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Keck Director
Franklin & Marshall College

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

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2007-2008 PROJECTS:

Tectonic and Climatic Forcing of the Swiss Alps
John Garver (Union College), Mark Brandon (Yale University), Alison Anders (University of Illinois), Jeff Rahl (Washington and Lee University), Devin McPhillips (Yale University)
Students: William Barnhart, Kat Compton, Rosalba Queirolo, Lindsay Rathnow, Scott Reynhout, Libby Ritz, Jessica Stanley, Michael Werner, Elizabeth Wong

Geologic Controls on Viticulture in the Walla Walla Valley, Washington
Kevin Pogue (Whitman College) and Chris Oze (Bryn Mawr College)
Students: Ruth Indrick, Karl Lang, Season Martin, Anna Mazzariello, John Nowinski, Anna Weber

The Árnes central volcano, Northwestern Iceland
Brennan Jordan (University of South Dakota), Bob Wiebe (Franklin & Marshall College), Paul Olin (Washington State U.)
Students: Michael Bernstein, Elizabeth Drewes, Kamilla Fellah, Daniel Hadley, Caitlyn Perlman, Lynne Stewart

Origin of big garnets in amphibolites during high-grade metamorphism, Adirondacks, NY
Kurt Hollocher (Union College)
Students: Denny Alden, Erica Emerson, Kathryn Stack

Carbonate Depositional Systems of St. Croix, US Virgin Islands
Dennis Hubbard and Karla Parsons-Hubbard (Oberlin College), Karl Wirth (Macalester College)
Students: Monica Arienzo, Ashley Burkett, Alexander Burpee, Sarah Chamlee, Timmons Erickson Andrew Estep, Dana Fisco, Matthew Klinman, Caitlin Tems, Selina Tirtajana

Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
Greg Wiles (The College of Wooster)
Students: Erica Erlanger, Alex Trutko, Adam Plourde

The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
Tim Ku (Wesleyan University) Suzanne O'Connell (Wesleyan University), Anna Martini (Amherst College)
Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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Keck Geology Consortium: Projects 2007-2008
Short Contributions – Alps

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QUANTIFYING RATES OF EROSION USING THE OCCURRENCE AND MAGNITUDE OF FLOOD EVENTS IN THE LEPONTINE DOME, SWITZERLAND

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Academic Advisor: Martin Wong

INTRODUCTION:

The tectonic collision between the Adriatic and European plates causes a broad regional uplift in the Swiss Alps. Recent arguments have suggested that rapid rates of erosion linked to locally enhanced precipitation may influence the rates of tectonic uplift in the Lepontine Dome region (Anders et al., 2002). Increased precipitation may intensify erosion and amplify the region's relief (Reiners et al., 2003). Increases in relief can further enhance erosive power in fluvial and mass wasting systems. In this situation it is possible that the rate of uplift will increase as the system tries to regain equilibrium (Roe et al., 2006).

We hypothesize that regions within the Alps that receive large amounts of precipitation will experience faster rates of erosion and uplift relative to regions with drier climates. In addition, we hypothesize that large flood events represent a significant fraction of the sediment transport in the wet Lepontine Dome region, which has both the largest annual precipitation totals in the Alps and experiences a large number of intense precipitation events (Frei and Schar, 1998).

This paper's objective is to estimate the rates of erosion and sediment transport in three fluvial systems in the Lepontine Dome; the Bosco Gurin River Valley, the Maggia River in the Vizzara Valley and the Verzasca Valley River. In order to quantify the rates of flood-related erosion and sediment transport in these fluvial systems, we estimated the occurrence and magnitude of high energy flood events experienced by each river.

METHODS

We estimated the occurrence of flood events using lichenometry. Since lichens grow at a certain rate the size of a lichen thallus can be used to determine its age. Therefore, the size of lichen on the surface of a boulder can be used in conjunction with a standard curve of lichen growth rate to determine when the surface was exposed and ultimately when the boulder was last transported by the river (Gob et al., 2003).

Because lichen growth rates are sensitive to climate conditions, it is necessary to develop a standard curve of growth rate specific to the study area. To establish the curve we measured the size of lichen on surfaces of gravestones with known ages. For each stone, we recorded the largest diameter of the largest single thallus found on the surface. Then we plotted the diameter of lichen growth versus the age of the surface. The data sets were separated according to the date they were recorded and the location of the cemetery where they were gathered (Fig. 1).

