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

April 2013
Pomona College, Claremont, CA

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

Dr. Jade Star Lackey
Symposium Convener
Pomona College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps 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-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2013

Robert J. Varga
Editor and Keck Director
Pomona College

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

Christina Kelly
Proceedings Layout & Design
Scripps 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

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, NORTHEASTERN 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.
Students: *MICHAEL BARTHELMES*, Cornell College, *WILLIAM TOWBIN*, Oberlin College, *ABIGAIL SEYMOUR*, Colorado College, *MITCHELL AWALT*, Macalester College, *FREDY, AGUIRRE*, Franklin & Marshall College, *LAUREN MAGLIOZZI*, Smith College.

GEOLOGY, PALEOECOLOGY AND PALEOCLIMATE OF THE PALEOGENE CHICKALOON FORMATION, MATANUSKA VALLEY, ALASKA
Faculty: *CHRIS WILLIAMS*, Franklin & Marshall College, *DAVID SUNDERLIN*, Lafayette College.
Students: *MOLLY REYNOLDS*, Franklin & Marshall College, *JACLYN WHITE*, Lafayette College, *LORELEI CURTIN*, Pomona College, *TYLER SCHUETZ*, Carleton College, *BRENNAN O'CONNELL*, Colorado College, *SHAWN MOORE*, Smith 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

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.

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 NORHTERN SNAKE RANGE DECOLLEMONT
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
MICHAEL KENNEY, University of California—Santa Barbara
Research Advisor: Phil Gans

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

Learning Science Through Research
Published by Keck Geology Consortium
Short Contriubtions
26th Annual Keck Symposium Volume
6 April, 2013
ISBN: 1528-7491

INSIGHTS INTO THE TECTONIC EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX FROM ^{40}AR/^{39}AR THERMOCHRONOLOGIC RESULTS, NORTHERN SNAKE RANGE, NEVADA

JOSEPH WILCH, College of Wooster
Research Advisor: Shelley Judge & Robert Wooster

INTRODUCTION

Located in eastern Nevada, the Snake Range represents a classic example of a Cordilleran metamorphic core complex. Large-scale crustal extension formed a gently domed detachment fault that separates highly strained and metamorphosed rocks in the footwall and normal faulted sedimentary rocks in the hanging wall. The detachment itself is known as the northern Snake Range decollement (NSRD) (Misch, 1960).

There have been multiple models proposed describing the formation of the northern Snake Range metamorphic core complex. A simple shear model was originally suggested for the fault, which proposed that the NSRD formed as a low angle normal fault and that there was up to 60 km of slip along it (Wernicke, 1981). The next model posed the NSRD as an exhumed brittle-ductile transition zone (Miller et al., 1983). The final model is the rotated normal fault model (Buck, 1988; Wernicke and Axen, 1988). This model assumes that detachment faults originate from the sequential development of high angle normal faults. New faults propagate outwards as increasing extension and footwall rebound cause each fault to be rotated to a lower dip and then abandoned.

Thermochronology has been an important tool for assessing the tectonic development of the Snake Range core complex (e.g. Lee and Sutter, 1991, Lee, 1995, Miller et al. 1999). The goal of this study is to assess the significance of new ^{40}Ar/^{39}Ar results on muscovite and K-feldspar from the Snake Range footwall. The argon results presented in this study were collected and analyzed by Phil Gans, and are part of a larger ^{40}Ar/^{39}Ar effort in the Snake Range. Initial results from this study (Gans et al., 2011) suggest that there were several phases of extension and that during the Miocene episode of slip there was a significant thermal gradient across the range. This thermal gradient suggests that the NSRD formed at a moderate to steep dip. ^{40}Ar/^{39}Ar muscovite results from Gans et al. (2011) as well as other studies conducted in the Snake Range (Lee and Sutter, 1991; Lee, 1995; Gebelin et al., 2011) yield complex age spectra that are difficult to interpret. One goal of this paper is to test what factors cause these complex muscovite results. In order to accomplish this, the composition of muscovite separates were analyzed by electron microprobe. Also, ^{40}Ar/^{39}Ar thermochronologic results of muscovite separates allowed us to compare their degassing behaviors. In addition we also present preliminary multiple diffusion domain (MDD) model thermal histories from a subset of the existing K-feldspar data presented by Gans et al. (2011) that may help to refine that tectonic model.

