KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

April 2008

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Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
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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)
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Brennan Jordan (University of South Dakota), Bob Wiebe (Franklin & Marshall College), Paul Olin (Washington State U.)
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Carbonate Depositional Systems of St. Croix, US Virgin Islands
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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

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

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

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)
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TECTONIC AND CLIMATIC FORCING OF THE SWISS ALPS

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INTRODUCTION

Mountainous topography is shaped by a balance between tectonic forces that tend to drive rock and surface uplift and erosive forces that work to reduce elevation. Increasingly, geologists recognize that feedbacks develop between tectonic and climatic forces, and understanding these relationships is an important goal of modern tectonic investigations. However, the relative importance of various tectonic and climatic processes remains controversial (Molnar and England, 1990; Whipple et al., 1999; Bernet et al., 2001; Montgomery and Brandon, 2002; Whipple and Meade, 2006). In order to evaluate how these processes interact to shape the evolution of a mountain belt, it is critical to establish long records of deformation, erosion, precipitation, and other processes. As one of the best studied orogens on the planet, the European Alps are an ideal locality to examine the influences of both tectonics and climate on orogenesis. In this project, we apply geomorphic, structural, and thermochronologic methods to the Lepontine Dome, a deeply exhumed part of the Swiss Alps where a zone of high long-term exhumation coincides with modern peak precipitation rates.

GEOLOGIC SETTING

The European Alps are the product of long-lived convergence between the European and African plates over the past 80 Ma. Beginning in the Eocene, this convergence led to the accretion of several ocean basins and continental fragments into a ~250 km wide doubly-vergent wedge (Fig. 1). Verging north within the wedge, convergence is accommodated in a series of lithologically distinct thrust nappes. Somewhat smaller, high-angle thrusts accommodate top-to-the-south motion. The Insubric Line is an orogen-scale, oblique-slip fault that marks the convergent plate boundary (Schmidt, 1996).

The Lepontine Dome is one of several tectonic windows in the Alps where high-grade metamorphic rocks of the lowest Penninic nappes have been exhumed to the surface. During deformation, back-folding in the wedge drove uplift and exhumation following amphibolite-facies metamorphism at ~30 Ma. Normal faulting around the Simplon Line contributed to exhumation, but much of the exhumation is inferred to have been driven by erosion (Schlunegger and Willet, 1999). By at least 15 Ma, the Alpine wedge apparently reached exhumational steady state, meaning that the flux of rock into the orogenic wedge and out through erosion has changed little since (Bernet et al., 2001). Several studies suggest that surface uplift and therefore mean topography essentially ceased by the beginning of the Pliocene, following large climatic shifts (Schumacher, 1996; Willet et al., 2006). The relationship between long-term exhumation and surface uplift remains under discussion, as is the case in almost all orogenic belts in the world.

Modern rain gauge data shows remarkable spatial variability in rainfall across the Alps (Fig. 2). Precipitation increases by a factor of five over a distance of 50 km along strike (Frei and Schär, 1998). The deeply exhumed Lepontine Dome coincides with a local precipitation maximum, while shallow Austroalpine units to the east coincide with zones of low precipitation (Anders et al., 2002). An important question is whether this modern configuration of precipitation has any bearing on the long-term exhumation in the Alps and what role structures

