FORMATION OF BASEMENT-INVOLVED FORELAND ARCHES: INTEGRATED STRUCTURAL AND SEISMOLOGICAL RESEARCH IN THE BIGHORN MOUNTAINS, WYOMING
Faculty: CHRISTINE SIDDOWAY, MEGAN ANDERSON, Colorado College, ERIC ERSLEV, University of Wyoming
Students: MOLLY CHAMBERLIN, Texas A&M University, ELIZABETH DALLEY, Oberlin College, JOHN SPENCE HORNBUCKLE III, Washington and Lee University, BRYAN MCATEE, Lafayette College, DAVID OAKLEY, Williams College, DREW C. THAYER, Colorado College, CHAD TREXLER, Whitman College, TRIANA N. UFRET, University of Puerto Rico, BRENNAN YOUNG, Utah State University.

EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SOUTHWEST MONTANA
Faculty: TEKLA A. HARMS, JOHN T. CHENEY, Amherst College, JOHN BRADY, Smith College
Students: JESSE DAVENPORT, College of Wooster, KRISTINA DOYLE, Amherst College, B. PARKER HAYNES, University Of North Carolina - Chapel Hill, DANIELLE LERNER, Mount Holyoke College, CALEB O. LUCY, Williams College, ALIANORA WALKER, Smith College.

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: DAVID P. DETHIER, Williams College, WILL OUMET, University of Connecticut
Students: ERIN CAMP, Amherst College, EVAN N. DETHIER, Williams College, HAYLEY CORSON-RIKERT, Wesleyan University, KEITH M. KANTACK, Williams College, ELLEN M. MALEY, Smith College, JAMES A. MCCARTHY, Williams College, COREY SHIRCLIFF, Beloit College, KATHLEEN WARRELL, Georgia Tech University, CIANNA E. WYSZNYSZYK, Amherst College.

SEDIMENT DYNAMICS & ENVIRONMENTS IN THE LOWER CONNECTICUT RIVER
Faculty: SUZANNE O’CONNELL, Wesleyan University
Students: LYNN M. GEIGER, Wellesley College, KARA JACOBACCI, University of Massachusetts (Amherst), GABRIEL ROMERO, Pomona College.

GEOMORPHIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.
Faculty: KELLY MACGREGOR, Macalester College, CATHERINE RIHIMAKI, Drew University, AMY MYRBO, LacCore Lab, University of Minnesota, KRISTINA BRADY, LacCore Lab, University of Minnesota
Students: HANNAH BOURNE, Wesleyan University, JONATHAN GRIFFITH, Union College, JACQUELINE KUTVIR, Macalester College, EMMA LOCATELLI, Macalester College, SARAH MATTESON, Bryn Mawr College, PERRY ODDO, Franklin and Marshall College, CLARK BRUNSON SIMCOE, Washington and Lee University.

GEOLOGIC, GEOMORPHIC, AND ENVIRONMENTAL CHANGE AT THE NORTHERN TERMINATION OF THE LAKE HÖVSGÖL RIFT, MONGOLIA
Faculty: KARL W. WEGMANN, North Carolina State University, TSALMAN AMGAA, Mongolian University of Science and Technology, KURT L. FRANKEL, Georgia Institute of Technology, ANDREW P. DEWET, Franklin & Marshall College, AMGALAN BAYASAGALN, Mongolian University of Science and Technology.
Students: BRIANA BERKOWITZ, Beloit College, DAENA CHARLES, Union College, MELISSA CROSS, Colgate University, JOHN MICHAELS, North Carolina State University, ERDENEBAYAR TSAGAANNARAN, Mongolian University of Science and Technology, BATTTOGTOH DAMDINSUREN, Mongolian University of Science and Technology, DANIEL ROTHBERG, Colorado College, ESUGEI GANBOLD, ARANZAL ERDENE, Mongolian University of Science and Technology, AFSHAN SHAikh, Georgia Institute of Technology, KRISTIN TADDEI, Franklin and Marshall College, GABRIELLE VANCE, Whitman College, ANDREW ZUZA, Cornell University.

LATE PLEISTOCENE EDIFICE FAILURE AND SECTOR COLLAPSE OF VOLCÁN BARÚ, PANAMA
Faculty: THOMAS GARDNER, Trinity University, KRISTIN MORELL, Penn State University
Students: SHANNON BRADY, Union College. LOGAN SCHUMACHER, Pomona College, HANNAH ZELLNER, Trinity University.

KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION
Faculty: JADE STAR LACKEY, Pomona College, STACI L. LOEWY, California State University-Bakersfield
Students: MARY BADAME, Oberlin College, MEGAN D’ERRICO, Trinity University, STANLEY HENSLEY, California State University, Bakersfield, JULIA HOLLAND, Trinity University, JESSLYN STARNES, Denison University, JULIANNE M. WALLAN, Colgate University.

EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING
Faculty: JOHN CRADDOCK, Macalester College, DAVE MALONE, Illinois State University
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KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION
Project Faculty: JADE STAR LACKEY, Pomona College, STACI L. LOEWY, California State University—Bakersfield

ORIGIN OF MIGMATITIC ROCKS IN THE SEQUOIA PENDANT, SIERRA NEVADA, CALIFORNIA
MARY BADAME, Oberlin College
Research Advisor: Steve Wojtal

PLUTON-WALLROCK INTERACTION OF THE EMPIRE QUARTZ DIORITE, SOUTHERN SIERRA NEVADA: IMPLICATIONS FOR SKARN FORMATION IN THE MINERAL KING PENDANT
MEGAN D’ERRICO, Trinity University
Research Advisor: Dr. Benjamin Surpless

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STANLEY HENSLEY, California State University, Bakersfield
Research Advisor: Dr. Staci Loewy

THE PETROGENESIS OF THE ASH MOUNTAIN INTRUSIVE COMPLEX: IMPLICATIONS FOR SIERRAN MAGMATISM
JULIA HOLLAND, Trinity University
Research Advisor: Ben Surpless

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JESSLYN STARNES, Denison University
Research Advisor: Dr. Erik Klemetti

STABLE ISOTOPE GEOCHEMISTRY OF MARBLES IN THE KINGS SEQUENCE, SIERRA NEVADA, CA
JULIANNE M. WALLAN, Colgate University
Research Advisor: William H. Peck

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INTRODUCTION

The Sierra Nevada has been the center for geologic discovery and fomented geologic thinking for well over 100 years. Pioneering explorations and studies by the likes of Clarence King, Joseph LeConte, and John Muir shaped how geologists understood granitoid rocks, glaciers, weathering, and the interplay of Biology and Geology. The discoveries that followed, especially after the discovery of plate tectonics, re-stoke discussions of how magmas form and crystallize to form plutons, how much crust is recycled at subduction zones, and the role of magmatism in climate change. This Keck project, the first in the Sierra, embraced many of the discoveries of the past—standing on the shoulders of giants—in its conception, while striving to use the Sierra to push the limits of our knowledge.

The Sequoia region (Fig. 1) was a natural choice for a project because of the geologic diversity, exceptional variety of igneous and metamorphic rocks in various associations telling the story of the interplay of magmas and the rocks they intrude. This area affords a cross section through rocks of many different ages, and the actions of tectonic uplift, water, and ice have conspired to expose many different structural levels in the batholith. Our fieldwork in the region was conducted in a wide range of environments. Some field sites in the Foothills, at just over 1100 feet saw daytime temperatures routinely exceeded 100°F (Fig. 2A). Chaparral and oak savannah landscapes graded into Sequoia groves in our mid-altitude sites (Fig. 2B), and at Mineral King, we worked in glacially "remodeled," quoting Muir, alpine terrains at over 11,000 feet (Fig. 2C).

SIERRAN GEOLOGY

The Sierra Nevada batholith is the classic example of a Cordilleran-type convergent margin batholith. Subduction of the Farallon plate beneath western North America in the Cretaceous produced at least 1,000,000 km3 of granitic magmas in the Sierran arc. Most magmatism occurred between 120 and 85 million years ago and involved melting, mixing, and recycling of various amounts of mantle, arc and crustal rocks (Ague and Brimhall, 1988; Bateman, 1992; Ducea, 2001; Saleeby et al., 2003; Coleman et al., 2004; Wenner and Coleman, 2004; Lackey et al., 2006; 2008). The resulting batholith is a collage of plutons interspersed with steeply dipping pendants and septa of pre-batholith metamorphic wallrocks (Fig. 1). The granitoid rocks range from gabbro to
high-silica, peraluminous rocks, with mafic and felsic plutons commonly displaying a range of textures indicative of mingling and mixing (Fig. 2D), as well as entrainment of xenolithic material (Fig. 2E). Several of the high-silica granites are peraluminous and have evidence of contamination at their margins (Ague and Brimhall, 1988; Lackey et al., 2006; 2008). Oxygen and strontium isotope data for Grant Grove and other Sequoia region plutons suggest contamination in areas close to contacts with wallrocks (Chen and Tilton, 1991; Lackey et al., 2006). Additionally, previous bulk zircon U-Pb analyses (Chen and Moore, 1982) for many of these plutons, indicate considerable complexity and inheritance of diverse age populations of zircon crystals, a result consistent with assimilation of metasedimentary rocks.

In the Sequoia region, metamorphic wallrocks of the Kings Sequence are typically biotite schist, marble, quartzite, and felsic to mafic metavolcanic rocks (Saleeby and Busby, 1993; Fig. 1). Kings Sequence metavolcanic rocks show pronounced evidence for a spectrum of metamorphic processes in the region. For example, biotite schist shows migmatitic textures close to contacts with plutons (Fig. 2F); marbles are coarsely recrystallized (Fig 2G), and in places aluminous, marl protoliths yield spectacular garnet + wollastonite ± diopside calc-silicate assemblages (Fig. 2H). At Empire Mountain, fluid infiltration during contact metamorphism allowed development of massive garnetite skarns (Fig. 2I).

