2012-2013 PROJECTS

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE: SHUMAGIN ISLANDS AND KENAI PENINSULA, ALASKA
Faculty: JOHN GARVER, Union College, CAMERON DAVIDSON, Carleton College
Students: MICHAEL DELUCA, Union College, NICOLAS ROBERTS, Carleton College, ROSE PETTIETTE, Washington & Lee University, ALEXANDER SHORT, University of Minnesota-Morris, CARLY ROE, Lawrence University.

LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTER N OREGON
Faculty: NICHOLAS BADER & KIRSTEN NICOLAYSEN, Whitman College.
Students: REBECCA RODD, University of California-Davis, RICARDO LOPEZ-MALDONADO, University of Idaho, JOHNNY RAY HINOJOSA, Williams College, ANNA MUDD, The College of Wooster, LUKE FERGUSON, Pomona College, MICHAEL BAEZ, California State University-Fullerton.

BIOGEOCHEMICAL CARBON CYCLING IN FLUVIAL SYSTEMS FROM BIVALVE SHELL GEOCHEMISTRY - USING THE MODERN TO UNDERSTAND THE PAST
Faculty: DAVID GILLIKIN, Union College, DAVID GOODWIN, Denison University.
Students: ROXANNE BANKER, Denison University, MAX DAVIDSON, Union College, GARY LINKEVICH, Vassar College, HANNAH SMITH, Rensselaer Polytechnic Institute, NICOLLETTE BUCKLE, Oberlin College, SCOTT EVANS, State University of New York-Geneseo.

METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND OLD MODELS
Faculty: ZEB PAGE, Oberlin College, EMILY WALSH, Cornell College.

GEOLOGY, PALEOECOLOGY AND PALEOClimATE OF THE PALEOGene CHICKALoON FORMATION, MATANUSKA VALLEY, ALASKA
Faculty: CHRIS WILLIAMS, Franklin & Marshall College, DAVID SUNDERLIN, Lafayette College.
CRETACEOUS TO MIocene EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX: ASSESSING THE SLIP HISTORY OF THE SNAKE RANGE DECOLLEMENT AND SPATIAL VARIATIONS IN THE TIMING OF FOOTWALL DEFORMATION, METAMORPHISM, AND EXHUMATION
Faculty: MARTIN WONG, Colgate University, PHIL GANS, University of California-Santa Barbara.
Students: EVAN MONROE, University of California-Santa Barbara, CASEY PORTELA, Colgate University, JOSEPH WILCH, The College of Wooster, JORY LERBACK, Franklin & Marshall College, WILLIAM BENDER, Whitman College, JORDAN ELMIGER, Virginia Polytechnic Institute and State University, MICHAEL KENNEY, University of California-Santa Barbara.

THE ROLE OF GROUNDWATER IN THE FLOODING HISTORY OF CLEAR LAKE, WISCONSIN
Faculty: SUSAN SWANSON, Beloit College, JUSTIN DODD, Northern Illinois University.
Students: NICHOLAS ICKS, Northern Illinois University, GRACE GRAHAM, Beloit College, NOA KARR, Mt. Holyoke College, CAROLINE LABRIOLA, Colgate University, BARRY CHEW, California State University-San Bernardino, LEIGH HONOROF, Mt. Holyoke College.

PALEOENVIRONMENTAL RECORDS AND EARLY DIAGENESIS OF MARL LAKE SEDIMENTS: A CASE STUDY FROM LOUGH CARRA, WESTERN IRELAND
Faculty: ANNA MARTINI, Amherst College, TIM KU, Wesleyan University.
Students: SARAH SHACKLETON, Wesleyan University, LAURA HAYNES, Pomona College, ALYSSA DONOVAN, Amherst College.

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: David Dethier, Williams College, Will Ouimet, U. Connecticut.
Students: CLAUDIA CORONA, Williams College, HANNAH MONDRACH, University of Connecticut, ANNETTE PATTON, Whitman College, BENJAMIN PURINTON, Wesleyan University, TIMOTHY BOATENG, Amherst College, CHRISTOPHER HALCSIK, Beloit College.

