KECK GEOLOGY CONSORTIUM

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

April 2012
Amherst College, Amherst, MA

Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Tekla Harms
Symposium Convenor
Amherst College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Diane Kadyk
Symposium Proceedings Layout & Design
Department of Earth & Environment
Franklin & Marshall College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491

April 2012

Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA 91711

Diane Kadyk
Proceedings Layout & Design
Franklin & Marshall College

Keck Geology Consortium Member Institutions:
Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College, Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University, Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2011-2012 PROJECTS

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE, SOUTH-CENTRAL ALASKA
Faculty: *JOHN GARVER*, Union College, *Cameron Davidson*, Carleton College
Students: *EMILY JOHNSON*, Whitman College, *BENJAMIN CARLSON*, Union College, *LUCY MINER*, Macalester College, *STEVEN ESPINOSA*, University of Texas-El Paso, *HANNAH HILBERT-WOLF*, Carleton College, *SARAH OLIVAS*, University of Texas-El Paso.

ORIGINS OF SINUOUS AND BRAIDED CHANNELS ON ASCRAEUS MONS, MARS
Faculty: *ANDREW DE WET*, Franklin & Marshall College, *JAKE BLEACHER*, NASA-GSFC, *BRENT GARRY*, Smithsonian
Students: *JULIA SIGNORELLA*, Franklin & Marshall College, *ANDREW COLLINS*, The College of Wooster, *ZACHARY SCHIERL*, Whitman College.

TROPICAL HOLOCENE CLIMATIC INSIGHTS FROM RECORDS OF VARIABILITY IN ANDEAN PALEOGLACIERS
Faculty: *DONALD RODBELL*, Union College, *NATHAN STANSELL*, Byrd Polar Research Center
Students: *CHRISTOPHER SEDLAK*, Ohio State University, *SASHA ROTHENBERG*, Union College, *EMMA CORONADO*, St. Lawrence University, *JESSICA TREANTON*, Colorado College.

EOCENE TECTONIC EVOLUTION OF THE TETON-ABSAROKA RANGES, WYOMING
Faculty: *JOHN CRADDOCK*. Macalester College, *DAVE MALONE*. Illinois State University
Students: *ANDREW KELLY*, Amherst College, *KATHRYN SCHROEDER*, Illinois State University, *MAREN MATHISEN*, Augustana College, *ALISON MACNAMEE*, Colgate University, *STUART KENDERES*, Western Kentucky University, *BEN KRASUSHAAR*

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: *DAVID DETHIER*, Williams College
Students: JAMES WINKLER, University of Connecticut, SARAH *BEGANSKAS*, Amherst College, *ALEXANDRA HORNE*, Mt. Holyoke College

DEPTH-RELATED PATTERNS OF BIOEROSION: ST. JOHN, U.S. VIRGIN ISLANDS
Faculty: *DENNY HUBBARD* and *KARLA PARSONS-HUBBARD*, Oberlin College
Students: *ELIZABETH WHITCHER*, Oberlin College, *JOHNATHAN ROGERS*, University of Wisconsin-Oshkosh, *WILLIAM BENSON*, Washington & Lee University, *CONOR NEAL*, Franklin & Marshall College, *CORNELIA CLARK*, Pomona College, *CLAIRE McELROY*, Otterbein College.

THE HRAFNFJORDUR CENTRAL VOLCANO, NORTHWESTERN ICELAND
Faculty: *BRENNAN JORDAN*, University of South Dakota, *MEAGEN POLLOCK*, The College of Wooster
Students: *KATHRYN KUMAMOTO*, Williams College, *EMILY CARBONE*, Smith College, *ERICA WINELAND-THOMSON*, Colorado College, *THAD STODDARD*, University of South Dakota, *NINA WHITNEY*, Carleton College, *KATHARINE, SCHLEICH*, The College of Wooster.

SEDIMENT DYNAMICS OF THE LOWER CONNECTICUT RIVER
Faculty: *SUZANNE O'CONNELL* and *PETER PATTON*, Wesleyan University
Students: *MICHAEL CUTTLER*, Boston College, *ELIZABETH GEORGE*, Washington & Lee University, *JONATHON SCHNEYER*, University of Massachusetts-Amherst, *TIRZAH ABBOTT*, Beloit College, *DANIELLE MARTIN*, Wesleyan University, *HANNAH BLATCHFORD*, Beloit College.