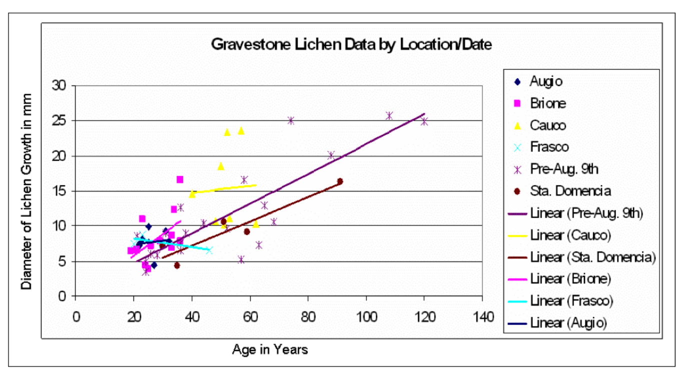

Figure 1: Gravestone data according to location and date collected. Trend lines represent the general trend of each data set.

We evaluated linear trend lines for each data set and eliminated any illogical data. Three data sets were eliminated from the standard curve based on the assumption that gravestone cleaning had interfered with the data. The remaining three data sets were re-graphed and a best-fit trend line was calculated (Fig. 2). The equation of the line is:

$$y = 0.1891x + 1.7888 \quad (1)$$

where y is the diameter of the lichen (mm) and x is the age of the surface (yr).

A regression analysis calculated an R^2 value of 0.6598 and a standard error of 14.7. Our lichen growth rate curve compares favorably with ones from similar studies (Orombelli and Porter, 1983; Gob et al., 2003; Bull and Brandon, 1998) and is most similar to the one established by Gob et al., (2003).

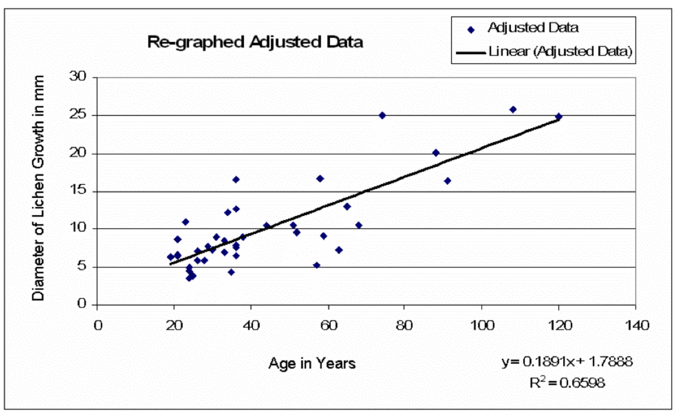

Figure 2: Re-graphed data sets (Pre Aug. 9th, Sta. Domencia and Brione) after eliminating poor data. Linear trend line gives the equation used for lichen calibration.

In order to estimate the age of past flood events the standard curve was applied to lichen size measured on the surfaces of boulders found in each river. For each boulder that was sampled we recorded the largest diameter of the largest single lichen thalli. We used the standard curve to date the age of the boulder surfaces and estimate when flood events had occurred in each river.

We also measured the length of each boulder's three axes. The measurement of the intermediate, or b-axis, of each boulder was used to estimate the competence, critical shear stress and capacity of each river during high energy flood events (Gob et al. 2003). Therefore, each river's flood magnitude was estimated using the size of the largest boulders it had transported (Williams, 1983). We also measured the average gradient and width of a 100 meter reach of each river to establish parameters for our shear stress and capacity equations.

The b-axis measurements were used to estimate the critical shear stress required by the river to initiate movement of the boulders. Lacking the required field data to empirically derive a critical shear stress equation specific to our field sites we used equations established by studies conducted in similar environments under comparable conditions (Baker and Ritter, 1975; Williams, 1983; Leopold et al., 1964). These studies derive a relationship between the b-axis of a particle (D), and the critical shear stress (r) required to initiate movement of the particle. The equations are:

Baker and Ritter (1975)

$$D = 65r^{0.54} \quad (2)$$

where D is in mm and r is in kg/m^2.

