachusetts, *RACHEL JOHNSON,* Carleton College, *SCOTT KUGEL*, The College of Wooster, *AIDA OROZCO*, Amherst College, *JULIA SEIDENSTEIN,* Lafayette College

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

A GEOBIOLOGICAL APPROACH TO UNDERSTANDING DOLOMITE FORMATION AT DEEP SPRINGS LAKE, CA
Faculty: *DAVID JONES*, Amherst College, *JASON TOR*, Hampshire College,
Students: *KYRA BRISSON*, Hampshire College, *KYLE METCALFE*, Pomona College, *MICHELLE PARDIS*, Williams College, *CECILIA PESSOA*, Amherst College, *HANNAH PLON*, Wesleyan Univ., *KERRY STREIFF*, Whitman College

POTENTIAL EFFECTS OF WATER-LEVEL CHANGES ON ON ISLAND ECOSYSTEMS: A GIS SPATIOTEMPORAL ANALYSIS OF SHORELINE CONFIGURATION
Faculty**:** *KIM DIVER*, Wesleyan Univ.
Students: *RYAN EDGLEY*, California State Polytecnical University-Pomona, *EMILIE SINKLER*, Wesleyan University

PĀHOEHOE LAVA ON MARS AND THE EARTH: A COMPARATIVE STUDY OF INFLATED AND DISRUPTED FLOWS
Faculty: *ANDREW DE WET*, Franklin & Marshall College, *CHRIS HAMILTON*. Univ. Maryland, *JACOB BLEACHER*, NASA, GSFC, *BRENT GARRY*, NASA-GSFC
Students: *SUSAN KONKOL*, Univ. Nevada-Reno, *JESSICA MCHALE*, Mt. Holyoke College, *RYAN SAMUELS,* Franklin & Marshall College, *MEGAN SWITZER*, Colgate University, *HESTER VON MEERSCHEIDT*, Boise State University, *CHARLES WISE*, Vassar College

THE GEOMORPHIC FOOTPRINT OF MEGATHRUST EARTHQUAKES: A FIELD INVESTIGATION OF CONVERGENT MARGIN MORPHOTECTONICS, NICOYA PENINSULA, COSTA RICA
Faculty*:* *JEFF MARSHALL*, Cal Poly Pomona, *TOM GARDNER*, Trinity University, *MARINO PROTTI, OVSICORI-UNA, SHAWN MORRISH*, Cal Poly Pomona
Students: *RICHARD ALFARO-DIAZ*, Univ. of Texas-El Paso, *GREGORY BRENN*, Union College, *PAULA BURGI*, Smith College, *CLAYTON FREIMUTH*, Trinity University, *SHANNON FASOLA*, St. Norbert College, *CLAIRE MARTINI*, Whitman College, *ELIZABETH OLSON*, Washington & Lee University, *CAROLYN PRESCOTT*, Macalester College, *DUSTIN STEWART*, California State Polytechnic University-Pomona, *ANTHONY MURILLO GUTIÉRREZ*, Universidad Nacional de Costa Rica (UNA)

HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD NORWAY
Faculty: *AL WERNER*, Mt. Holyoke College, *STEVE ROOF,* Hampshire College, *MIKE RETELLE*, Bates College
Students: *JOHANNA EIDMANN*, Williams College, *DANA REUTER*, Mt. Holyoke College, *NATASHA SIMPSON*, Pomona (Pitzer) College, *JOSHUA SOLOMON*, Colgate University

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Keck Geology Consortium: Projects 2013-2014
Short Contributions— Fluvial Response to Extreme Weather Project

EVALUATING EXTREME WEATHER RESPONSE IN THE CONNECTICUT RIVER FLOODPLAIN ENVIRONMENT
Faculty: ROBERT NEWTON, Smith College
JON WOODRUFF, University of Massachusetts
ANNA MARTINI, Amherst College
BRIAN YELLEN, University of Massachusetts

EXTREME PRECIPITATION AND EROSION IN UPLAND WATERSHEDS: A CASE STUDY FROM SHERMAN RESERVOIR, MA
LUCY ANDREWS, Macalester College
Research Advisors: Kelly MacGregor and Brian Yellen

IDENTIFYING STORM DEPOSITS IN A DRY FLOOD CONTROL RESERVOIR IN WESTERN MASSACHUSETTS, USA
AMY DELBECQ, Beloit College
Research Advisor: Susan Swanson