ANATOMY OF A MID-CRUSTAL SUTURE: PETROLOGY OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE, GRENVILLE PROVINCE, ONTARIO
Faculty: *WILLIAM PECK,* Colgate University, *STEVE DUNN,* Mount Holyoke College, *MICHELLE MARKLEY*, Mount Holyoke College
Students: *KENJO AGUSTSSON*, California Polytechnic State University, *BO MONTANYE*, Colgate University, *NAOMI BARSHI*, Smith College, *CALLIE SENDEK*, Pomona College, *CALVIN MAKO*, University of Maine, Orono, *ABIGAIL MONREAL*, University of Texas-El Paso, *EDWARD MARSHALL*, Earlham College, *NEVA FOWLER-GERACE*, Oberlin College, *JACQUELYNE NESBIT*, Princeton University.

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1005122
ExxonMobil Corporation

Keck Geology Consortium: Projects 2011-2012
Short Contributions— Teton-Absaroka Ranges, Wyoming Project

EOCENE TECTONIC EVOLUTION OF THE TETON-ABSAROKA RANGES, WYOMING
Project Faculty: JOHN P. CRADDOCK, Macalester College & DAVE MALONE, Illinois State University

DETRITAL ZIRCON PROVENANCE STUDY OF YELLOW SANDSTONES FROM THE WILLWOOD FORMATION IN THE BIGHORN BASIN, WYOMING, USA
ANDREW L. KELLY**,** Amherst College
Research Advisors: Tekla A. Harms & Peter D. Crowley

A MINERALOGICAL TEXTURAL AND CHEMICAL CHARACTERIZATION OF A HYPOTHESIZED KIMBERLITE AT WHITE MOUNTAIN, SUNLIGHT BASIN, WYOMING
STUART KENDERES**,** Western Kentucky University
Research Advisor: Andrew Wulff

THE DYNAMICS AND EMPLACEMENT OF THE HEART MOUNTAIN DETACHMENT: ANISOTROPY OF MAGNETIC SUCEPTIBILITY AND DETRITIAL ZIRCON ANALYSIS OF VERTICAL INJECTITES AT WHITE MOUNTAIN AND SILVERGATE, WYOMING
BENJAMIN KRAUSHAAR**,** Fort Lewis College
Research Advisor: John P. Craddock

STRUCTURAL EVOLUTION OF THE EOCENE SOUTH FORK DETACHMENT, PARK COUNTY, WYOMING
ALISON MACNAMEE**,** Colgate University
Research Advisor: Martin Wong

CALCITE TWINNING STRAIN ANALYSIS OF THE ALLOCHTHONOUS JURASSIC SUNDANCE, SOUTH FORK DETACHMENT, NORTHWEST WYOMING
MAREN MATHISON**,** Augustana College
Research Advisor: Jeffrey Strasser & Michael Wolf

PROVENANCE ANALYSIS OF THE WAPITI FORMATION (EOCENE) SANDSTONE IN THE ABSAROKA BASIN, WY USING DETRITAL ZIRCON GEOCHRONOLOGY
KAT HRYN SCHROEDER**,** Illinois State University
Research Advisor: David H. Malone

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

PROVENANCE ANALYSIS OF THE WAPITI FORMATION (EOCENE) SANDSTONE IN THE ABSAROKA BASIN, WY USING DETRITAL ZIRCON GEOCHRONOLOGY

KATHRYN SCHROEDER, Illinois State University
Research Advisor: David H. Malone

ABSTRACT

The transition from Laramide syntectonic sedimentation of the Lower Eocene Willwood formation to the post-Laramide volcanogenic sedimentation of the Middle Eocene Wapiti Formation was studied in the upper South Fork Shoshone River Valley, Wyoming. To better understand the regional age, paleogeography and provenance of volcaniclastic sandstones in the lower stratified member of the Wapiti Formation, we sampled three units for detrital zircon geochronology (n=241). The age for the sandstone units for the lowermost, middle, and uppermost units are 49.5, 48.8. and 48.8 respectively, which is consistent with previous geochronologic and paleontologic studies. These ages also are consistent with rocks deposited immediately prior to Heart Mountain Faulting. Detrital zircon spectra show a transition from a mixed (recycled?) provenance consistent with drainage from the west with minor primary Eocene volcanic contributions to one dominated by primary Eocene and Archean contributions from the northern Absaroka volcanoes and the Laramide Beartooth Uplift.

INTRODUCTION

The Eocene volcanic succession within the Absaroka Range has been formally named the Absaroka Volcanic Supergroup (AVS) (Smedes and Prostka, 1972, Sundell, 1990). The rocks of the AVS extend over an area of approximately 7000 mi^2 (18,000 km^2), most of which is underlain by a Laramide structural basin (Absaroka Basin); the volcanic rocks overlie rock units which range in age from Archean to Eocene (Figure 1). Deeply-incised valleys provide excellent natural cross sections, and they display a volcanic stratigraphic succession in excess of 6000 ft (1875 m) thick. The rocks of the AVS are unconformably overlain to the west by Quaternary volcanic rocks of the Yellowstone Volcanic Plateau.

