KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2011
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2010-2011 PROJECTS

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 OUIMET*. University of Connecticut
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SEDIMENT DYNAMICS & ENVIRONMENTS IN THE LOWER CONNECTICUT RIVER
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GEOMORPHIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.
Faculty: *KELLY MACGREGOR*, Macalester College, *CATHERINE RIIHIMAKI*, 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 KUTVIRT*, 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, *MELLISSA CROSS*, Colgate University, *JOHN MICHAELS*, North Carolina State University, *ERDENEBAYAR TSAGAANNARAN*, Mongolian University of Science and Technology, *BATTOGTOH 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.

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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
Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Teton Range, Wyoming

EOCENE TECTONIC EVOLUTION OF THE TETON RANGE, WYOMING
JOHN CRADDOCK, Macalester College, DAVE MALONE, Illinois State University

FAULT-GENERATED CARBONATE INTRUSIONS FOUND AT WHITE MOUNTAIN, HEART MOUNTAIN DETACHMENT, WYOMING
JESSE GEARY, Macalester College
Research Advisor: John P. Craddock

INSIGHTS INTO THE ORIGIN OF THE SOUTH FORK DETACHMENT, WYOMING, USING CALCITE STRAIN ANALYSIS
KATHERINE KRAVITZ, Smith College
Research Advisor: Robert Burger

U-PB DETRITAL ZIRCON PEAK, WYOMING MOUNTAIN
RAY MCGAUGHEY, Carleton College
Research Advisor: Cameron Davidson

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Upper Plate Strain

The upper plate samples all contain <40% NEVs. SFD-5.1 contains 37.5% NEVs, and SFD-1, SFD-2, SFD-7 and SFD-10 have 20% NEVs. The majority of the remaining samples contained <10% NEVs (Table 1). All the samples exhibit LPS, though the proximity of the shortening axis to bedding varies (Fig. 1). The orientations of the shortening axes in the hanging wall are scattered. SFD-5, SFD-6 and SFD-7 are in the NE quadrant and have a shallow plunge of 8°-22°. SFD-14.2, SFD-14.3, SFD-12 and SFD-3 are in the SE quadrant and have a plunge ~20°-50°. The southern portion of the SW quadrant contains SFD-1, SFD-2 and SFD-10 plunging from 6°-50°. SFD-14.1 plunges 19° in the NW quadrant (Fig. 3). The extension axes are also dispersed throughout the upper plate with a concentration to the SE, W and N. The extension axes have moderate to shallow plunges ranging from 8° to 50° (Fig. 3). When the beds are rotated back to horizontal, the compression axes are still scattered, but all have a shallow plunge ranging from 4° to 30°. The extension axes in horizontal bedding are mostly scattered within the western hemisphere and plunge from 2° to 80° (Fig. 3).

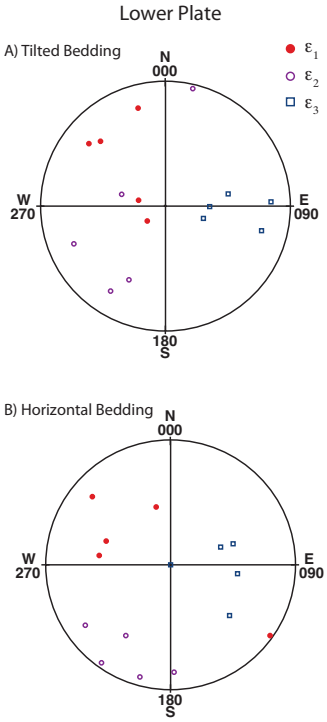

Figure 2. Plots showing ε1, ε2, ε3 of PEVs in the lower plate of the SFF. A demonstrates the strain orientations when the bedding is tilted. B shows the strain orientation when bedding is rotated to horizontal.