SEDIMENTATION BEHIND CONWAY ELECTRIC DAM, SOUTH RIVER, WESTERN MASSACHUSETTS
SAMANTHA DOW, University of Connecticut
Research Advisor: William Ouimet

A CASE STUDY OF STORM DEPOSITION IN LITTLEVILLE LAKE, HUNTINGTON, MA
CATHERINE DUNN, Oberlin College
Research Advisor: Amanda Schmidt

DELTA PROGRADATION IN A FLOOD CONTROL RESERVOIR: A CASE STUDY FROM LITTLEVILLE LAKE, HUNTINGTON, MA
RACHEL JOHNSON, Carleton College
Research Advisor: Mary Savina

IMPACTS OF EXTREME PRECIPITATION ON SEDIMENT YIELDS FOR POST GLACIAL UPLANDS OF THE NORTHEAST
WESLEY JOHNSON, University of Massachusetts Amherst
Research Advisor: Jon Woodruff

DISCERNING EXTREME WEATHER EVENTS IN THE CONNECTICUT RIVER SYSTEM THROUGH THE STUDY OF SEDIMENTS IN UPLAND DAMS AND FLOOD CONTROL RESERVOIRS OF WESTERN MASSACHUSETTS AND SOUTHWESTERN VERMONT
SCOTT KUGEL, The College Of Wooster
Research Advisors: Dr. Mark Wilson and Dr. Meagen Pollock

GEOCHEMICAL AND MICROFOSSIL RECORD OF MASS HEMLOCK DECLINES IN THE SEDIMENT OF BARTON'S COVE, WESTERN MASSACHUSSETS: IMPLICATIONS OF HEMLOCK DIEOFF TODAY
AIDA OROZCO, Amherst College
Research Advisor: Anna M. Martini

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

CLAY MINERALOGY FINGERPRINTING OF SEDIMENTS DEPOSITED FROM TROPICAL STORM IRENE IN THE CONNECTICUT RIVER WATERSHED

JULIA SEIDENSTEIN, Lafayette College
Research Advisor: Dru Germanoski

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
27th Annual Keck Symposium Volume
26 April, 2014
ISBN: 1528-7491

DELTA PROGRADATION IN A FLOOD CONTROL RESERVOIR: A CASE STUDY FROM LITTLEVILLE LAKE, HUNTINGTON, MA

RACHEL JOHNSON, Carleton College
Research Advisor: Mary Savina

INTRODUCTION

Flooding due to tropical disturbances and spring snowmelt erodes sediment from upland areas in the watersheds of Western Massachusetts (Yellen et al., in review). Some sediment is trapped behind dams, the coarser fraction of which tends to be concentrated within the deltas of flood control reservoirs (Heinemann, 1981; Meade, 1982; Snyder et al., 2006; Diemer, 2011; Woodruff et al., 2014). The sedimentary record within reservoirs can help decipher larger sedimentation processes within watersheds. Coarse-grained sediments and organics in reservoir deltas may record flooding and land use signatures (Ambers, 2001; Snyder, 2006). Deltas within the flood control reservoirs of Western Massachusetts remain largely unstudied. This study focuses on the Littleville Lake delta, located where the Middle Branch of the Westfield River enters Littleville Lake near Huntington, MA. Littleville Lake is a flood control reservoir that was formed with the construction of Littleville Lake dam in 1962. Delta composition, stratigraphy, and volume help constrain the origin of sediments and the ways that sediment is mobilized and stored at a watershed level. Furthermore, this study sheds light on the longevity of flood control structures in the region and makes an inventory of material that is starved from downstream reaches.

LITTLEVILLE LAKE AND DELTA

Littleville Lake and dam are situated in the Middle Branch Westfield River sub-watershed within the Westfield River watershed. Steep slopes, narrow valleys, and high-density drainage characterize the region surrounding Littleville Lake. The Middle Branch Westfield River originates in the temperate forests of the Peru Wildlife Management area in Peru, Massachusetts and its corresponding sub-watershed encompasses an area of 85 km^2 (Fig. 1). The river cuts through a deep, preglacial valley, traveling 29 km and dropping about 470 meters in elevation before reaching Littleville Lake (USACE, 2014). Ninety-three percent of the watershed is undeveloped forest and Littleville Lake dam is the only dam on the river (Curtis and Zingarelli, 2006).