The Heart Mountain detachment (HMD) resulted from a contemporaneous volcanic eruption localizing the 2° dipping slip surface in the basal Ordovician Bighorn Dolomite and liberating upper plate Paleozoic carbonate rocks over an area of 3400 km2 with an upper plate run-out of up to 160 km to the southeast (Beutner and Gerbi, 2005; Malone and Craddock, 2008; Craddock et al., 2009). The volcanic eruption-landslide association is clear (Malone, 1995; Beutner and Gerbi, 2005; Ahranov and Anders, 2006, Anders et al., 2010) but the timing (landslide then volcanic burial; Pierce, 1973), duration (millions of years; Hauge, 1985), direction (horizontal upper plate rotations about a vertical axes during SE motion; Craddock et al., 2000) and rate (<5 minutes Craddock et al., 2009) of emplacement are still in dispute.

More than 300 m of distal facies Wapiti Formation volcaniclastic rocks unconformably overlie the Willwood Formation in (Malone, 1997) in the upper South Fork Shoshone River Valley (Figure 1). These distal facies rocks are absent in the North Fork Shoshone Valley, where the older Willwood Formation is overlain directly by allochthonous volcanic and Paleozoic rocks of the Heart Mountain Detachment upper plate (Craddock and others, 2009) Our goal is to characterize provenance and detrital zircon ages of the Wapiti Formation that was deposited immediately prior to Heart Mountain faulting. This work will also enable a better understanding of the paleogeography of the region during the early episodes of Absaroka Volcanism and at the onset of the HMD collapse.

METHODOLOGY

Three detrital zircon samples were collected from sandstones within the lower stratified member of the Wapiti Formation in the South Fork Shoshone River Valley. Sample 10-WY-11 was collected from the

