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2007-2008 PROJECTS:

Tectonic and Climatic Forcing of the Swiss Alps
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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

TECTONIC AND CLIMATIC FORCING OF THE SWISS ALPS: p1-5
Project Director: JOHN I. GARVER: Union College
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DEFORMATION CONDITIONS AND DEFORMATION MECHANISMS OF DUCTILE SHEAR ZONES OF THE MAGGIA NAPPE, SWITZERLAND: p6-11
WILLIAM D. BARNHART: Washington and Lee University
Research Advisor: Jeffrey Rahl

STRAIN ANALYSIS AND INTEGRATION: QUANTIFYING THE DEFORMATION OF THE LAGHETTI AREA, MAGGIA NAPPE, SWITZERLAND: p12-17
KATHLEEN COMPTON: Whitman College
Research Advisor: Jeffrey Rahl

ZIRCON FISSION-TRACK THERMOCHRONOLOGY OF THE LEPONTINE DOME, SWISS ALPS: p 18-22
ROSALBA QUEIROLO: Union College
Research Advisor: John Garver

QUANTIFICATION OF FLOOD MAGNITUDES AND EROSION RATES USING DENDROCHRONOLOGY: TICINO CANTON, SWITZERLAND: p23-28
LINDSAY RATHNOW: University of Illinois
Research Advisor: Alison Anders

EQUILIBRIUM-LINE ALTITUDE VARIANCE WITH PRECIPITATION IN THE SOUTH-CENTRAL ALPS: IMPLICATIONS FOR LONG-TERM EXHUMATION: p29-34
SCOTT REYNHOUT: Beloit College
Research Advisor: Alison Anders

CAN THE STREAM POWER LAW BE USED TO QUANTIFY DIFFERENTIAL LANDSCAPE EVOLUTION FROM BEDROCK INCISION IN THE CENTRAL ALPS, SWITZERLAND?: p35-39
LIBBY RITZ: Carleton College
Research Advisors: Mary Savina

USING (U-Th)/He THERMOCHRONOLOGY TO CONSTRAIN EXHUMATION IN THE SWISS-ITALIAN ALPS: p40-43
JESSICA STANLEY: Massachusetts Institute of Technology
Research Advisor: Samuel Bowring

QUANTIFYING RATES OF EROSION USING THE OCCURRENCE AND MAGNITUDE OF FLOOD EVENTS IN THE LEPONTINE DOME, SWITZERLAND: p44-48
MIKE WERNER: Colgate University
Research Advisors: Martin Wong

THE RELATIONSHIP BETWEEN CHANNEL MORPHOLOGY OF BEDROCK RIVERS AND EROSIONAL PROCESSES IN TICINO, SWITZERLAND: p49-54
ELIZABETH WONG: Yale University
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ZIRCON FISSION-TRACK THERMOCHRONOLOGY OF THE LEPONTINE DOME, SWISS ALPS

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INTRODUCTION

The Alps are a Tertiary collision zone that resulted from suturing Apulia with Eurasia. Within the Alps there are local exposures of deeply exhumed, metamorphic, lower crustal rocks including the Lepontine Dome in Switzerland. The dome is comprised of gneisses with metamorphic ages of 30-40 Ma and exhumation ages of 10-20 Ma. The Insubric line is the southern border of the Lepontine Dome and rocks to the south show little exhumation.

This research is focused on the timing and nature of the exhumation north of the Insubric Line and how it relates to mountain building. There are two competing hypotheses for how the Lepontine rocks were exposed: one suggests that uplift was regionally similar, the other suggests a fanning motion due to crustal backfolding. Samples were collected to test these hypotheses and their cooling ages were determined by thermochronology. The zircon fission track ages are between 14-18 Ma and complementary zircon helium ages range between 9-14 Ma (see Stanley, this volume). Therefore, exhumation rates of ~400-600 m/myr occur at ~15 Ma and ~900 m/yr at ~10 Ma. At this time in the study there is clear change in exhumation through time but data concerning exhumation trends across the dome awaits further analysis.

TECTONIC SETTING

The Alps have a complex history dominated by episodes of deformation, metamorphism, and exhumation. All of these processes are associated with the interaction of the Eurasian and African tectonic plates and the intervening Tethyan marginal strata (Hurford et al., 1986). Several varying and detailed accounts of the Alpine construction are available, including Schmidt et al., 1996; Stampfli et al., 2002; and Trumpy, 1980, and the following is simplified from these works.