Williams (1983)

Upper limit: $r = 3.9D^1$ (range 15-900mm) (3)

Lower limit: $r = 0.17D^1$ (range 10-1500mm) (4)

Average: $r = 2.04D$

where D is in mm and r is in N/m2.

Leopold et al. (1964)

$$D = 77.966r^{1.042} \quad (5)$$

where D is in mm and r is in lbs/ft^2.

In comparing the three equations, a large variation in output values suggests that a high amount of uncertainty is associated with the empirical methods used in all three studies. The values of critical shear stress calculated using the Leopold et al. (1964) equation best represent an average of all the equations, therefore, we used these to calculate capacity (Eq.5).

The largest boulders are only transported during the peak flow of flood events, therefore, they represent the river's maximum competence. To estimate the capacity of our field sites we used the Parker equation as modified by Mueller and Pitlick (2005).

$$Q_s = 11.2\frac{(\tau^* - \tau_c^*)^{4.5}}{\tau^{*3}}\left[(s-1)g\,D_{50}^3\right]^{0.5}B, \qquad (6)$$

Qs -rate of sediment transport in m^3/s
τ^* -dimensionless shear stress
τc^* -critical dimensionless shear stress
s -specific gravity of sediment, assumed to be 2.65 (Mueller and Pitlick, 2005)
g -acceleration due to gravity, 9.8 m/s
D50 -median grain size of bed sediment
B -average width of the channel

To convert our critical shear stress estimates into dimensionless and critical dimensionless shear stress values we used the dimensionless shear stress equation (Mueller and Pitlick, 2005).

$$\tau^* = \frac{\tau}{(\rho_s - \rho)gD_{50}}, \qquad (7)$$

τ -estimated shear stress
τ^* -dimensionless shear stress
ρs -specific gravity of sediment, assumed to be 2.65 (Mueller and Pitlick, 2005)
ρ -specific gravity of water
g -acceleration due to gravity 9800 mm/s
D50 -median grain size of bed sediment in mm

Estimates of the critical shear stress required to move the median grain size of bed sediment were used to calculate the critical dimensionless shear stress of each river. Similarly, critical shear stress estimates required to move the boulders in each river were used to calculate the dimensionless shear stress.

RESULTS

For each river we plotted the size of the largest boulders and the date they were last moved. The plot of boulder size verses estimated surface age for the Bosco Gurin River shows that as time passes abrupt increases in boulder size occur at distinct ages (Fig. 3). This pattern is not shared by any of the other rivers. The Verzasca Valley plot has no pattern linking the size of boulders to the estimated age of last movement. The Maggia River plot has an upward sloping trend indicating that larger boulders have older surfaces, representing older dates of last movement (Fig. 4). However, there is also a horizontal trend connecting boulders of similar sizes to a large range of dates. For example, the movement of boulders with a b-axis measuring less than 1000 millimeters ranged from 25 to 82 years (Fig. 4).

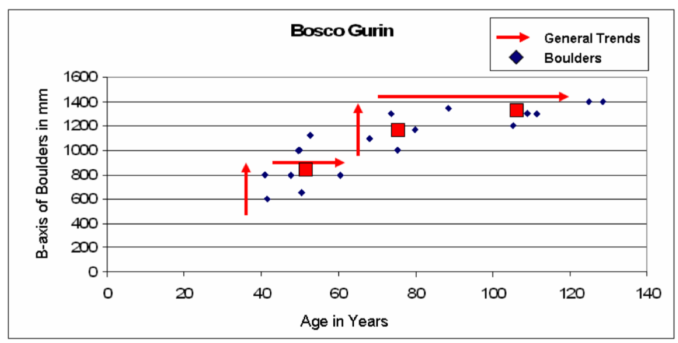

Figure 3: Bosco Gurin River plot of boulder b-axis in mm against age of surface exposure in years. Trend line shows a stair stepping pattern indicating distinct jumps in age of boulders of similar size. Large red boxes indicate the average b-axis of boulders (mm) measured for each flood event.

INTERPRETATIONS

The stepping pattern shown by the Bosco Gurin River plot can be explained by the succession of flood events of varying magnitudes (Fig. 3). Since the largest boulders can only be moved during the highest energy flow in the river, they record the largest flood events. The plot suggests that the largest boulders were only moved during older floods of higher magnitude while smaller boulders have since been moved by younger floods of less magnitude.