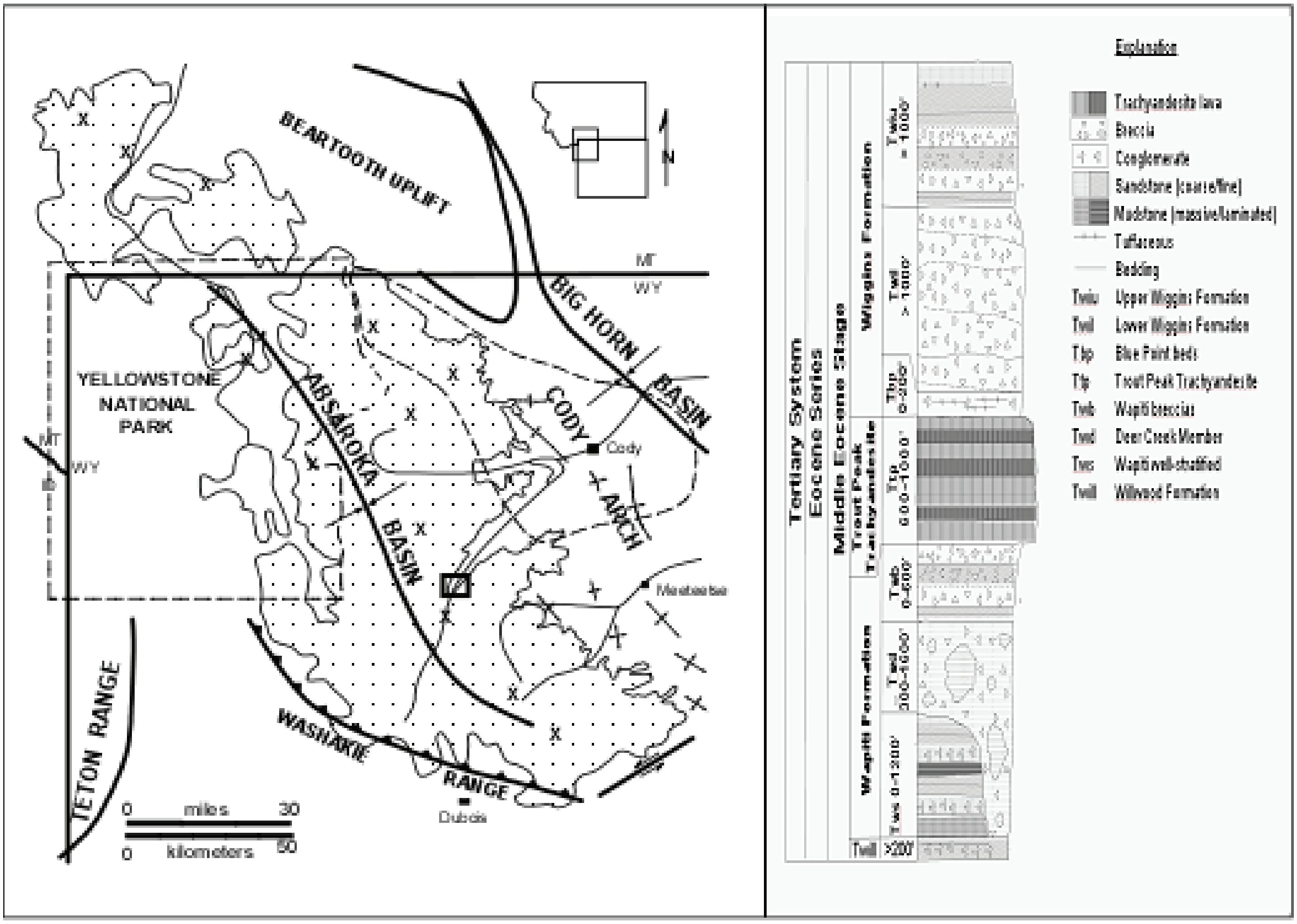

Figure 1. On the left is a map of the Absaroka volcanic field and surrounding structural features. Intrusive centers are represented with an X. The South Fork (Wapiti) study area is marked by a box. The Heart Mountain Detachment area is marked with the dashed line. On the right is a Stratigraphic Column of Eocene strata exposed in the South Fork Shoshone River valley, with sample locations shown.

base of the Wapiti Formation just above the Willwood Formation at Ishawooa Hills. Sample 10-WY-12 was collected from the middle of the section near Deer Creek, and Sample 10-WY-13 was collected from the top of the section near Boulder Creek, just beneath the overlying Deer Creek Member.

From each of the three locations, five to ten kg samples were collected. Zircons were then extracted by traditional methods of crushing and grinding, followed by separation with a Wilfley table or panning, heavy liquids, and a Frantz magnetic separator. Samples are processed such that all zircons are retained in the final heavy mineral fraction. A large split of these grains (generally thousands of grains) is incorporated into a 1” epoxy mount together with fragments of our Sri Lanka standard zircon. The mounts are sanded down to a depth of ~20 microns, polished, imaged, and cleaned prior to isotopic analysis. U-Pb geochronology of zircons is conducted by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center (Gehrels et al., 2006, 2008). For each analysis, the errors in determining 206Pb/238U and 206Pb/204Pb result in a measurement error of ~1-2% (at 2-sigma level) in the 206Pb/238U age. Data was reduced using the various Excel macros prepared by the Laserchron center.

Heavy mineral grains were distributed on carbon tape and placed into the chamber of the JEOL 6610LV scanning electron microscope at Macalester College.

The grains were left uncoated and exposed to 15 Kv accelerating voltage. Electron dispersive spectrometry using an Oxford Instruments X-MAX 50 mm2 silicon-drift detector yielded an accurate spectrum for each grain. At least 80 grains per sample were analyzed for quantitative mineral identification.

RESULTS

Heavy Mineral Analysis

10-WY-11. This sample was light gray, contained 10% quartzite and chert granules and 90% coarse and medium sand. It was weakly cemented with calcite. The sand sized fraction consisted of 60% quartz, 20% feldspar, and 20% rock fragments and mafic minerals. The Heavy mineral assemblage consisted of 74% garnet, 10% Iron Oxide, 9% ilmenite, 4% zircon, and 3% rutile.

10-WY- 12. This sample was light greenish-gray and consisted of 75% fine and medium sand and 25% detrital matrix. It was weakly cemented with calcite. The sand sized fraction consisted of 60% quartz, 15% feldspar, and 25% rock fragments and mafic minerals. The Heavy mineral assemblage consisted of 43% garnet, 15% Iron Oxide, 29% ilmenite, 7% zircon, and 5% apatite.

10-WY-13. This sample was light gray, and consisted of well sorted medium sand. It was weakly cemented with calcite. The sand sized fraction consisted of 80% quartz, 10% feldspar, and 10% rock fragments and mafic minerals. The Heavy mineral assemblage consisted of 47% garnet, 7% iron oxide, 24% ilmenite, 22% zircon, and 1% rutile.

Zircon Ages

Age-pick ages were determined for each of the three samples. These data are graphically portrayed in Figure 2. The final age sandstone at Ishawooa Hills (10-WY-11), which is at the base of the lower stratified succession, is 49.5 ± 1.4 Ma based on the population of 12 Eocene detrital zircons. The final sandstone age for middle sandstone at Deer Creek (10-WY-12) is 48.8± 1.2 Ma based on the population of 18 Eocene detrital zircons. The final age for the sandstone at the top of the succession near Boulder Creek (10-WY-13) is 48.8 ± 0.9 Ma, based on the population of 49 Eocene detrital zircons.