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation
Keck Geology Consortium: Projects 2012-2013
Short Contributions—Snake Range, Nevada Project

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Faculty: MARTIN WONG, Colgate University, PHIL GANS, University of California-Santa Barbara.

GEOCHRONOLOGY AND STRAIN ANALYSIS OF THE JURASSIC PLUTONIC COMPLEX ON THE SOUTHERN FLANK OF THE ORTHERN SNAKE RANGE, NEVADA
EVAN MONROE, University of California, Santa Barbara
Research Advisors: Phillip Gans, Martin Wong

MICROSTRUCTURAL ANALYSIS OF MYLONITIC MARBLE OF THE NORTHERN SNAKE RANGE
CASEY PORTELA, Colgate University
Research Advisor: Martin Wong

INSIGHTS INTO THE TECTONIC EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX FROM 40AR/39AR THERMOCHRONOLOGIC RESULTS, NORTHERN SNAKE RANGE, NEVADA
JOSEPH WILCH, College of Wooster
Research Advisor: Shelley Judge & Robert Wooster

METAMORPHIC CORE COMPLEX EVOLUTION: VERTICAL STRAIN GRADIENT IN THE NORTHERN SNAKE RANGE DECOLLEMENT
JORY LERBACK, Franklin & Marshall College
Research Advisor: Zeshan Ismat, Martin Wong, Phillip Gans

GEOCHEMISTRY AND GENESIS OF JURASSIC GRANITOIDS FROM THE NORTHERN SNAKE RANGE, NV
WILL BENDER, Whitman College
Research Advisor: Kirsten Nicolaysen

INTRUSIVE AND DEFORMATIONAL HISTORIES OF THE FOOTWALL ROCKS IN THE CENTRAL PART OF THE NORTHERN SNAKE RANGE, NEVADA
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INTRUSIVE AND DEFORMATIONAL HISTORIES OF THE FOOTWALL ROCKS IN THE CENTRAL PART OF THE NORTHERN SNAKE RANGE, NEVADA

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INTRODUCTION

Metamorphic core complexes are generally accepted as a manifestation of large-magnitude extension. In these complexes, low-angle (detachment) faults juxtapose a ductilely deformed lower plate against a brittly deformed upper plate. The Northern Snake Range (NSR) in east-central Nevada is considered a classic example of a metamorphic core complex (Gans et al. 1999; Miller et al. 1983). The Northern Snake Range Decollement (NSRD) has been carefully mapped; however questions to its formation still remain (Fig. 1). Deeply incised canyons in the range provide superb exposures of the footwall quartzites and schist's, permitting detailed study of how footwall fabrics relate to the detachment fault.

Previous studies suggested that there are at least two major unroofing events recorded in the footwall: a late Eocene early-Oligocene event and an early Miocene event (Miller et al. 1988; Lee et al. 1987; Miller et al. 1999). Prior work done by Miller et al. (1983) on the fabrics in the footwall interpreted an early history of coaxial stretching and thinning followed by non-coaxial top-to-the-east simple shear with lesser thinning. Lee (1987) showed that quartzite from Hendry's Creek experienced intense dynamic recrystallization of quartz and that they were well developed L-S tectonites throughout the stratigraphic section. Feldspars were deforming in a brittle fashion and micas were being deformed into mica fish. Quartz petrofabrics indicated non-coaxial simple shear for samples studied from the eastern part of the range while western samples were more indicative of coaxial pure shear (Lee et al. 1987). A later study by Gebelin et al. (2010) on quartzite from Hendry's Creek that showed consistent shear sense throughout the section supported the work done by Lee (1995). Miller et al. (1983) suggest temperatures of deformation in the lower greenschist facies. The temperatures of deformation have also been estimated through microstructures under the assumption that the quartz is wet, which significantly reduces the temperatures needed for deformation (Lister & Hobbs 1980). Gebelin et al (2010) also concluded that a hydrothermal system operated along the detachment and may have added water to the quartzite.