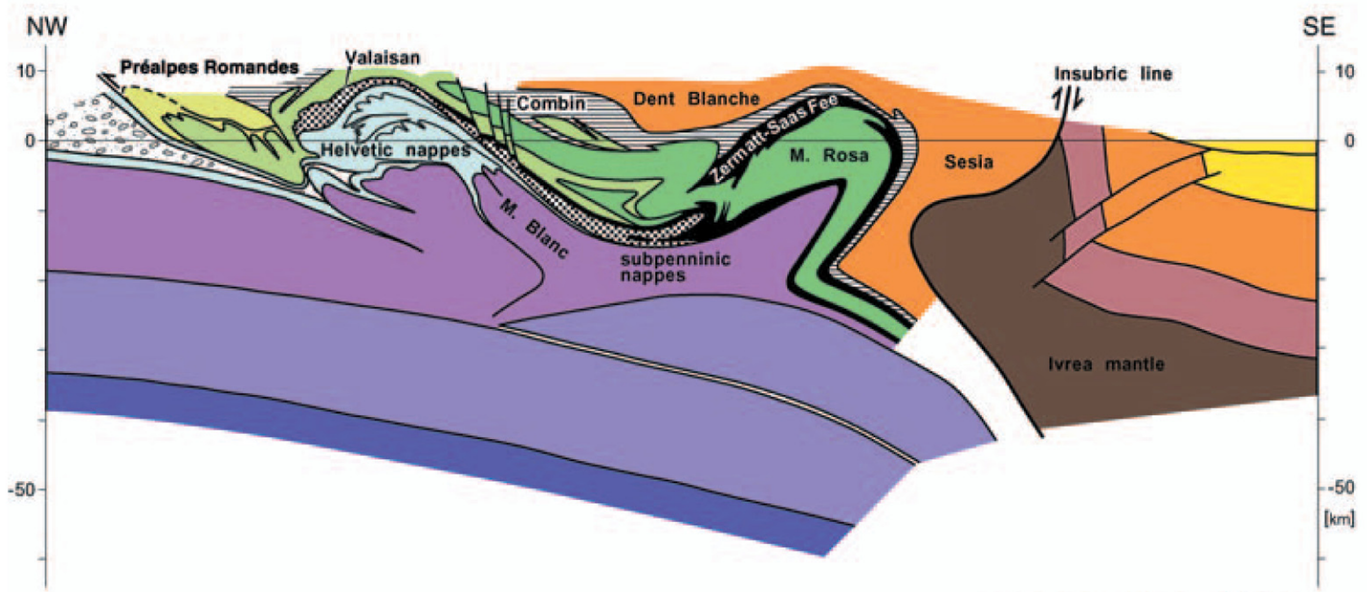

Figure 1. Cross-section of the Alps in the area of the western Lepontine Dome, showing wedge geometry and nappe stacks. From Schmid et al. (2004).

have played in orogenic development. Here we look at the three broad scientific approaches that we have used to address these questions.

1. GEOMORPHOLOGY

The Lepontine Dome experiences significantly higher annual precipitation rates and much more frequent large precipitation events than regions along strike to the east and west. With the ultimate goal of understanding the significance of erosional exhumation for the long-term evolution of the Lepontine Dome, the geomorphic research focused on determining the importance of precipitation for modern and Quaternary glacial and fluvial erosion rates. Two main research areas were pursued. One group explored the spatial relationships between modern precipitation patterns and small-scale glacial and fluvial erosion rates to determine if spatial gradients in precipitation correspond to spatial gradients in erosion rate. The other group worked to constrain the energy available for erosion and potential sediment transport rates during frequent and rare discharge events.

Scott Reynhout examined the relationship between modern precipitation rates and the elevation of Quaternary cirque floors within the Lepontine Dome and in surrounding regions using GIS techniques. Field work identified cirques that provided a test set for the development of a remote sensing technique for distinguishing cirques across a broad region. Cirque-floor elevations show a negative linear relationship with annual precipitation, suggesting that precipitation is a strong control on glacial erosion rates.

Libby Ritz quantified post-glacial fluvial incision rates into cirque floors through field surveys of river gorges cut into glacially-shaped surfaces. A statistical comparison of these erosion rates with river discharge and slope indicated that the widely-used stream power model of fluvial incision is insufficient to explain the observed variation in post-glacial erosion rates.

Elizabeth Wong used river bed grain-size distribution data in combination with channel slope and geometry surveys to quantify the mobility of the bed and sediment transport rates during bankfull flow events. This analysis provides a framework for comparison of the geomorphic effects of frequent (1-2 year recurrence interval) flooding with the extreme events documented by Michael Werner and Lindsay Rathnow.