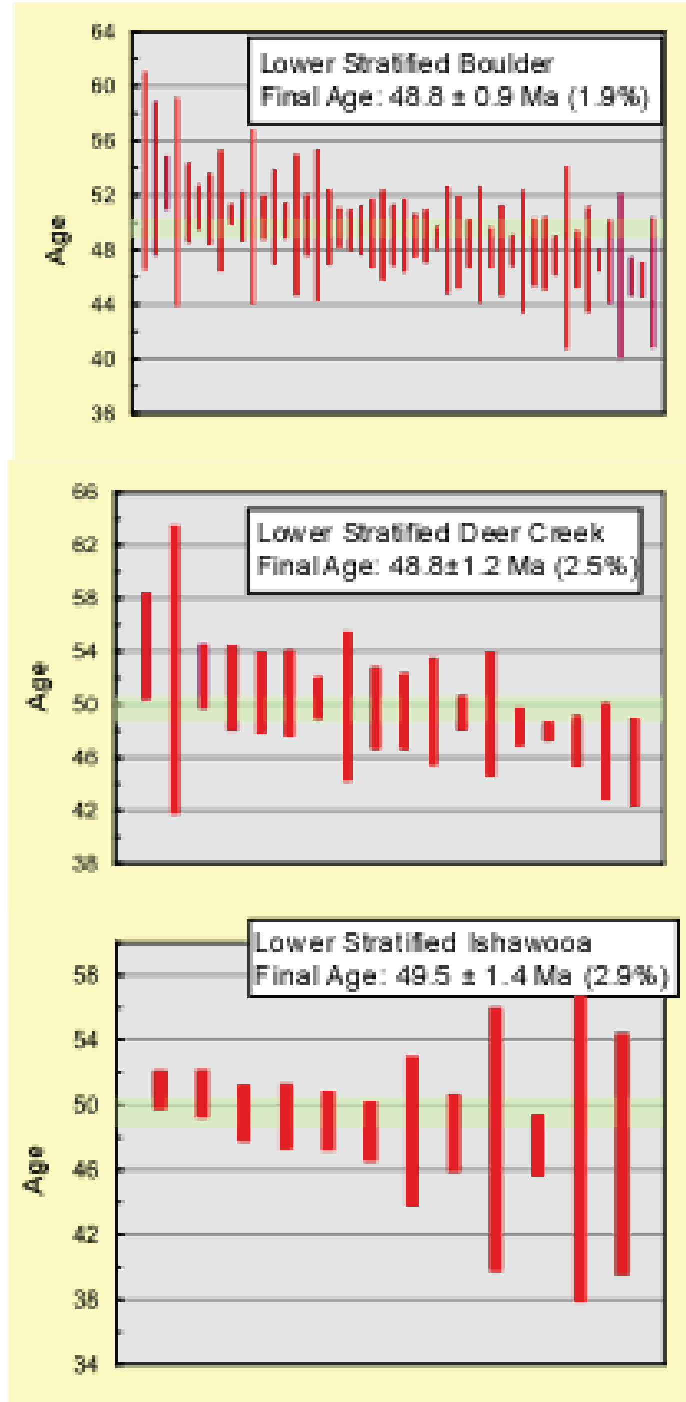

Figure 2. Age-Pick ages for Wapiti Formation sanstones. All results are 2 sigma.

Wapiti Formation DetritaL Zircon Spectra

The detrital zircon histograms and frequency spectra are presented in Figure 3. The Ishawooa sample (lowermost; 10-WY-11) is dominated by Yavapai-