This study combines field observations, microstructure analysis, and electron backscatter diffraction (EBSD) on quartzite to shed light on the type and temperature of deformation undergone throughout the eastern half of the range in the areas of Smith Creek, Horse Canyon, and Deadman Creek (Fig. 1). Intrusive phases were sampled to refine and clarify ages specifically of the Horse Canyon orthogneiss and a late Cretaceous swarm of aplite-pegmatite dikes and sills.
U-PB GEOCHRONOLOGY OF INTRUSIVE PHASES

Intrusive phases, the Horse Canyon Orthogneiss (Khg) and a swarm of aplite-pegmatite dikes and sills (Kpa), intrude metasedimentary rocks in the footwall in the central part of the NSR. Prior field observations and U-Pb dating by Miller et al. (1988) indicated they were largely late Cretaceous. Samples of various intrusive phases from Smith Creek, Horse Canyon and Deadman Creek were collected for U-Pb zircon dating by laser ablation multi-collector inductively coupled plasma mass spectrometer (LA-MC-ICPMS).

Four samples of aplite-pegmatite intrusions as well as two samples of an orthogneiss intrusion were collected from Smith Creek, Horse Canyon, and Deadman Creek (Figure 2). Samples were processed using standard mineral separation techniques (milling, sieving, panning, Frantzing, and heavy liquid separation) in order to concentrate zircon grains for analysis. Roughly 80-100 zircon grains of varying size and shape were selected for mounting, with care taken to avoid metamict grains. Analysis was done in the LA-ICPMS at UC Santa Barbara. Measurements were collected for U-Pb ratios 238/206, 235/207, and 207/206 to plot along concordia diagrams and to determine the age of cooling for the zircon grain.

Standards were run before and during analysis of unknown samples to enable the correction of data. A proper curve is applied to the standards after the run to observe any variations or errors that might have occurred. From this curve, corrections can be made to the unknowns. Plotted data exclude inherited ages and analyses with elevated Pb.

Analysis of four leucogranite samples from Smith Creek, Deadman Creek, and Horse Canyon was carried out to obtain more precise ages on these intrusions (Fig. 2). Previous work presented ages for intrusions between 82-78 Ma (Miller et al. 1988; Gans et al. 1999). MK-NSR-06 is a fine-medium grain leucogranite intrusion from Smith Creek. U-Pb zircon dating gave an age of 84.6±0.4 Ma (n=28, MSWD=0.84). MK-NSR-23 is also a fine-medium grained leucogranite from Horse Canyon. It returned an age of 84.6±0.4 Ma (n=28, MSWD=0.84). MK-NSR-12 is a medium grain leucogranite from Smith Creek. A concordant age of 84.9±0.7 Ma was obtained (n=25, MSWD=1.4). MK-NSR-32 is a 2-mica leucogranite, which cross-cuts Cpm, Khg, and another aplite. A concordant U-Pb age of 76.1±1.5 Ma resulted from analysis of seven zircons. Three samples are nearly identical in age while one sample is distinctly younger, indicated prolonged magmatism.

Two widely separated samples of Khg were collected to obtain more precise emplacement ages on this intrusion and to test whether the entire unit is one age (Fig. 2). Khg is a mylonitized Cretaceous granitic intrusion best exposed in Horse Canyon. MK-NSR-22 was collected near the eastern limit in Horse Canyon and yielded an age of 101.6±0.5 Ma (n=25, MSWD=1.4). MK-NSR-37, the westernmost exposure of the orthogneiss was collected from upper Deadman Creek and gave an age of 100.9±0.5 Ma (n=30, MSWD=1.4). Previous work showed an age of 100±8 Ma (Gans et al. 1999; Miller et al. 1988). This new data supports and provides more precise ages than the previous work and confirms that the Horse Canyon orthogneiss is a single intrusion.