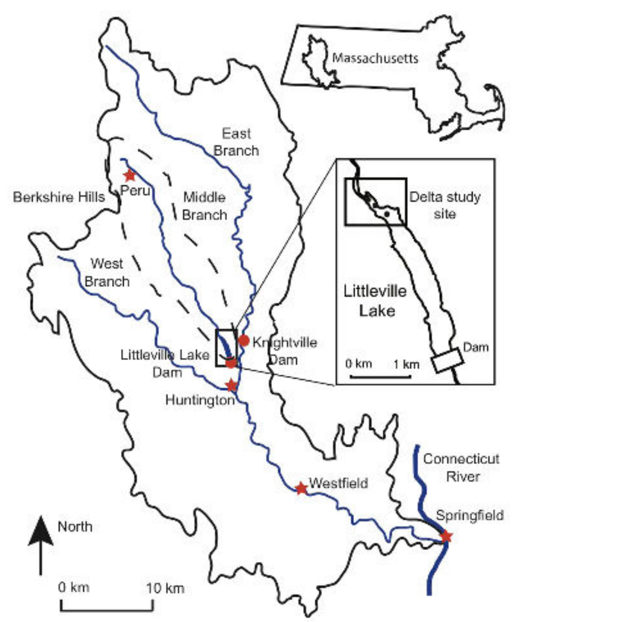

Figure 1. Map showing the Westfield River watershed. Dashed line indicates Middle Branch Westfield River sub-watershed. Inset shows watershed position within the state of Massachusetts. The Westfield River has three main branches: West, Middle, and East. The Westfield River joins the Connecticut River near Springfield, MA. Cities of interest are indicated by stars. Red dots indicate Littleville Lake Dam and nearby Knightville Dam. Littleville Lake is shown in detail as well as the Littleville Lake delta study site. Dots within the delta indicate the location of three cores taken.

Construction of Littleville Lake dam began in June of 1962 after the authorization of the Flood Control Act of 1958 (USACE, 2014). Previously, the Middle Branch Westfield River ran unimpeded through the small town of Littleville. Upon the completion of the dam in October of 1965, sediment settled out in Littleville Lake creating the Littleville Lake delta. Normal lake surface area is 1.1 km^2 and flood storage of Littleville Lake covers 2 km^2 and extends 6 km upstream of the dam (USACE, 2014). Average daily discharge (Q) of water from Littleville Lake dam was 174 cfs in 2013 (USACE, 2014). Average yearly precipitation between 1981 and 2010 at the neighboring Knightville dam was 115 cm per year with the greatest precipitation concentrated in the spring and autumn (NOAA, 2014). Flooding of rivers in western Massachusetts is caused either by spring freshets resulting from annual snowmelt or from individual storm events. The most severe floods in the region have been caused by extreme precipitation associated with hurricanes and tropical storm systems in late summer and fall, such as Tropical Storm Irene in late August 2011 (Barlow, 2011; Woodruff et al., 2013; Yellen et al., 2014).

DELTA FACIES AND COMPOSITION

In July 2013, I collected bathymetric data along transects in Littleville Lake and delta with a StrataBox sonar operating at 10 kHz and a Mala Ex ground penetrating radar (GPR) unit with 200 MHz antennae. GPR transects were processessed using RadExplorer 1.4 software and allowed me to identify appropriate coring locations to sample interpreted topset, foreset, and bottomset regions of the delta. On July 17, 2013, I extracted vibracores from the Littleville Lake delta at the three sites (Fig. 2). Each core was driven into the sediment until we reached resistance, which ranged from 4 m (LTD1) to 6 m (LTD2). Based on the difference between water depth and length of core drive, I calculated compaction of each core, which was less than 20% for each core.

Water and organic content within the cores were determined by procedures similar to those of Dean (1974). Organic content percentage and water content percentages were graphed together to show the remaining non-organic content percentage. Grain sizing at select intervals determined percentages of sediment greater than 63 µm diameter. Together these data along with qualitative notes and bulk density scans were used to define six facies and additional subfacies for the cores (Table 1). These facies include varying proportions of sands, silts + clays, and organic materials. By making the assumption that the three vibracore locations in Littleville Lake delta are representative of the delta as a whole, it was possible to calculate each facies as a percent of the total delta. With these calculations, it becomes evident that facies 1, 3, 4, and 6 comprise the majority of the delta with facies 3, alternating, layered sand, silt + clay, and organic layers, representing about 37% of the total delta volume (Table 1).