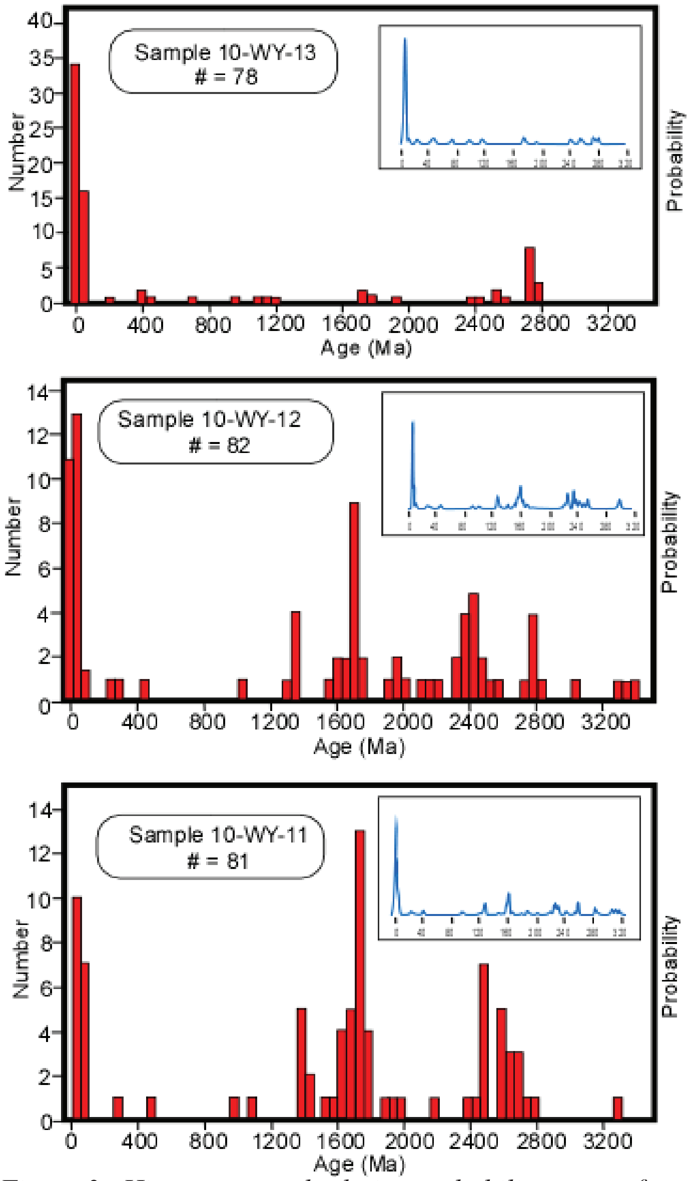

Figure 3. Histograms and relative probability curves for Wapiti Formation detrital zircon suites.

Mazatzal (#=34) and Archean (#=23 zircons). Eocene (#12), Mesozoic, Paleozoic, Neoproterozoic-Grenville, and Trans-Hudson zircons also are present. The middle sandstone (Deer Creek; 10-WY-12) has a similar detrital zircon spectrum to 10-WY-11, where Archean (#=24) and Yavapai-Mazatzal (#=21) are most abundant. The uppermost sandstone (Boulder Creek; 10-WY-13) has a detrital zircon spectrum that is distinct from the lower two sandstones. Here, Eocene (#=48) and Archean (#=16) zircons are most abundant. Mesozoic, Paleozoic, Neoproterozoic-Grenville, Yavapai-Mazatzal and Trans-Hudson zircons also are present.

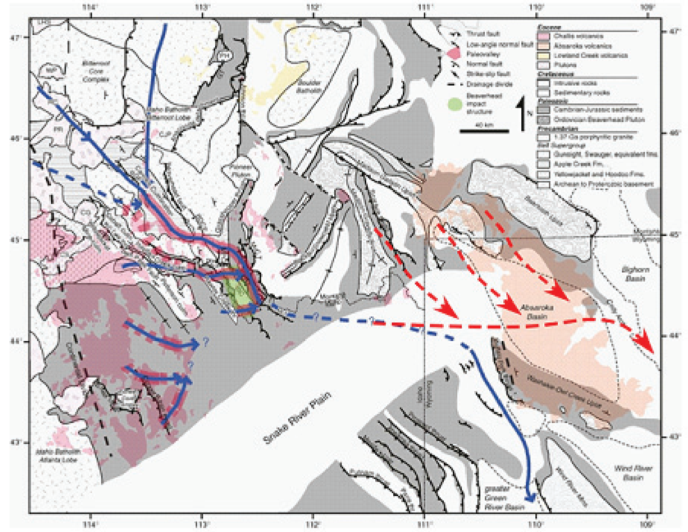

Figure 4. Eocene Idaho River Reconstruction (from Chetel and others, 2011). Original interpreted drainage network is indicated in blue. Possible alternative mode presented herein indicated in red.

DISCUSSION

Wapiti Provenance

The detrital zircon suite of the lower and middle sandstone units in the lower stratified section was surprisingly rich in pre-Eocene zircons (85% and 78%, respectively). The overlap and similarity indices for these two sandstones are high as well, which indicates a similar provenance. More than half of the zircons in each spectrum are Archean or Yavapai-Mazatzal in age. The Archean zircons could be recycled from Phanerozoic strata or derived directly from exposed basement rocks in the Beartooth uplift. Yavapai-Mazatzal zircons also could be recycled, or they could be derived from a westerly source. The presence of some Mesozoic zircons indicates at least some westerly contribution to the zircon suite.