Figure 1. Geologic Map of Field Area with Sample Locations (Lee et al. 1999; Gans et al. 1999)
STRUCTURAL STUDIES

Two weeks were spent in the field collecting structural data and samples from the mylonitic quartzites in the footwall in Smith Creek, Horse Canyon, Hampton Creek, and Deadman Creek.

Mylonitic foliations in the study area generally dip gently to the north or east and the poles to foliation are distributed about a NNE trending girdle that suggest folding about a ESE trending fold axis (Fig. 3). In contrast, lineations are very consistently oriented WNW-ESE (Fig. 3).

MICROSTRUCTURES AND CPOS FOR QUARTZITE

Thirty-four oriented quartzite samples were collected from Smith Creek, Deadman Creek, Horse Canyon, and Hampton Creek. These samples were taken from varying depths in the stratigraphy but the majority comes from the Prospect Mountain Quartzite. Eleven quartzite samples were prepared for analysis on the SEM.

Quartzite microstructures and crystallographic preferred orientations (CPOs) were analyzed to assess the approximate temperatures of deformation and vorticities (Hirth & Tullis 1992; Stipp et al. 2002). Samples MK-NSR-11, 13, 08, 03, 05, and JW-NSR-02 were collected from Smith Creek. They all are typical L-S tectonites with ~5% mica. Quartz grains show undulatory extinction and variable amounts of deformation lamellae. Feldspar crystals are cracked and broken with small amounts of recrystallization (Fig. 4C). Quartz is ductilely deformed into ribbons and recrystallized into subgrains (Fig. 4B, D).

Recrystallization and recovery textures in quartz indicate both subgrain rotation and grain boundary migration, which correlates to regime II and III (Hirth & Tullis 1992). X to Z ratios for quartz ribbons are as much as 20:1 while in recrystallized grains they are typically 4:1. Quartz grains often pinch
and neck around mica, which limits the maximum recrystallization (Fig. 4D). Asymmetric mica fish in the mylonitized quartzites are abundant and consistently display top-to-east shear. Quartz ribbons and subgrains define an oblique grain shape foliation that makes an acute angle with C planes (Fig. 4B, D). The assumption is made that the fabric is entirely a product of simple shear and the angle between the grainshape foliation and C planes can serve as a proxy for the angle ($\Theta'$) between the X-Y plane of the finite strain ellipse and the shear zone boundary. Solving for the relationship ($\gamma = 2\theta / \tan 2\theta$) allows for an assessment of the overall amount of shear parallel to the shear zone boundary. A $\Theta'$ of 20° implies a shear strain of ~2.4 which is a minimum estimate given the oblique grainshape foliation is defined by recrystallized subgrains that formed after some amount of strain had already accumulated. This value multiplied by the structural thickness of the Prospect Mountain Quartzite (~0.5km) implies a minimum amount of top-to-east ductile shear of 1.2km.

Samples MK-NSR-32b, 36, 17, and JW-NSR-03, 06 are from Deadman Creek and Horse Canyon, characterized by a strong foliation and lineation, regime II and III recrystallization, and most show oblique grainshape foliation. Additionally, deformation of micas into mica fish is common. MK-NSR-36, 32b and JW-NSR-06 show a high degree of recovery compared to other samples (Fig. 4A). Similar deformation textures are observed in each sample including: undulatory extinction and less commonly deformation lamellae. Those samples that show a high degree of recovery do not provide oblique grain shape foliations; however those few samples that still retain sub grains and quartz ribbons show similar angles of intersection of ~20°.