Facies	Description	Location	Density (gm/cc)	% Water	% Organic	% Sand (> 63 µm)	% Delta Volume	Total Mass (metric tons)
1	Uniform, relatively clean sand with some sections with more clay + silt.	LTD 3	1.65 - 2.1	8 - 22	0 - 18	96%	**16**	397
2	Silt + clay in fine sand matrix.	LTD 3	1.15 - 2.15	11 - 55	0 - 10	95%	**2**	49
3							**37**	1745
	3.1: Organic dominated packages of alternating organics, silt + clay, and very fine sand lenses.	LTD 1, LTD 3	1 – 1.85	20 – 70	0 – 21	50%	(13)	
	3.2: Silt + clay dominated packages of alternating silt + clay layers with very fine sand lenses.	LTD 1, LTD 3	1.45 – 1.9	27.5 – 60	2.5 – 12	73%	(21)	
	3.3: Sand dominated packages with alternating fine-grained sand and organic layers mixed with silt + clay.	LTD 3	1.05 – 2.25	20 – 62.5	1 - 25	78%	(3)	
4							**18**	323
	4.1: Uniform, wet, silt + clay matrix with sporadic organics.	LTD 1	1.3 – 1.5	50 – 65	3 – 20	17%	(16)	
	4.2: Silt + clay matrix with fine sand and organic leaves, sticks, and woody debris. Some gaps in matrix volume.	LTD 1	0.9 – 1.95	46 - 56	6 – 8	50%	(2)	
5	Sand matrix with some clay + silt. Variations in grain size and some gaps in matrix volume. Organics consist of pine needles, leaves, and roots near bottom.	LTD 1	0.5 - 2.25	15 - 42	0 - 4	< 55%	**4**	102
6	Organic matrix, semi-suspended in water, with some sandier sections. Organics consist of large sticks, twigs, pine needles, roots, and leaves.	LTD 2	0.55 - 1.5	35 - 88	4 - 18		**23**	389

Table 1. Core facies descriptions and compositions (see Figure 2 for core locations).

DELTA AND LAKE BATYHMETRY

With ArcGIS, I converted bathymetric data and a 2012 USGS topographic map to create an image of the Littleville Lake delta top (Fig. 2). The delta can be split into three topographic regions based on patterns in bathymetry, extending from northeast to southwest (Fig. 2). Each region corresponds with a slight widening of the delta. At the transition between the first two regions, the bottom surface of the delta drops a few meters and then rises again to the open, flat surface of region two. In Region 3, delta surface elevation decreases sharply downstream in an elongated shape (Fig. 2). Elevations within the first two regions are relatively constant, with no indication of a remnant channel. In Region 3, the reservoir has a generally concave bottom that follows the remnant Westfield River 1956 channel; surface elevation is higher at the shores of the reservoir and lower in the center.

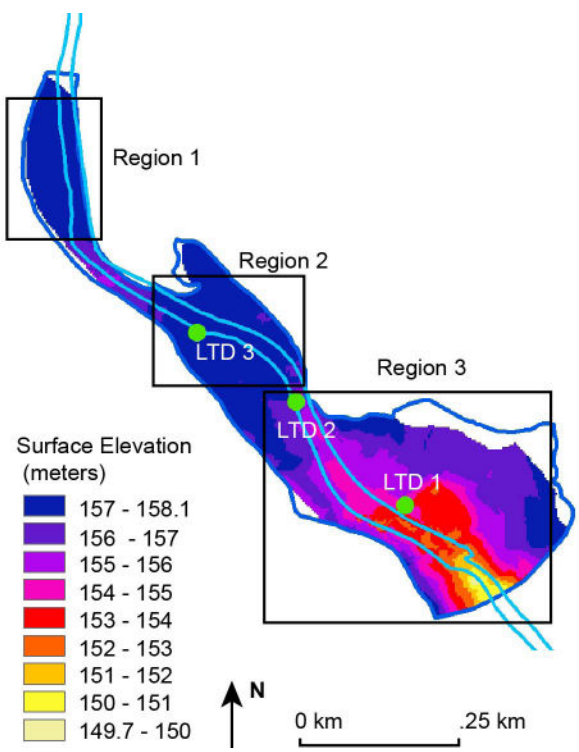

Figure 2. Littleville Lake delta surface topography. Dark blues and purples indicate areas of higher elevation and yellows represent areas of lower elevation. Three regions of interest are labeled and indicated by boxes. The three core locations are shown as green dots. Middle Branch Westfield River in 1956 is outlined in blue.