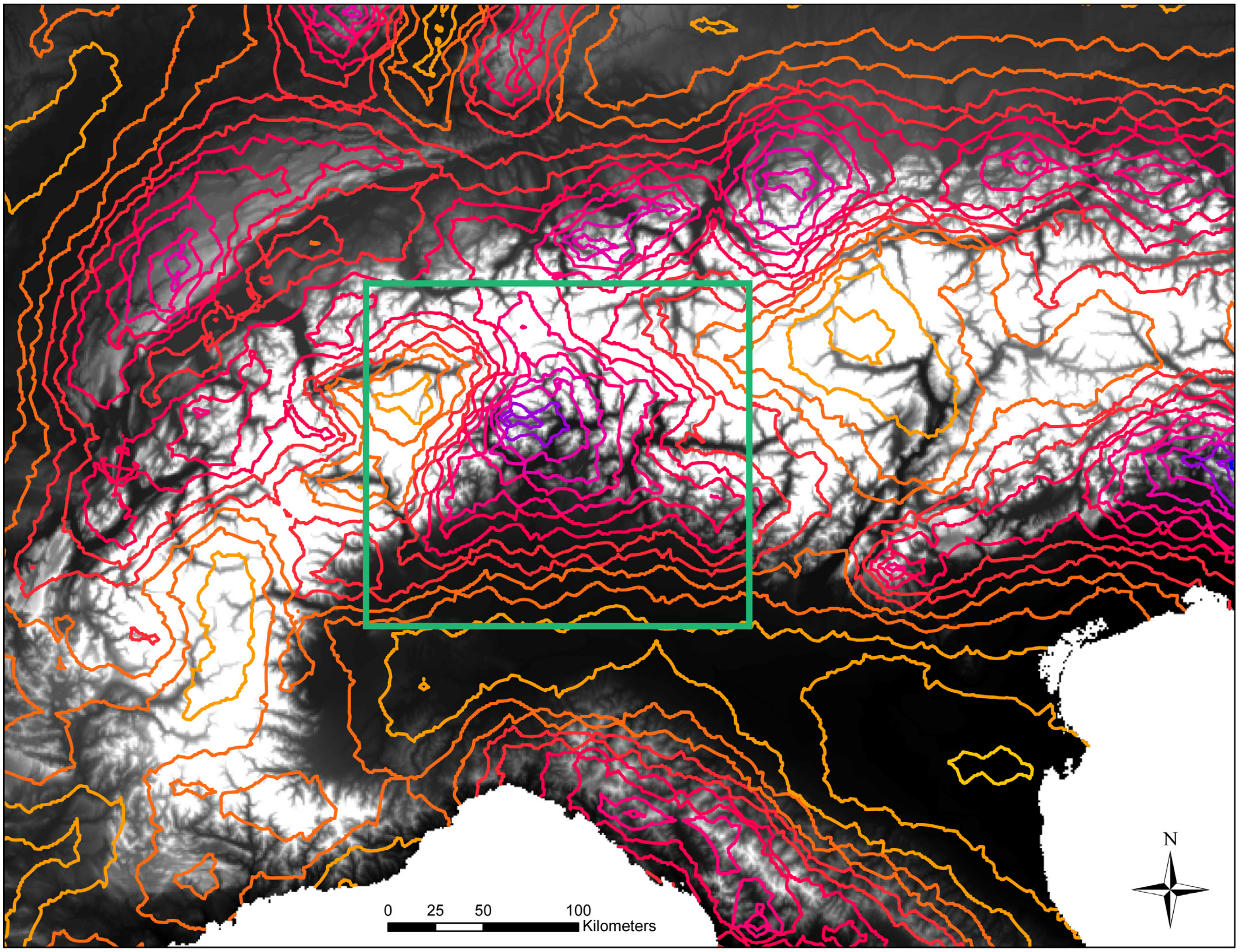

Figure 2. Digital elevation model of the Alps, showing peak precipitation in the area of the Lepontine Dome (boxed). Scale ranges from yellow (500 mm/yr) to purple (3000 mm/yr).

Michael Werner documented evidence for flood events capable of moving boulders from 0.5 to nearly 3 meters in diameter. He established a regional growth curve for lichen and applied it to determine the timing of flooding events. Three rivers indicate stability of boulders greater than 0.5 meters in diameter over the past 25-50 years. Clustered ages of lichen on boulders in the Bosco Gurin River record three large events in approximately 1900, 1930 and 1955.