The Early- to Mid Jurassic sinistral opening of the Central Atlantic resulted in the motion of Africa relative to Eurasia and the resulting development of the passive margin Piemont-Ligurin Ocean (located at the present-day site of the Appenines and Alps). During the mid-Cretaceous, the southern Atlantic opened producing an anti-clockwise rotation of the African plate that closed the Tethys and flanking continental margin. Crustal shortening in the Tethys produced source regions that fed later flysch deposition.

It is uncertain whether tectonism was continuous or a series of multiple collisions/events, but Mesoalpine shortening and closure of the Tethyan geosyncline resulted from the northward movement of the Apulian plate. During the Upper Cretaceous and Eocene-Oligocene, major Mesoalpine deformation occurred forming the Pennine nappes from Central Tethyan Mesozoic sediments and Pre-Triassic crystalline basement. Overthrusting of Austroalpine nappes from the southern Tethyan shelf and northern Apulian continental margin resulted from continent-continent collision. Deep within the Pennine nappes temperatures rose and amphibolite facies metamorphism occurred.

The Insubric Line is commonly referred to as the continent to continent suture zone but recent studies suggest that the actual suture is farther north and represented by the Zermatt ophiolites in western Switzerland. The lower Austroalpine-Pennine boundary is in eastern Switzerland. The Insubric Line, which runs through the southern Lepontine

Alps, delineates Alpine structures and metamorphism in the north from the Prealpine structures and metamorphism of the southern part of the Alps. In the Oligocene, noticeable exhumation only occurred north of the Insubric Line, and combined with erosion of the Pennine and Austroalpine nappes created Molasse deposits to the north and south. Exhumation was accompanied by minor post-kinematic granite emplacement. The Helvetic napes were produced by Neoalpine thrusting of sediments in the northern Tethyan margin and overrode the Hercynian Aar massif. Later compression, a northward push of the Apulian Plate, is represented by the “root zone” or Steep Belt at the southern border of the Pennine Zone.

METHODS

Sample Collection

Several zircon and apatite bearing, orthogneiss and paragneiss samples were collected in a vertical (highest 2870 m) and horizontal transect in the Southern Swiss Alps and Northern Italian Alps. Each sample site was chosen because the location was meant to optimize distribution for testing the regional cooling pattern. The Insubric line was assumed to be the shear zone that the regional tilting at the sample locations hinged upon. Vertical transects were taken in Val Maggie, Locarno, Bocchette de Val Maggia, Val Verzasca, and along the western shore of Lago Maggiore.

A north-south horizontal transect through the Southern Alps was taken on either side of the Insubric Line. For the vertical transects samples were taken at ~200 to 300 m vertical intervals. The highest, central and lowest sample of each vertical transect is the initial focus of detailed analysis. The samples have been processed and analyzed with fission track dating and helium dating methods (Stanley, MIT 2008) revealing the pattern of regional exhumation that has then been related to the tectonic evolution of the Alps.

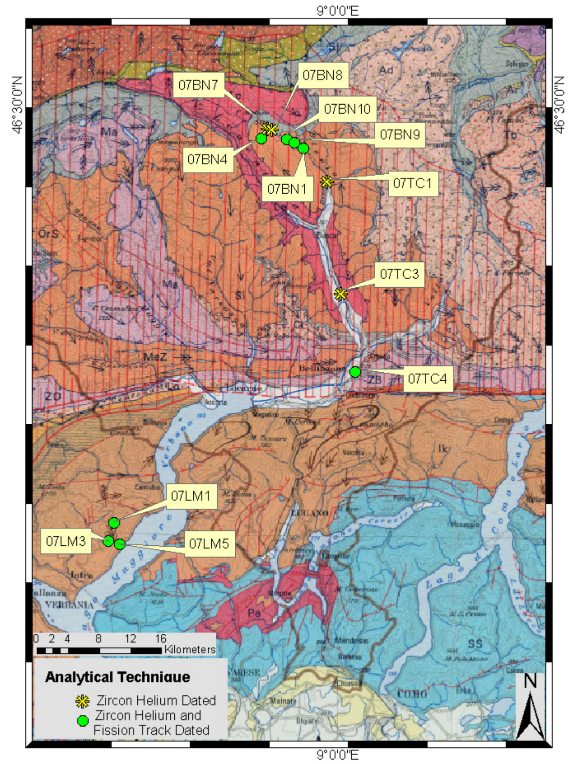

Figure 1: Sample location map. The tectonic map of Switzerland is taken from the Swiss geologic commission (1980)