SEDIMENT DISTRIBUTION

Using ArcGIS, I converted a topography map from 1956 into a triangulated irregular network (TIN) and compared it to a TIN derived from a 2012 topographic map and the collected bathymetry data (Fig. 3). The difference in elevations across the study area was used to estimate the volume of sediment in the delta that has accumulated in the 51-year interval between when dam construction began in 1962 and 2013. This method makes the assumption that an insignificant amount of sediment was deposited in the river between 1956 and 1965 and is reasonable because the dam was not completed until 1965. Across an area of 131,000 m^2, a volume of 246,000 m^3 of sediment has accumulated since 1956. This corresponds to an average sediment thickness in the delta of 1.88 meters.

Sediment has accumulated in the Littleville Lake delta at an average rate of 4,820 m^3 per year between 1962 and 2013. To find the average mass of sediment that has accumulated in the Littleville delta yearly, I used calculations of delta composition, bulk density, water content, organic content, and non-organic content to calculate the average masses for each facies unit. The delta has a total mass of 3000 metric tons, which corresponds to an accumulation rate of 60 T/yr.

An isopach map of the Littleville Lake delta shows that areas of thickest delta sedimentation (> 5 meters of accumulation) appear to be preferentially along the pre-dam Middle Branch Westfield River channel in Region 2 (Fig. 3). As the reservoir widens, thick sedimentation in Region 3 tapers off in an elongated boot shape, extending into the reservoir and also towards the eastern bank. Conversely, regions of the delta that have the minimum sedimentation (< 0.9 meters of accumulation) are focused in thin bands on edges of the delta. Regions where net erosion has occurred exist on peripheral edges and constitute a very small percent of total delta area (Fig. 3).

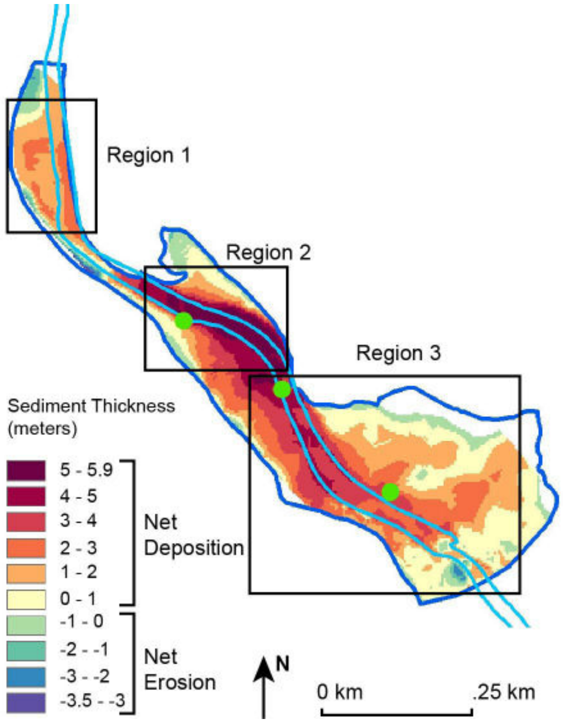

Figure 3. Distribution of sediment in Littleville Lake delta. Warm colors indicate areas of net deposition. Cooler colors represent areas of net erosion. The three core locations are shown as green dots. Middle Branch Westfield River in 1956 is outlined in blue.

DISCUSSION

Although flood control reservoirs provide ideal areas to study watershed sedimentation, deltas in flood control reservoirs can be very difficult to study. Variable base level due to drawdowns and floods complicate reservoir stratigraphy and make it challenging to interpret sedimentation patterns and flooding history (Noller et al., 2000; Ambers, 2001; Snyder et al., 2006). However, with certain assumptions, I am able to discuss delta history and sedimentation patterns.