Lindsay Rathnow used paleoflood analysis based on dendrochronologic dating of vegetation-clearing flood events in river gorges. The elevation of the trees above the river, together with channel geometry and slope data obtained in field surveys provides an estimate of the discharge, shear stress and sediment transport capability of these large events. Correlation across several rivers suggests large events around 1950 and 1965 which are estimated to have the ability to transport the sediment equivalent to 30-100 years of basin-wide erosion.

2. DEFORMATION OF THE MAGGIA NAPPE

The structural geology team seeks to understand how strain within and between thrust nappes integrates to give a bulk deformation on the scale of the mountain belt. If the deformational history is well-understood, it enables a kinematic description of the mountain belt that may be used to test erosional histories provided by the thermochronologic data.

We focused our efforts on the Maggia Nappe, a crystalline unit in the Pennine Zone of the Alps. The area is well-known among geologists for spectacular exposures of shear zones that offset dikes and other features (Ramsay and Allison, 1979).

Kat Compton has focused on quantifying deformation throughout the nappe, including both the shear zones and the surrounding wallrock. Careful field measurements of dikes and other features offset by the shear zones enabled Kat to determine the slip vector for several shear zones. She also quantified deformation in shear zones as well as the surrounding wallrock with two additional approaches. First, Kat digitized the shapes of biotite clots on three mutually perpendicular rock faces and applied the Rf/φ technique. As a second approach, Kat traveled to Yale University to measure the lattice-preferred orientation (LPO) using Electron Backscatter Diffraction (EBSD). Assuming an initially random biotite fabric, the LPO data were used to generate a strain ellipsoid. All three approaches provided consistent results: plane-strain deformation with a northwest-southeast shortening direction, supporting an interpretation that these structures developed during emplacement of the Maggia Nappe.

Bill Barnhart studied the deformation of quartz, looking for microstructural evidence to constrain the conditions of deformation and pattern of strain within the Maggia Nappe. His observations indicate dislocation accommodated dynamic recrystallization, as evidenced by grain size reduction and grain boundary area reduction. Surprisingly, EBSD work at Yale University revealed that even the rocks from the high-strain shear zones show at most only a weak LPO, suggesting that any fabric acquired during the dislocation-assisted deformation must have been weakened or destroyed by subsequent deformation. These observations provide important constraints on the structural evolution of the Maggia Nappe.

3. THERMOCHRONOLOGY AND RATES OF EROSION

The thermochronology team focused on measuring rates of exhumation in the Lepontine Dome. Working together, transects were identified and then three different transects were sampled. The approach was to use complimentary thermochronological systems on shared separates to capture the longest record possible. Two vertical transects at Lavorgno and Monte Morissolino provide quantitative exhumation rates both north and south of the Insubric line, and one horizontal transect along the Ticino River identifies a north-south gradient in cooling ages. Low zircon abundances, despite promising gneissic lithologies, limited the transect resolution. Likewise the near complete absence of apatite restricted our ability to fully quantify the exhumation history of the different transects. Nonetheless, the data indicate sustained exhumation from ~9-19 Ma, possibly beginning at ~23 Ma.

Jessica Stanley used the (U-Th)/He system in both zircon and apatite. After separating the minerals from whole-rock samples, Jessica travelled to the University of Arizona, where she measured (U-Th)/He ages of zircons and on apatite sample. Her results indicate continuous exhumation of 900 m/Myr from ~9 to 11 Ma to the north of the Insubric Line. To the south of the Insubric line, exhumation proceeded much more slowly from ~180 to 150 Ma until it accelerated at ~23 Ma. A slight north-south gradient in ages exists along the Ticino River, perhaps as a result of deformation following closure.

Rosalba Queirolo used the fission-track system in zircon, which she prepared and at Union College. The Zircon FT results show an exhumation rate similar to the helium result, and the inference is that erosion rates early in the orogenic cycle (~14-18 Ma), were the same as those later as seen in the Helium data. Radiation damage and complicated zoning in zircons from the samples south of the Insubric line delayed counting and prevent inclusion of ages in this volume. A north-south gradient in the horizontal transect ages exists, although it is very slight.

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