PREVIOUS STUDIES

Thermochronologic studies of footwall rocks in the northern Snake range have identified three major uplift and cooling events in the Cenozoic (Miller et al., 1999). The first event occurred in the middle Eocene (48-41 Ma) and was related to initial slip along the NSRD. The second event shows a slow migration of fault activity in the range from west to east, beginning in the Oligocene and continuing to the Miocene (Lee, 1995). The third event accounts for at least 12-15 km

of slip along the NSRD and began ~17 Ma (Miller et al., 1999). From the body of thermochronologic work, Lee (1995) interpreted the formation of the range as agreeing with the rolling-hinge model with an initial fault angle of >40˚.

Gans et al. (2011) proposed that there were at least two distinct tertiary events; the first occurring in the Eocene-Early Oligocene (40-30? Ma) and the second event being Early to Mid Miocene (20-15 Ma). Prior to the second slip event the western part of the footwall was ≤150 ˚C, but the eastern part of the footwall was still ≥350 ˚C, implying that the east-dipping normal fault originated at a moderate to high angle.

Many of these studies incorporate muscovite $^{40}Ar/^{39}Ar$ results with saddle-shaped age spectra into their results. Irregularly-shaped spectra from nearly undeformed muscovites have shown a mixing of mineral phases at the grain scale, both muscovite and recrystallized muscovite (Alexandrov et al., 2002). Wijbrans and McDougall (1986) have shown that combinations of phengite and white mica yield complex age spectra. They interpret these as two separate generations of micas in the same rock and suggest that their convex up age spectrum resulted from the mixing of an initial phengite and a younger muscovite. So it isn't unreasonable to think that an initial muscovite mixed with a younger more phengitic recrystallized muscovite would yield a saddle-shaped age spectra. This may be the case in muscovites from the northern Snake Range.

METHODS

All samples discussed in this study were collected by Phil Gans from the Prospect Mountain quartzite along Hendry's Creek below the NSRD in a transect from the eastern edge of the range to near Mount Moriah. All $^{40}Ar/^{39}Ar$ analyses were conducted by Phil Gans at the $^{40}Ar/^{39}Ar$ geochronology laboratory at UC Santa Barbra. Replicate temperature steps for the K-feldspar samples were conducted in order to degas excess argon. Magnetic fractions of the muscovites were obtained by Phil Gans by using the Frantz magnetic separator. I obtained compositional data from the muscovite separates and thin sections using a Cameca SX-100 electron microprobe at UC Santa Barbra.

Potassium feldspar $^{40}Ar/^{39}Ar$ data were modeled according to the multiple diffusion domain (MDD) model to obtain model thermal histories from ~300–150° C (Lovera et al., 1991). In this study, six potassium feldspar samples were analyzed using the MDD modeling software Arvert (Zeitler, 2004).

RESULTS

From each analysis we provide the relative size and distribution of domains and obtain a potential thermal history (Figure 1) and a modeled age spectra (Figure 2). NSR-44 is a sample from the Prospect Mountain quartzite on the west side of the table. Ignoring what appears to be excess argon near the beginning of the age spectrum, apparent ages climb from 18 to 20 Ma over the first 60% of gas released. The spectrum then ascends relatively steadily for the next 30% of cumulative ^{39}Ar released to 40 Ma. The rest of the steps can be ignored as they are above the melting temperature of K-feldspar. The sample was modeled using 6 domains and an activation energy of 45.8 kcal/mol. The modeled age spectrum shows only slight variations from the observed. The thermal model shows sample at ~275 ˚C until ~21 Ma at which it undergoes rapid cooling until around 10 Ma where it is at ~40 ˚C.