Figure 4 illustrates my interpretations of the delta deposit in the context of my understanding of reservoir depositional processes. The Littleville Lake delta appears to follow the spatial geometry of the traditional Gilbert delta model over the history of the reservoir. As the delta started to form, coarser materials like sands and gravels carried as bedload were deposited rapidly and migrated down-reservoir at the delta face as foreset wedges, infilling the incisions originally cut by the Middle Branch Westfield River (Gilbert, 1890; Snyder et al., 2006). Finer materials like silts + clays and fine sands stayed in suspension longer and were carried beyond the delta face, into the reservoir, before being deposited as bottomset layers (Gilbert, 1890; Snyder et al., 2006).

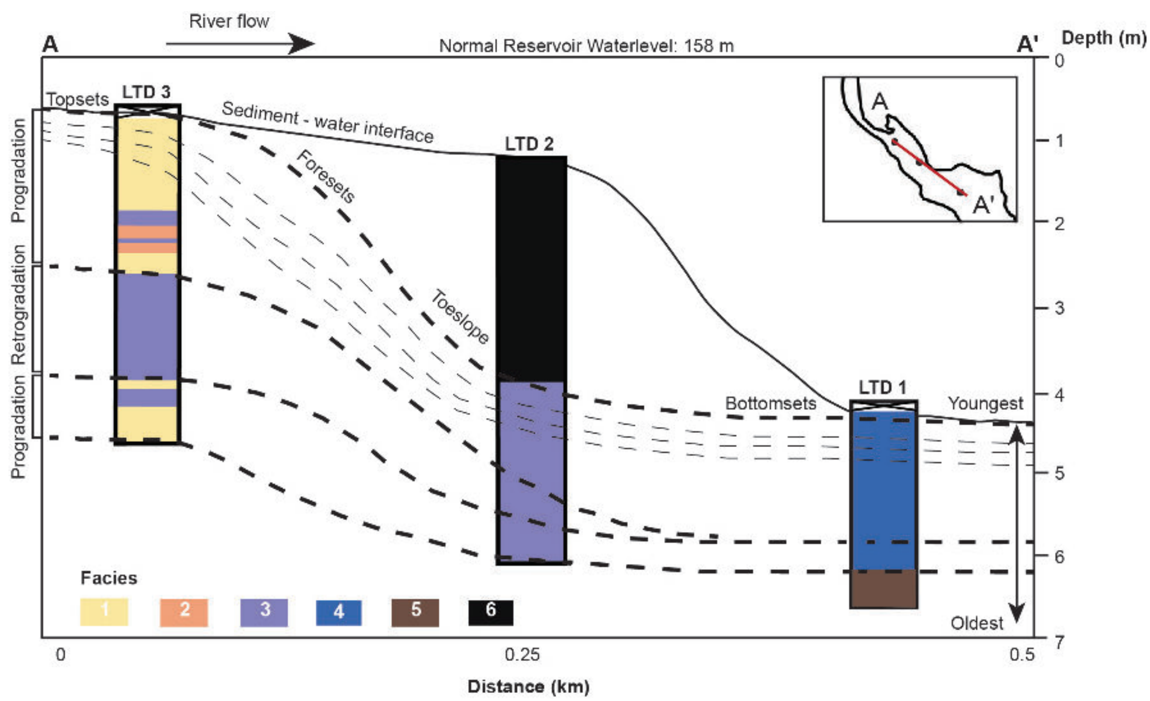

Figure 4. Side-profile of the Littleville Lake delta front from data collected in July of 2013. Transect and core locations are shown in the top right image. Colors indicate different facies (described in Table 1). The delta records a history of overall progradation with a period of retrogradation. Core LTD 3 is presently located in the topset delta region, LTD 2 is located at the toeslope of the delta front, and LTD 3 is located in the bottomset region of the delta.

Facies interpretation is critical to understanding sedimentary processes because facies changes record changing conditions in depositional environments (Snyder et al., 2006; Diemer, 2011). The Littleville Lake delta records in the three extracted vibracroes, a trend of overall progradation as well as smaller regressions and flood events (Fig. 4). Coring location LTD 3 indicates a sequence of progradation, regression, and a second progradation in thick foreset sand packages (facies 1 and 2) sandwiching layers of fine sediments and organics (facies 3). Core LTD 2 records an overall progradational pattern into the reservoir as seen in bottomset toeslope layers (facies 3) overlain by organic layers (facies 6). Core LTD 3 records progradation into the reservoir as bottomset layers (facies 4) deposited over older, pre-dam riverbed sediments (facies 5). Cores beyond this location contain minimal thicknesses of very fine-grained sediment, as fine-grained sediment is widely dispersed and only transported to distal bottomset regions during floods (Gilbert 1890; Snyder et al., 2006; Dunn, 2014).