THE MAGMA-WALLROCK INTERFACE

The balance of evidence indicates that high-silica plutons in the Sequoia region, especially those with peraluminous compositions, are locally contaminated in response to partial melting of the Kings Sequence (Lackey et al., 2008), and thus have veneers of superimposed contamination. Contamination and melting of metamorphic wallrocks is widely recognized in deeper exposures of the batholith (25–30 km) in the Southern Sierra (Saleeby et al., 1987; Pickett and Saleeby, 1994; Zeng et al., 2005), but mid-crustal (10–20 km; Ague and Brimhall, 1988) contamination was largely unrecognized until recently and has not been studied in detail. Thus our governing research theme was to test the hypothesis that magmas, both felsic and mafic, ascended from source regions, and locally became contaminated by partial melting or wholesale assimilation of metamorphic wallrocks. In this scenario, mafic magmas associated with the high-silica plutons are largely coeval and potentially supplied heat to drive partial melting of the metamorphic rocks. Migmatite complexes in the region may contain quenched former partial melts and therefore can be evaluated for melting reactions and potentially the “budget” of melt that they could produce. While the granites exposed at the current crustal levels are complex integrations of different source and contamination histories, crystal cargoes of inherited xenocrysts (zircon, garnet, aluminosilicate minerals, spinel, monazite) can be employed to begin to deconvolute this history.

The significance of testing this hypothesis is that it
directly informs our understanding of the tempo and mode by which convergent margin batholiths recycle pre-existing crust (Kay et al., 1991; Ducea, 2001, 2002; Saleeby et al., 2003). Such constraints allow estimation of mass and thermal transport in such settings, which lends to understanding of the crustal growth and evolution. The findings can also shed light on ongoing discoveries regarding the mechanisms by which plutons are assembled and crystallize (Coleman et al., 2004; Glazner et al., 2004).

With this in mind, we designed student projects to look at the records of the timing of intrusion of different plutons, both mafic and felsic, as well as to look at the crystal cargoes in these rocks. From the perspective of metamorphic rocks, projects were designed to appraise peak metamorphic temperatures, the record of partial melting, and how fluids moved between magmas and their metamorphic wallrocks.

**PROJECTS AND FINDINGS**

Our team worked an aggressive schedule, allowing us to gather field observations and samples for the first half of the project, and date and analyze geochemistry on many of the rocks in the following half of the project. Despite the usual host of hiccups in the field and challenges with weather, we literally went from standing on outcrops, discussing the cross-cutting relations, to knowing the exact age of the same rocks in less than two weeks. The effort produced several data sets, including U-Pb and trace element data for single zircons, and major, minor, and trace element, data from whole rock. These data were shared among all students. A flurry of abstract writing before the National GSA deadline produced four abstracts before the end of the project. These and a later abstract to AGU served to consolidate the major findings of projects in order to send students home with a first pass sense their findings, priming them to use the fall and spring to reconcile petrographic and geochemical data, and frame their data against the literature. The findings detailed in the following student contributions show a range of discoveries in their individual projects that address aspects of the overall theme of the project. They are briefly summarized below.

Julia Holland’s (Trinity University) study added several new U-Pb age determinations in high silica granites, granodiorites, and gabbros in the Ash Peaks region (Holland et al., 2010, this volume). An important finding of Julia’s work is that much of the felsic and mafic magmatism at the Ash Mountain complex, including the Fry’s Point granite, occurred in a narrow span of time at ca. 105 Ma. This is a period when few plutonic units are recognized and a point in the batholith evolution when major episodes of rhyolitic volcanism occurred. The range of composition and AFC trend indicates that a diverse suite of magmas were generated and synchronously emplaced in the Ash Mountain complex.

Stanley Hensley (CSU-Bakersfield) completed a companion study of the large Grant Grove and Giant Forest plutons (Hensley et al., 2010, this volume). Stanley’s work refined the age of emplacement of the Grant Grove and Giant Forest plutons, and showed that ca. 113 Ma Grant Grove has considerably more crustal contamination from wallrocks than the ca. 100 Ma Giant Forest pluton, but that both plutons have locally assimilated material from their metamorphic wallrocks. Zircons in both plutons provide evidence of both inheritance and Pb loss, factors that complicated the interpretation of early bulk U-Pb zircon ages.

Mary Badame (Oberlin College) investigated migmatites in the Marble Fork of the Kaweah River, a site where the Sequoia pendant is in direct contact with the Fry’s Point Granite. A lone magmatic zircon from a leucosome provided a critical link between the timing of the formation of the migmatites and intrusion of the Ash Mountain Complex (Badame et al., 2010, this volume). Her petrologic and geochemical results further elucidate the origin and condition by which these migmatites formed, including the potential melting conditions.

Julianne Wallan (Colgate University) addressed the metamorphic history of marbles in the Ash Mountain and Sequoia Pendant area, using carbon and oxygen isotopes, including an evaluation of carbon isotope thermometry. Working in outcrops of marble, in the Sequoia pendant and in plutons, Julie shows that $^{13}C/^{12}C$ partitioning between of calcite and graphite are consistent with peak metamorphic temperatures of 560–610°C in the marbles (Wallan et al., this vol-
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