NSR-50 comes from the eastern flank of the range. It was modeled using 7 domains with an activation energy of 48.3 kcal/mol. The modeled age spectrum also shows slight departures from the original age spectra which climbs from 14 to 33 Ma. The thermal model shows rapid cooling occurring later than more western samples at ~16 Ma. Rapid cooling also starts at a higher temperature (~300 ˚C) than more western samples. In general, all the samples begin rapid cooling later and at a higher temperature in the east. The other samples were modeled using 6 or 7 domains and activation energies between 45 and 50 kcal/mol. The modeled age spectra show mild departures at most from the observed age spectra

All of the muscovite spectra were obtained by using replicate heating schedules. The muscovite spectra for the initial samples (black line, Figure 3) display a saddle-shape, with an initial rise in the apparent age of low temperature step heating experiments, a dip in apparent ages around the 970-1000 ˚C step, and

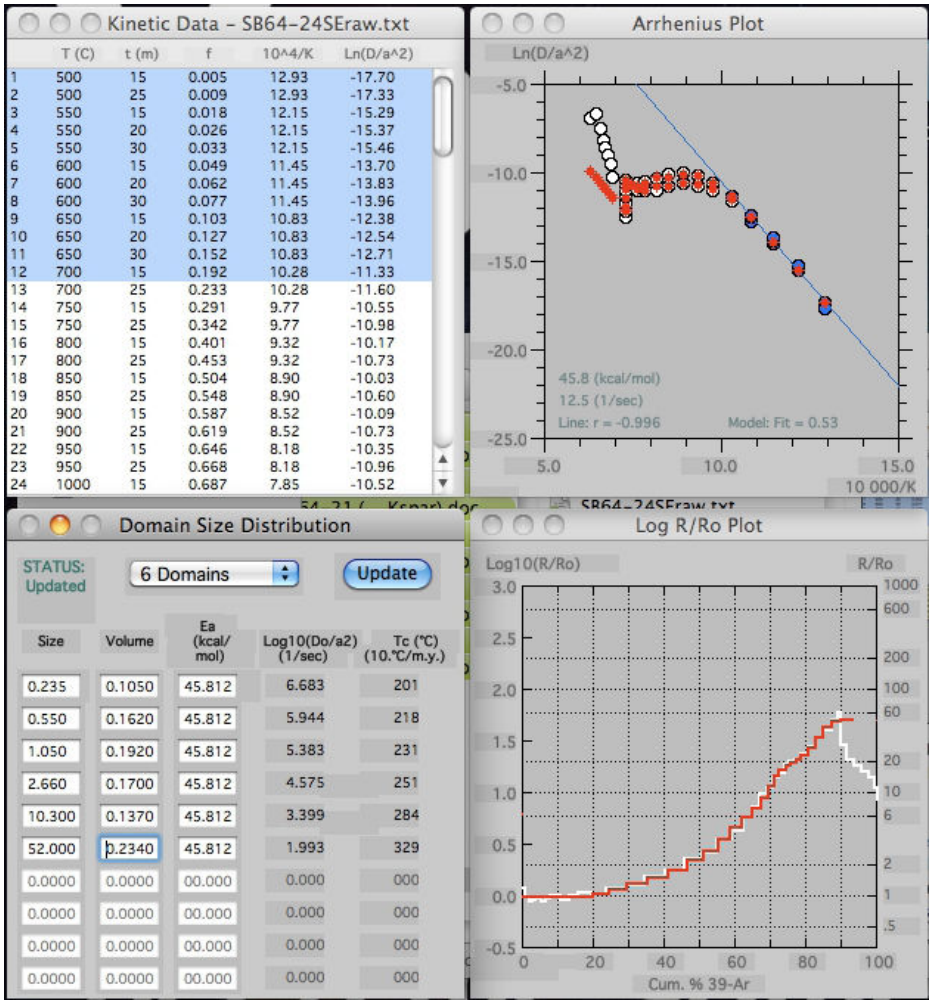

Figure 1. Modeled domain size and distribution for sample NSR-44. Red points and line represent the model, while the white points and line reflect the observed data.