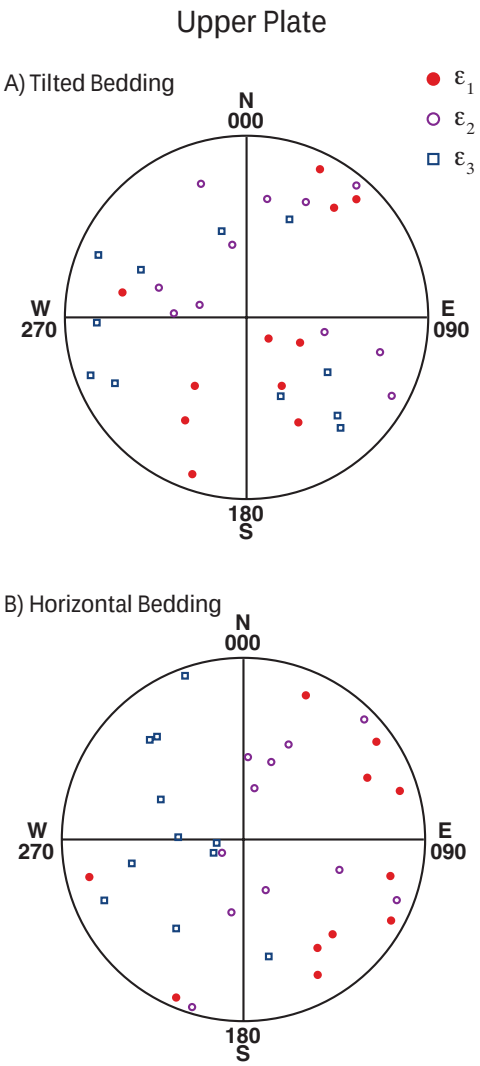

Figure 3. Plots showing ε1, ε2, ε3 of PEVs in the upper plate of the SFF. A demonstrates the strain orientations when the bedding is tilted. B shows the strain orientation when bedding is rotated to horizontal.

DISCUSSION

Teufel (1980) found that two deformation events can be distinguished if the second deformation event has a stress orientation >45° from the original. These two events are differentiated in the dataset by the presence of >40% NEVs. Craddock et al. (2000) examined calcite twinning strain within the upper and lower plate of the HMD to better understand the deformation of the allochthon during emplacement. The HMD carbonate rocks in the upper plate and lower plate contain a pre-HMD calcite twinning strain from the Laramide-Sevier orogeny that shows thrust

transport-parallel (E-W) shortening strain. The low percentage of NEVs implies the upper plate did not contain a HMD related strain overprint, which has significant implications for the emplacement rate of the allochthon. Because twinning is a time-dependent deformation mechanism, the absence of a detachment related overprint indicates rapid emplacement of the allochthon. Craddock et al. (2009) later used geochemical data and thermodynamic calculations to quantify the emplacement rate of the HMD and found that it traveled as much as 50 km in 3-4 minutes. The PEV shortening axes in the southwest footwall have an approximate WNW trend (Table 1), exhibit LPS (Fig. 1) and have moderately steep plunges even when bedding is rotated back to horizontal (Fig. 2). The relatively steep plunges and WNW trend are not consistent with Sevier-Laramide-related shortening, which is characteristic of shallow E-W or NE-SW trends (Craddock, 1992). It is very likely that this strain is directly related to the emplacement of the SFD allochthon. The absence of any Sevier-Laramide related strain in the lower plate and the low percentage of NEVs makes it unlikely the PEV strains within the upper plate demonstrate Sevier-Laramide strain. The variety of percent NEVs (Table 1) as well as the scatter within the strain orientations (Fig. 3) could be the result of continuous strain as the beds were tilted. If the calcite was twinned by a constant orientation of maximum compressive stress while the beds were simultaneously tilting, the finite strain ellipsoid calculated from calcite twins may represent a combination of many incremental strain ellipsoids. The calcite strain-gage technique does not account for rotational strain (Groshong, 1972), which could explain the scatter among the strain orientations.

Since the SFD has twinning strain that is most likely directly related to the SFD emplacement, the allochthon must have been emplaced in enough time to develop mechanical twins. Because twins are present, the SFD allochthon was not emplaced at such a rapid rate as the HMD, but still could have been emplaced catastrophically. Clarey (2009) defines the SFD as a superfault, which is an allochthon emplaced >100m at >0.1m/s. If the SFD traveled 10 times faster than the minimum rate of a superfault, it would still allow time for mechanical twins to develop (Friedman and Heard, 1974).

An overprint found in the Sundance Formation would likely be the result of Laramide-Sevier strain. However, none of the samples within the SFD contain ≥40% NEVs. Therefore, there is no evidence for a non-coaxial event. The absence of Sevier-Laramide-related strain in the SFD is striking because it is abundant within the HMD upper and lower plate (Craddock et al., 2000). Because the strata related to the SFD are younger than those of the HMD, it is possible that these beds were not buried deeply enough to produce twinning strain related to the Sevier-Laramide orogenic events.

CONCLUSIONS

The twinning strain in both the upper and lower plate of the SFD are the result of SFD related emplacement. This indicates that the allochthon was emplaced at a slower rate than the HMD because mechanical twinning is time dependent. Even if the SFD was emplaced at a slower rate, it still could have been a catastrophic event. There are not enough NEVs within the sample suite to demonstrate a noncoaxial strain overprint. Therefore, there is no sign of Sevier-Laramide-related strain in the SFD. This is unexpected because Sevier-Laramide-related strain is present within the HMD. The strata within the SFD may not have been buried deeply enough to produce a Sevier-Laramide strain overprint.

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