The detrital zircon suite for the uppermost sandstone is distinct from the other two, as indicated by the low overlap and similarity indices. It is dominated by Eocene and Archean zircons. This increase in primary zircons points to the growth and development of Absaroka vent complexes to the north and west. Archean zircons were likely contributed from the exposed Beartooth uplift to the north. Some Eocene zircons could have been contributed from the Challis Volcanic Field to the west.

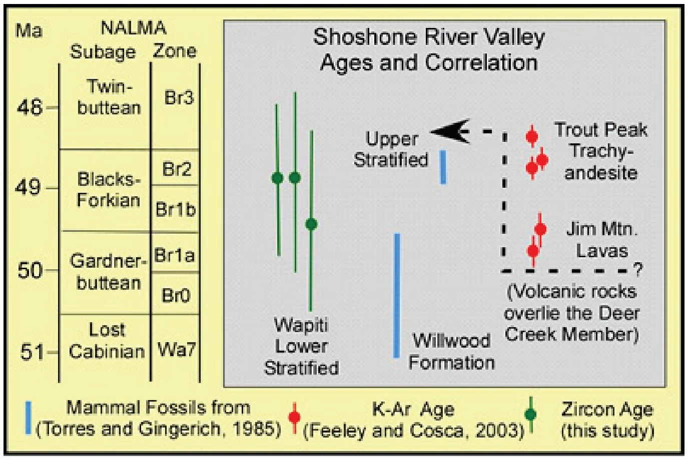

Figure 5. Correlation diagram for Eocene Volcanic Rocks in the eastern Absaroka Mountains.

Implications for Eocene Paleodrainage

Chetel and others (2011) developed a detailed model of Eocene (~49-50 Ma) paleo-drainage in the region (Figure 4). Their Eocence Idaho River headed Idaho Batholith-Challis Volcanic field region of the Cordillera, flowed west across what is now the Snake River Plane, and then ultimately southwest through the Jackson Hole area to the Green River Basin and Lake Gossuite. The Challis rather than Absaroka source area was based on K-Ar detrital feldspar geochronology and Pb isotopic data on Eocene grains. The detrital zircon geochronology data presented here for Wapiti (~49 Ma) sandstones in the Absaroka Basin have significant age populations from both local (e.g. Beartooth and recycled Phanerozoic) and distal Cordilleran (.e.g. Idaho Batholith) source areas. Thus the Idaho River may have travelled east across the Absaroka Basin before ultimately reaching Lake Gossuite.

Implications for the timing Heart Mountain Faulting

In the early 1990s, the best estimate for the timing of the emplacement of the upper plate of the HMD was based on vertebrate paleontology of Willwood and Wapiti Formation rocks at the base of Jim Mountain. Stratigraphic evidence from Eocene sedimentary and volcanic rocks (Pierce 1973, Torres and Gingerich 1983) indicates that the emplacement of the upper plate of the HMD occurred within a 2 million year window during the early middle Eocene (49.5-47.5 million years ago). Feeley and Cosca (2003) provide an excellent summary of the petrology, geochemistry, and geochronology of the Sunlight Peak vent complex at Jim Mountain (Figure 5). The timing of Heart Mountain faulting is now well constrained in the distal areas of the HMD where upper plate rocks overlay Eocene strata of the Willwood formation. Feeley and Cosca (2003) report an 40Ar/39Ar age of 49.5 ± 0.16 Ma for basal Jim Mountain lava at Jim Mountain, which is about 100 m above the Heart Mountain interval.

Heart Mountain faulting correlates with a major dessication horizon in the Laney Member. Rhodes and others (2007) recognized mudcracks as much as 2 m deep superimposed on lacustrine mudstones of the lower LaClede Bed of the Green River Formation in the Washakie Basin. These mudcracks reflect a sudden and intense desiccation of Eocene Lake Gosiute. In a related study of Eocene stratigraphy of Wyoming, Smith et al. (2003) reported 40Ar/39Ar weighted mean ages of tuffs overlying and underlying the dessication horizon to be 49.70 ± 0.10 and 48.94 ± 0.12 Ma, respectively, which correlates well with the timing of the Heart Mountain event further to the north.

The zircon final age for the uppermost sandstone at Boulder Creek is 48.8 Ma

REFERENCES

Aharono, E., and Anders, M.H., 2006, Hot water: A solution to the Heart Mountain detachment problem? Geology, v. 34, p. 165-168.

Anders, M.H., Fouke, B.W., Zerkle, A.L., Tavarnelli, E., Alvarez, W., and Harlows, G.E., 2010. The Role of Calcining and Basal Fluidization in the Long Runout of Carbonate Slides: An Example from the Heart Mountain Slide Block, Wyoming and Montana, U.S.A.: The Journal of Geology, v. 118, p. 577–599.