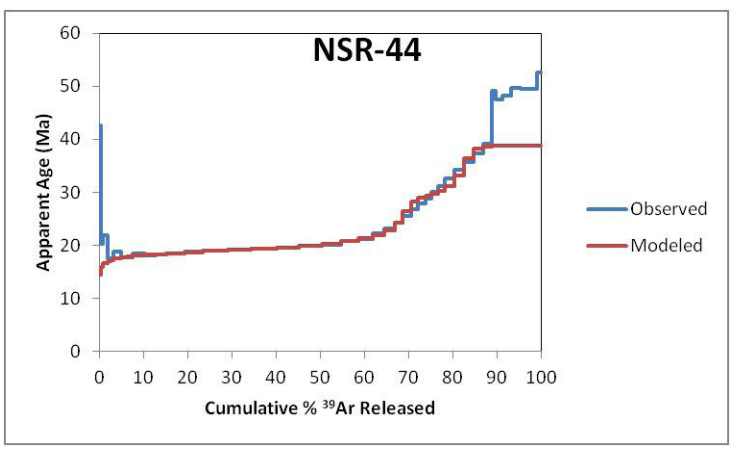

Figure 2. Age spectra from the thermal model compared with the observed age spectra.

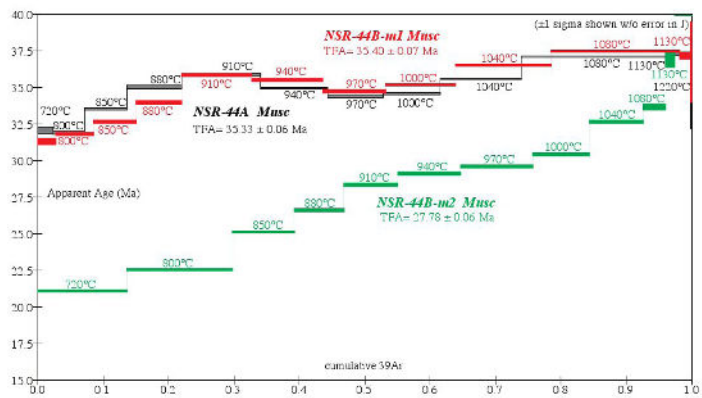

Figure 3. Age spectra for NSR-44. The black line represents the original sample, the red line represents the more magnetic fraction (m1), and the green line represents the less magnetic fraction (m2).

a climb in ages for the rest of the experiment. The samples were also split into a more magnetic fraction (20-25 volts on the Frantz, denoted m1) and a less magnetic fraction (40-55 volts denoted m2). The spectra for the more magnetic separates (red line, Figure 3) show a saddle-shaped age spectra similar to the initial samples, but with a higher total fusion age (TFA). The less magnetic fractions show age spectra (green line, Figure 3) that are younger than the bulk separate and that rise in apparent age throughout the experiment but occasionally have a small dip in apparent age around the 970-1000 ˚C step.

Compositional data from the m2 fractions show quartz inclusions in the muscovite. In multiple cases, points sampled from the same grain show both muscovite (~45% $Si0_2$ by weight) as well as quartz (~98% $Si0_2$ by weight). In the m1 fraction this was never observed and all the points analyzed were muscovite. Aside from the quartz inclusions the compositional variations between the separates appear to be negligible.

DISCUSSION

The thermal histories presented here (Figure 4) suggest that the most recent period of rapid cooling began ~20 Ma near the center of the range and ~16 Ma on the eastern flank. Samples NSR-65 and NSR-59 experienced similar Miocene cooling histories. NSR-42, NSR-50, and NSR-48 are all further to the east of the range and exhibit more rapid and later inception of cooling, beginning 16-19 Ma and proceeding for the next 9 Ma. These data are in agreement with previous studies (Lee, 1995; Gans et al., 2011; etc.) and suggest that a phase of rapid exhumation began between 20-16 Ma.