The inorganic sediment that makes up the delta could come from two different sources or a combination of them: upland glacial tills or riverbank alluvium sources along the channel of the Middle Branch Westfield River and its tributaries. If 100% of the delta material is sand and originated as glacial tills, about 4,850 metric tons of glacial till would have to be eroded to construct the delta. This is based on Newton's (1978) findings that lower till is composed of 58% sand and upper till is composed of 66% sand. Organic material may be stored on upland hillslopes and be washed downstream by spring floods. Extreme precipitation events may then erode the organics, deposit other sediments above, or rework the organic beds with silt + clays and sands.

Thicknesses of layers within the facies may vary with intensity and duration of spring floods and extreme precipitation and reservoir drawdowns (Snyder et al., 2006; Ambers, 2001). I interpret the Littleville Lake delta to follow Snyder et al.'s (2006) conceptual temporal model of delta progradation occurring during short (day-long) flooding events. Spring floods and extreme precipitation events deposit dense materials in the foreset regions of the delta. During these events, reservoir stage changes dramatically and sediment suspended in the river settles out at progressively greater distances from the delta. Delta modification conversely occurs during reservoir drawdowns that occur over weeks to months (Snyder et al., 2006). During drawdowns, sediment is not transported as far into the reservoir and topset beds are reworked, transporting sand from topset to foreset regions (Snyder et al., 2006). Due to these numerous events and drawdowns, it is difficult to put time constraints on certain layers within the Littleville Lake delta. Tropical Storm Irene passed over the reservoir in late August of 2011; however, no unique signature from the event is recorded in the delta, such as an anomalous fine-grained inorganic layer of silts + clays as described by Woodruff et al. (2013) and Yellen et al. (2014). This may be because the floodwaters from Tropical Storm Irene left fine silts + clays suspended long enough to pass through the dam and move downstream (Ambers, 2001).

The Middle Branch Westfield River sub-watershed's average sediment yield of 57 $m^3/km^2/year$, or 0.76 $tons/km^2/year$, as measured by the sediment trapped in the Littleville Lake delta, is much lower than that of neighboring watersheds or watersheds of a similar size (Walling and Webb, 1983; Ambers, 2001; Yellen et al., 2014). Lower sediment yield may be attributed to several reasons. First, the assumption that the Littleville delta has 100% trapping efficiency may be incorrect. The delta is not composed entirely of sand, in fact less than 50% of the delta volume is coarser than 63 μm, and more distal areas in the lake are receiving transported sand (Dunn, 2014). Sediment yield values could also be dependent on extreme rainfall events that export sediment from postglacial, upland tributaries of the Atlantic Slope due to instability of upland slopes and channel bank failure (Ambers, 2001; Yellen et al., 2014). The Middle Branch Westfield River sub-watershed is 93% forested and the cover helps protect against erosive mass wasting events, thus less sediment is eroded. A lack of ice dam features around Littleville Lake also suggest that there may be less sediment available to be transported in the sub-watershed because ice dams would have blocked glacial meltwater sediments. A lower sediment yield could also signify that the river system is out of phase and upland erosion is greater than the amount transported (Meade, 1982). Additional testing on deltaic sediments could reveal further clues about sediment provenance within the watershed.

CONCLUSIONS

1. Littleville Lake delta can be classified spatially as a classic Gilbert model delta that is actively prograding into the reservoir.

2. The delta is composed of sand, silt + clay, and organic layers that can be defined as six different facies with quantifiable volumes and masses of sediment.

3. Temporally, the delta follows Snyder et al.'s (2006) conceptual model of a flood control reservoir delta where delta progradation occurs during short (day-long) flooding events and delta modification occurs during longer drawdowns (week- to month-long).

4. Although the delta may record individual event layers, it does not appear to have recorded the fine-grained signature from Tropical Storm Irene.