Beutner, E.C. and Gerbi, G.P. 2005, Catastrophic emplacement of the Heart Mountain block slide, Wyoming and Montana, USA: Geological Society of America Bulletin, v. 117, p. 724-35.

Craddock, John P., Neilson, K. J. and Malone, D.H., 2000, Calcite twinning strain constraints on Heart Mountain detachment kinematics, Wyoming: Journal of Structural Geology, v. 22, p. 983-991.

Craddock, J.P., Malone, D.H., Cook, A.L., Rieser, M.E., and Doyle, J.R., 2009, Dynamics of emplacement of the Heart Mountain allochthon at White Mountain: constraints from calcite twinning strains, anisotropy of magnetic susceptibility and thermodynamic calculations: Geological Society of America Bulletin, v. 121, n. 5, p. 919-938, doi:10.1130/B26340.\

Chetel, L.M., Janecke, S.U., Carroll, A.R., Beard, B.L., Johnson, C.M., and Singer, B.S., 2011, Paleogeographic Reconstruction of the Eocene Idaho River, North American Cordillera: Geological Society of America Bulletin, v. 123, n. 1/2, p. 71-88.

Feeley, T.C., and M.A. Cosca, 2003, Time vs. composition trends of magmatism at Sunlight volcano, Absaroka volcanic province, Wyoming, GSA Bulletin, v. 115, p. 714-728.

Gehrels, G., Valencia, V., Pullen, A., 2006, Detrital Zircon Geochronology by Laser Ablation Multicollector ICPMS at the Arizona LaserChron Center, in Olszewski, T., ed., Geochronology: Emerging Opportunities: Paleontology Society Papers, Volume 12, p. 67-76.

Gehrels, G.E., Valencia, V., Ruiz, J., 2008, Enhanced precision, accuracy, efficiency, and spatial resolution of U-Pb ages by laser ablation-multicollector-inductively coupled plasma-mass spectrometry: Geochemistry, Geophysics, Geosystems, v. 9, Q03017, doi:10.1029/2007GC001805.

Hauge, T.A., 1985, Gravity-spreading origin of the Heart Mountain Allochthon, northwestern Wyoming: Geological Society of America Bulletin, v. 96, p. 1440-1452.

Krause, M.J., 1983, Genesis of Early Tertiary Exotic Metaquartzite Conglomerates in the Absaroka-Bighorn Region, Northwest Wyoming: Wyoming Geological Association Field Conference Guidebook, Vol. 33. P.103-110.

Malone, D.H., 1996, A revised interpretation of Eocene volcanic stratigraphy in the lower North and South Fork Shoshone River Valleys, Wyoming: Wyoming Geological Association, 47th Annual Field Conference Guidebook, p. 109-138.

Malone, D.H., 1997, Recognition of a Distal Facies Greatly Extends the Domain of the Deer Creek Debris-Avalanche Deposit (Eocene), Absaroka Range, Wyoming: Wyoming Geological Association Annual Field Conference Guidebook, vol. 48, p. 1-9.

Malone, D.H. and Craddock, J.P., 2008, Recent Contributions to the Understanding of the Heart Mountain Detachment, Wyoming: Northwest Geology, v. 37, p. 21-40.

Pierce, W.G., 1973, Principal features of the Heart Mountain fault and the mechanism problem: Gravity and Tectonics, DeJong, K., ed., John Wiley & Sons, New York, p. 457-471.

Rhodes, M.K., Malone, D.H., Carroll, A.R., and Smith, M., 2007, Sudden Desiccation of Lake Gosiute at 49 Ma: A Downstream Effect of Heart Mountain Faulting? The Mountain Geologist, v. 1, p 1-10.

Smedes, H.W., and Prostka, H.J., 1972, Stratigraphic Framework of the Absaroka Volcanic Supergroup in the Yellowstone Park Region: United States Geological Survey Professional Paper #729C, 33 pp.

Smith, M.E., Singer, B., and Carroll, A.R., 2003, 40Ar/39Ar geochronology of the Green River Formation, Wyoming: Geological Society of America Bulletin, v. 115, p. 549-565.

Sundell, K.A., 1990, Sedimentation and Tectonics of the Absaroka Basin of Northwest Wyoming:

Wyoming Geological Association 41st Annual Field Conference Guidebook, p. 105-122.

Torres, V., and Gingerich, P.D., 1983, Summary of Eocene stratigraphy at the base of Jim Mountain, North Fork of the Shoshone River, Northwestern Wyoming: Wyoming Geological Association, 34th Annual Field Conference Guidebook, p. 205-208.