EBSD analysis of crystallographic lattice preferred orientation was carried out on eight quartz samples: MK-NSR-03, 05, 08, 13, 32, 36 and JW-NSR-04, 06 (Figure 5). For quartz, the c-axis and a-axis are of most interest because they indicate the active slip systems as well as the sense of shear. For increasing temperature or decreasing strain rate different slip systems are active: basal $<a>$, rhomb $<a>$, prism $<a>$, and prism $<c>$ (Lister & Hobbs 1980). All of the samples analyzed showed strong y-axis maxima, Figure 4. Photomicrographs
inclined a-axes, and asymmetric single girdles (Fig. 5). The strong y-axis maxima indicates prism<a> slip being the dominant slip system while the single girdles indicate rhomb<a> slip (Fig. 5) (Lister & Hobbs 1980). MK-NSR-05 (Fig. 5H) stands out because it has a high concentration of prism<a> slip with very little rhomb<a> slip and weak asymmetry. All samples, except MK-NSR-05, clearly show top-to-the-east non-coaxial simple shear based on the asymmetric single girdle of c-axis concentrations and inclined a-axis plots parallel to the lineation direction. The types of active slip systems are virtually constant with depth and laterally.

DISCUSSION

The footwall of the NSRD is comprised of mylonitized quartzites, schists, and various intrusive phases. The intrusive phases of Khg and Kpa were sampled and dated by U-Pb zircon. Two samples of Khg yielded identical ages ~101Ma supporting previous work. Kpa samples showed a range of intrusion from ~85Ma to ~76Ma. This expands upon the range previously suggested of 82Ma-78Ma. Additional dating of leucogranite sills and dikes in the NSR is needed to establish the total age span of leucogranite emplacement and whether it occurred in distinct pulses or continuously throughout the late Cretaceous.

The mylonitized quartzites of the Prospect Mountain Quartzite and McCoy Creek Group in the study are classic L-S tectonites. Recovery textures of GBM and SGR imply deformation in regime II and III (Hirth & Tullis 1990), suggesting temperature constraints of 450-550°C (Stipp et al. 2002). Additionally, EBSD analysis shows that the primary slip system active is prism<a> based on y-axis maxima plots (Fig. 5), which is a relatively high temperature slip system with lesser amounts of rhomb<a> slip (a slightly lower temperature system) active (Lister & Hobbs 1980; Lee et al. 1987). Top-to-the-east simple shear is interpreted from asymmetric single girdle c-axis orientations, mica fish, and oblique grainshape foliation. This further supports that the eastern part of the NSR last recorded simple shear; however the amount of top-to-east shearing estimated accounts for a minimum of 1.2km; pure shear, as seen in western samples, must have played a larger role then to accommodate the roughly 330% extension of Prospect Mountain Quartzite estimated (Miller et al. 1983; 1988; 1999). Overprinting of older pure shear fabrics likely occurred as deformation became progressively non-coaxial.

Cooling ages of the footwall using Ar/Ar of micas indicate that footwall temperatures had already dropped below 300°C by ~20Ma (Miller et al. 1988; Lee et al. 1987; 1995; Gans et al. 2011). Thus quartz had to cease ductile deformation by 20Ma. This is further supported by a new U-Pb zircon age (Monroe et al., this volume) of an undeformed 23Ma rhyolitic dike that cuts the southeastern part of the footwall, which is dated at 23Ma. Given the evidence that
the footwall cooled below 300°C by 20Ma and an undeformed 23Ma dike cut lower plate fabrics, the strain recorded in the area of Smith Creek, Horse Canyon, and Deadman Creek must be older than 23Ma and younger than the 76Ma deformed dike swarm. Thus none of the top-to-east shearing can be coeval with the Miocene slip event.

ACKNOWLEDGEMENTS

I would like to thank Dr. Phil B. Gans for his tireless efforts in the field and in the classroom helping to make this project a success. Excellent field samples could not have been collected without the help of Joe Welch. Also, a huge thank you goes to Evan Monroe for his help both in the field and in the lab. This research project was made possible by Keck Geology Consortium: Cretaceous to Miocene evolution of the northern Snake Range metamorphic core complex, and URCA grant #231. Additional thanks to Dr. Martin Wong for his essential advising on the project and Dr. Gareth Seward and Dr. Andrew Kylander-Clark for trusting me with invaluable lab equipment.

REFERENCES