Fission Track Dating Processes

After sample preparation was completed, one fraction of the split was zircon or apatite helium dated (Stanley, this volume) and the other was zircon fission track dated in this study. Using two different dating techniques allows for the rate of exhumation to be calculatedfor each system. This work focuses on the zircon FT dating.

Fission tracks in zircon are formed from the spontaneous fission of ^{238}U (Garver et al., 2005). The tracks are stable and retained in the crystal structure after the crystal cools to a closure temperature of 250 ^{o}C +/- 40 ^{o}C, but the closure temperature depends on the rate of cooling (Brandon et al., 1998). Before the crystal in a rock is exhumed to a depth corresponding with the temperature of ~250 ^{o} C all tracks that form, anneal in place. Once at a depth with a temperature around closure, the crystal is in the partial annealing zone (PAZ) where tracks can be partially or fully annealed. A quick exhumation rate would result in rapid passage through the PAZ to the surface. If a grain undergoes re-heating will be annealed and the thermochronometric clock will be reset or partly reset. In this case the rate of exhumation can no longer be determined, and instead the age dates the last re-heating event.

DATA

The ages of the Lavorgno Village vertical transect, north of the Insubric Line, has an elevation range of 1574 m and an age range of 3.3 Myr (Table 1). The two higher elevations have similar ages with a 0.2 Myr age difference and the two lower elevation samples have similar ages with a 0.6 Myr age difference (Table. 1). All of the ZFT ages are within one standard error of each other. Ages for the Lago Maggiore vertical transect, south of the Insubric Line and Ticino River Valley horizontal transect have yet to be dated (Table 1).

Note: In this table, ρs is the density (10^6 cm^2) of spontaneous tracks and Ns is the number of spontaneous tracks counted; ρi is the density (in 10^6 cm^2) of induced tracks and Ni is the number of induced tracks counted; ρd is the density (in 10^5 cm^2) of tracks on the fluence monitor (CN5) and Nd is the number of tracks on the monitor (averaged if more than one sample); n is the number of grains counted; X^2 is the Chi-squared probability (%). Zircon fission track ages (± 1σ, which are average values) were determined using the Zeta method, and calculated using the computer program and equations in Brandon (1992). A Zeta factor of 363.2 ± 10.1 (± 1 se) is based on 8 determinations on standard samples from the Fish Canyon Tuff, Buluk Tuff, and Peach Springs Tuff. Ages are reported as pooled ages if X^2 is above 1%, otherwise a X^2 age is given. Glass monitors (CN5) placed at the top and bottom of the irradiation package were used to determine the fluence gradient. All samples were counted at 1250x using a dry 100x objective (10x oculars and 1.25x tube factor) on an Olympus BX60 microscope fitted with an automated stage and a Calcomp digitizing tablet.

The best fit line to the data (solid line), shows that there is ~2 Ma of difference between the lowest elevation fission track sample (511 m) and the third sample at 1124 m resulting in a 613 m elevation difference (Fig. 2). A simple calculation of exhumation rate gives a likely minimum exhumation rate ~250 m/Myr. A rate was also calculated between the highest elevation sample (2085 m) and the same third sample point (1124 m) yielding a different likely minimum exhumation rate of ~500 m/Myr (Fig. 2). The dotted line shows the best linear fit, which is a single, constant, exhumation rate of ~500 m/Myr. The helium dating, plotted to the

	Elev.	ρ_s	N_s	ρ_i	N_i	ρ_d	N_d	n	χ^2	Age
Lavorgno Village (Brenno River - North)										
BN01	511	2.34	498	6.6	1406	2.44	3621	22	18.5	15.7 ± 1.0
BN10	779	2.96	714	8.94	2157	2.52	3728	20	28.4	15.1 ± 0.8
BN09	1124	4.41	1024	10.8	2516	2.48	3684	20	1.7	18.4 ± 0.9
BN04	2085	3.07	665	7.49	1623	2.45	3646	21	10.1	18.2 ± 1.0
Ticino River Valley (South)										
TC04	405	4.23	724	10.9	1862	2.61	3874	20	0.2	18.4 ± 1.0