The different age spectra from distinct magnetic separates of muscovite from the same sample show that there is the potential for two unique populations of muscovite. The older population, which we associate with the more magnetic separate, may have been detrital, but overprinted by Cretaceous metamorphism. Some data points also show an intermediate percent of silica by weight which we interpret as an analysis occurring at or near a boundary of these quartz inclusions. We suggest that this younger population of muscovite is a result of recrystallization during the

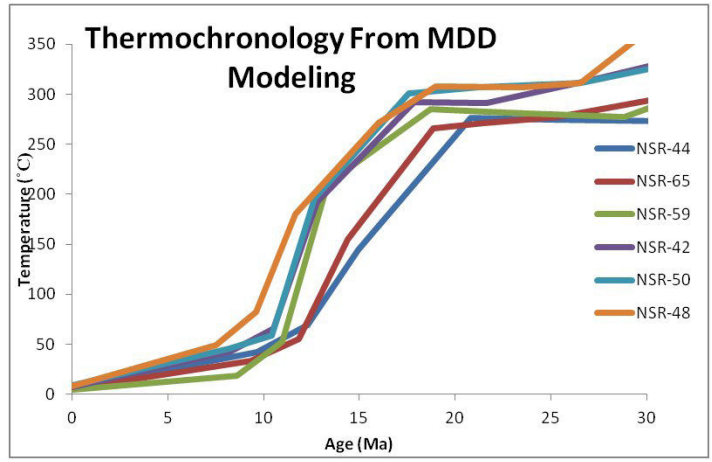

Figure 4. Composite graph of the thermal histories from the W-E transect along Hendry's Creek.

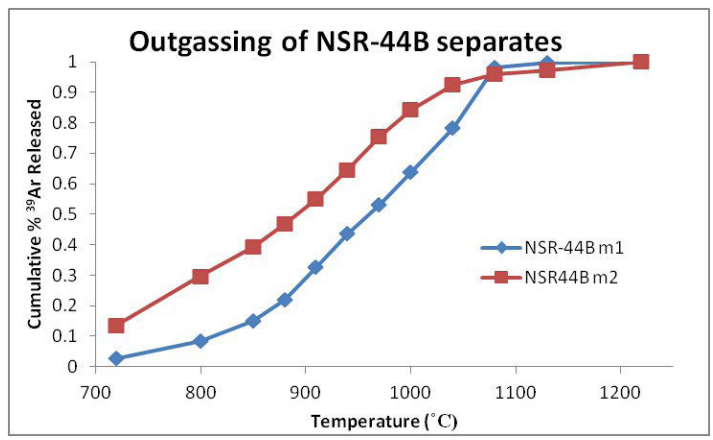

Figure 5. Graph comparing the degassing rates of the NSR-44B separates.

Miocene. In this process existing muscovite may have overgrown quartz fragments or crystals during a more recent low-temperature deformation event (Dunlap, 1997).

Notably, the m2 fractions have more step-like age spectra with smaller saddles if any. Similar staircase-shaped age spectra in muscovites are linked to partially recrystallized quartzite samples (Dunlap, 1997). The m2 separates consistently outgas earlier in the step heating experiment than the m1 separates. In (Figure 5) we see that m1 consistently lags behind m2. This is in agreement with Wijbrans and McDougall (1986) who noted that the degassing domain of muscovite is wider than that of phengite and thus it will lag behind phengite as it degasses. Although the compositional

data does not indicate a more phengitic composition, we may be observing a similar phenomenon due to the quartz inclusions.

Wijbrans and McDougall (1986) interpreted that the effective cooling age of the first generation is older than the oldest high-temperature apparent age, and that the "disturbing event(s)" would be younger than the youngest apparent age in the saddle of the spectrum. Applying this approach to our muscovite age spectra we would see that the most recent deformation began near the center of the range (NSR-44) no later than ~33 Ma and on the eastern flank of the range (NSR-48) more recently than 21 Ma. However, the recrystallization process may have affected different samples to various degrees. Thus, the age distribution could be caused by various degrees of recrystallization of the muscovites (Alexandrov et al., 2002).