5. The Middle Branch Westfield river sub-watershed has a quantifiable average sediment yield that is extremely low compared to watersheds of a similar size. This may indicate unique features about the sub-watershed and thus investigation at both small and large scales is needed to understand how sediment is eroded, transported, and trapped in post-glacial environments.

ACKNOWLEDGEMENTS

Many thanks to my advisor, Mary Savina (Carleton College) and to Wei-Hsin Fu (Carleton College) for their guidance, pateience, advice, and support. This project would not have been possible without funding from the National Science Foundation and the Keck Geology Consortium. Additional thanks go to my Keck Extreme Weather Geomorphology team, my family and friends, and the entire Carleton geology department.

REFERENCES

Ambers, R. K., 2001, Using the sediment record in a western Oregon flood-control reservoir to assess the influence of storm history and logging on sediment yield: Journal of Hydrology, v. 244, n. 3, p. 181-200.

Barlow, M., 2011, Influence of Hurricane-Related Activity on North American Extreme Precipitation: Geophysical Research Letters, v. 38, L04705.

Curtis, C. and S., Zingarelli, 2006, Westfield River: Five Year Watershed Action Plan: Pioneer Valley Planning Commission (PVPC) http://www.pvpc.org/resources/landuse/wap final_small.pdf (accessed February 2014).

Dunn, C., 2014, How Unusual is Tropical Storm Irene? A Case Study of Storm Deposition in Littleville Lake, Huntington, MA, Unpublished undergraduate thesis, Oberlin College, Oberlin, OH.

Diemer, J.C., Allan, C., Eckhardt, I., Kroening, D., and Vinsion, D., 2011, Sedimentation in a Piedmont Reservoir: Evidence from Brown's Cove, Lake Wylie, North Carolina: Environmental and Engineering Geoscience, v. 17, n. 2, p. 123-142

Gilbert, G. K., 1890, Lake Bonneville: Washington, D.C., U.S. Government Printing Office, USGS Monograph, v. 1, p. 153 – 166.

Heinemann, H.G., 1981, A New Sediment Trap Efficiency Curve for Small Reservoirs: Water Resources Bulletin, v. 17, n. 5, p. 825 – 830.

Meade, R.H., 1982, Sources, Sinks, and Storage of River Sediment in the Atlantic Drainage of the United States: The Journal of Geology, v. 90, n. 3, p. 235-252.

National Oceanic and Atmospheric Administration (NOAA), 2014, Data Tools: 1981 – 2010 Normals: http://www.ncdc.noaa.gov/cdo-web/datatools/normals (accessed March 2014).

Newton, R.M., 1978, Stratigraphy and structure of some New England tills: Amherst, Mass., University ofMassachusetts,unpublished Ph.D. dissertation, p. 256.

Noller, J.S., Sowers, J.M., and W.R. Lettis, 2000, Quaternary Geology Methods and Applications: American Geophysical Union, Washington, D.C., p. 582.

Snyder, N. P., Wright, S.A., Alpers, C.N., Flint, L.E., Holmes, C.W., and D. M. Rubin, 2006, Reconstructing Depositional Processes and History from Reservoir Stratigraphy: Englebright Lake, Yuba River, northern California: Journal of Geophysical Research, v. 111, p. 1 – 16.

US Army Corps of Engineers (USACE), 2014, Littleville Lake Flood Risk Management Program: http://www.nae.usace.army.mil/Missions/CivilWorks/FloodRiskManagement/Massachusetts/Littleville.aspx (accessed March 2014).

Verstraeten, G. and Poesen, J., 2000, Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield: Progress in Physical Geography, v. 24, n. 2, p. 219-251.

Walling, D.E. and B.W. Webb, 1983, Patterns of sediment yield: Background to Paleohydrology: Wiley, New York, p. 69 – 100.

Woodruff, J.D., Kratz, L.N., Yellen, B., Mabee, S.B., Morrizon, J., and Martini, A.M., 2013, Geomorphic impacts of extreme precipitation on post-glacial rivers: Insights from Hurricane Irene, unpublished.

Yellen, B., Woodruff, J.D., Kratz, L.N., Mabee, S.B., Morrison, J., and A.M. Martini, 2014, Geomorphic impacts of extreme precipitation in post-glacial watersheds: Insights from Hurricane Irene, unpublished.