Table 1: Zircon fission track data, Lepontine Dome, Swiss Alps. Note: In this table, ρs is the density (10^6 cm^2) of spontaneous tracks and Ns is the number of spontaneous tracks counted; ρi is the density (in 10^6 cm^2) of induced tracks and Ni is the number of induced tracks counted; ρd is the density (in 10^5 cm^2) of tracks on the fluence monitor (CN5) and Nd is the number of tracks on the monitor (averaged if more than one sample); n is the number of grains counted; X^2 is the Chi-squared probability (%). Zircon fission track ages (± 1σ, which are average values) were determined using the Zeta method, and calculated using the computer program and equations in Brandon (1992). A Zeta factor of 363.2 ± 10.1 (± 1 se) is based on 8 determinations on standard samples from the Fish Canyon Tuff, Buluk Tuff, and Peach Springs Tuff. Ages are reported as pooled ages if X^2 is above 1%, otherwise a X^2 age is given. Glass monitors (CN5) placed at the top and bottom of the irradiation package were used to determine the fluence gradient. All samples were counted at 1250x using a dry 100x objective (10x oculars and 1.25x tube factor) on an Olympus BX60 microscope fitted with an automated stage and a Calcomp digitizing tablet.

left, has a linear fit showing relatively fast and constant exhumation rate of ~900 m/Myr.

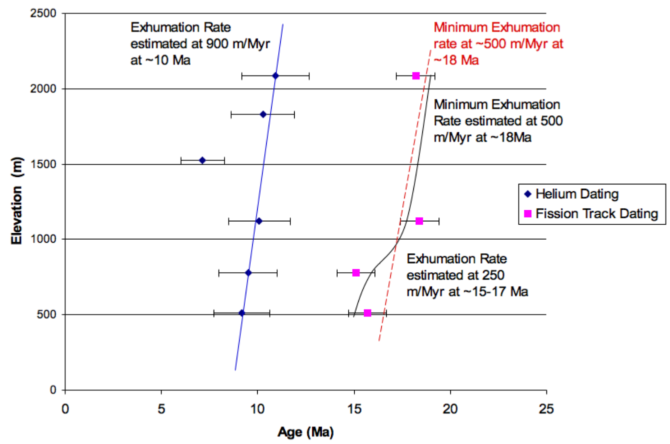

Figure 2. Age-elevation plot showing probable exhumation rates using the two different methods. Zircon Helium results (blue) and Zircon Fission Track results (pink), are shown for the verticle transect in Lavorgno Village (Brenno River – North) of the Lepontine dome. The non-linear curve is a possible cooling path that emphasizes an initial rapid cooling at the onset of orogenic activity at c. 18 Ma.

DISCUSSION

The vertical transect samples were taken at 200-300m intervals which make the individual calculation of an exhumation rate between each sample possible, revealing potential chnages in exhumation. The geothermal gradient of Hurfurd (1986) and a conventional zircon fission track closure temperature of 280 °C (Reiners and Brandon, 2006), we calculated the closure depth at 9-10 km depth. The zircon helium system has a closure temperature of ~200 °C (Reiners and Brandon, 2006), and a calculated closure depth of 6-7 km. With such assumptions exhumation rates between any sample site and the depth of closure (T=0) can be calculated. Any change in exhumation rates will not be obviously expressed. The average exhumation rate between each sample site and the closure temperature depth is ~700 m/Myr. This is a rapid exhumation rate, which is a significantly higher rate than that calculated from the elevation transect (Fig. 2).

The extrapolated exhumation rate is ~200 m/Myr higher than the actual calculation of the potential constant exhumation rate, which suggests that an undetected break in slope was averaged out. Two important observations were made based on the data. First, in the two upper elevation samples, at ~18 Ma, there appears to be a ~1km thick slab of rock with uniform cooling. Second, the two lower elevation samples are younger, and show a slower period cooling at ~15-17 Ma. It is likely that the early rapid cooling represent the onset of erosionally dirven cooling in this part of the Alps. Rapid exhumation had begun by 18 Myr, and continued until at least 9 Myr.

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