This is only a general trend and some of the data points are outliers. It is possible that the shapes of some boulders or their position in the river may limit their mobility, causing them to remain stationary during an event that has enough power to transport them.

This logic can also be used to explain the erratic behavior of the Verzasca Valley plot. No distinguishable trend was reveled by this plot connecting the size of the boulders to the age of their surfaces. Without a trend connecting the size of the boulders to the age of their last movement, it is impossible to estimate the occurrence of flood events using this method.

Similarly, the ages of flood events could not be determined for the Vizzara Valley River because the trend shown by the graph was inconclusive. It is possible that some of these smaller boulders were lodged into areas of the river where they remained immobile during high energy events.

The Bosco Gurin River was the only field site with a pattern connecting boulder sizes to surface dates

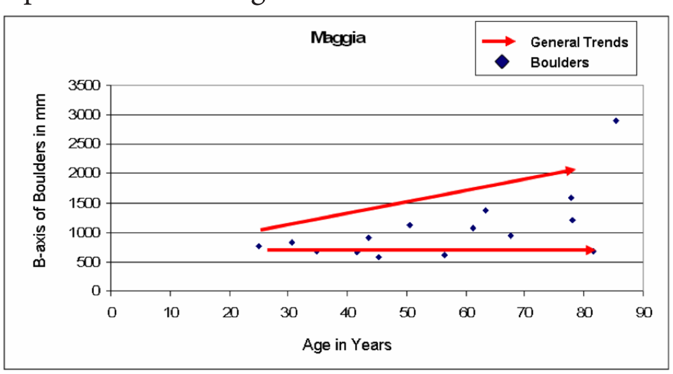

Figure 4. Maggia River plot of boulder b-axis in mm against age of surface exposure in years. Inclined trend shows that age of surface exposure increases with boulder size. Horizontal trend indicates that boulders of similar size can have a range of ages.

that could be used to estimate the occurrence of floods. The pattern showed that the size of boulders that had been moved by flood events increased at certain intervals over time. This allowed us to estimate the age of the flood events. We separated the boulders into three groups based on the size of their b-axis:

1) b-axis ≤ 1000mm
2) 1000mm < b-axis ≥ 1200mm
3) 1200mm < b-axis ≥ 1400mm

We calculated the average age and size of each group (Fig. 3). From this graph we were able to estimate that the Bosco Gurin River had experienced flood

	competence	estimated τ	τ*	τc*	D50	B	Qs - capacity
Bosco Gurin	Mm	N/m²			m	m	m³/s
52 year old flood	831	464	0.48	0.4	0.06	6.97	1.03
76 year old flood	1148	633	0.65	0.4	0.06	6.97	1.83
106 year old flood	1340	734	0.76	0.4	0.06	6.97	2.38

Table 1: Summary of calculations and parameters for Bosco Gurin River flood events.

events of varying magnitudes around 52, 76 and 106 years ago. The competence, shear stress and capacity of each flood were estimated from the size of the boulders representing each event. The calculations of competence, critical shear stress and capacity are summarized above in Table 1.

CONCLUSION

We used lichenometry to date the occurrence of flood events in the Lepontine Dome. The erosional power of three floods on the Bocso Gurin River was estimated in terms of competence, shear stress and capacity based on the size of the largest boulders, channel width and slope.

The methods used include a number of uncertainties and assumptions. The comparison of the standard lichen curve with those of Orombelli and Porter (1983), Gob et al. (2003), and Bull and Brandon (1998), and the regression analysis results shows the uncertainty in lichenometric surface dating. A large amount of uncertainty is also associated with the estimation of the competence, shear stress and capacity. These uncertainties must be considered when interpreting the calculated values and the results of this study.

However, this study has provided insight into the potential significance of large floods for erosion and sediment transport in the Lepontine Dome. The occurrence of at least three events capable of transporting boulders of more than 500 mm diameter within the last century indicates that large floods are relatively common in the region and mobilize even the coarsest fraction of the sediment supplied to the system. Furthermore, this finding supports the hypothesis that large floods significantly contribute to erosion and sediment transport in the Lepontine Dome.

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