This complex behavior observed in the muscovites could have possible implications on previous interpretations of muscovite ages in the area. Due to the irregular shaped spectra seemingly caused by multiple deformational events the existing muscovite results in the northern Snake Range may not accurately represent the thermal history of the range.

Samples NSR-44 and NSR-48 have both K-feldspar thermal histories and muscovite age spectra. Plotting the total fusion age of the muscovites (all separates) on the thermal histories of the samples assuming a muscovite closure temperature of 350 ˚C shows no agreement between the data. In both cases the muscovite projects the rock at a higher temperature than the thermal model. This illustrates the complex nature of the muscovite results, but this could also be highlighting issues with the thermal models. If we were to assign a higher activation energy to the domains it would raise the closure temperatures. These may lead to a better fit with the muscovite data.

CONCLUSIONS

Modeled $^{40}Ar/^{39}Ar$ age spectra from potassium feldspars indicate an episode of cooling beginning ~21 Ma near the center range and ~16 Ma near the eastern edge of the range, suggesting that a phase of rapid exhumation began at ~21-16 Ma. Analyses of muscovite with complex age spectra should be approached with caution. Numerous studies (Wijbrans and McDougall, 1986; Dunlap, 1997; Alexandrov et al., 2002) have shown that muscovite yielding irregular age spectra are the result of compositional mixing. Our own data suggest that muscovite samples from the northern Snake Range may consist of at least two compositions, reflecting different deformational events (possibly those described by Gans et al. (2011)). This may also mean that existing ages from muscovite data in the northern Snake Range may not accurately reflect the thermal history of the range.

REFERENCES

Alexandrov, P., Ruffet, G., and Cheilletz, A., 2002, Muscovite recrystallization and saddle-shaped 40Ar/39Ar spectra: Example from the Blond granite: Geochimica et Cosmochimica Acta, v. 66, n. 10, p. 1793-1807.

Buck, W.R., 1988, Flexural rotation of normal faults: Tectonics, v. 7, p. 959-973.

Dunlap, W.J., 1997, Neocrystallization or cooling? 40Ar/39Ar ages of white micas from low-grade mylonites: Chemical Geology, v. 143, p. 181-203.

Gans, P.B., Wong, M., and Calver, A.T., 2011, Late Mesozoic and Cenozoic evolution of east-central Nevada: hinterland tectonics and the origin of metamorphic core complexes, Geological Society of America Abstracts with programs, v. 43, n. 4, p. 3.

Gebelin, A., Mulch, A., Teyssier, C., Heizler, M., Vennemann, T., and Seaton, N.D.A., 2011, Oligo-Miocene extensional tectonics and fluid flow across the Northern Snake Range detachment system, Nevada: Tectonics, v. 30, TC5010.

Lee, J., 1995, Rapid uplift and rotation of mylonitic rocks from beneath a detachment fault; insights from potassium feldspar $^{40}Ar/^{39}Ar$ thermochronology, northern Snake Range, Nevada: Tectonics, v. 14, p. 54-77.

Lee, J., and Sutter, J.F., 1991, Incremental $^{40}Ar/^{39}Ar$ thermochronology of mylonitic rocks from the northern Snake Range, Nevada: Tectonics, v. 10, p. 77-100.

Lovera, O.M., Richter, F.M., and Harrison, T.M., 1989, 40Ar/39Ar thermochronometry for slowly cooled samples having a distribution of diffusion domain sizes: Journal of Geophysical Research, v. 94, p. 17917-17935.

Miller, E.L., Gans, P.B., and Garing, J., 1983, The Snake Range decollement: An exhumed mid-Tertiary ductile-brittle transition: Tectonics, v. 2, p. 239-263.

Miller, E.L., Dumitru, T.A., Brown, R.W., and Gans, P.B., 1999 Rapid Miocene slip on the Snake Range-Deep Creek Range fault system, east-central Nevada: Geological Society of America Bulletin, v. 111, p. 886-905.

Misch, P.H., 1960, Regional structural reconnaissance in central-northeast Nevada and some adjacent areas: Observations and interpretations, International Association of Petroleum Geologists 11th Annual Field Conference Guidebook, p. 17-42.

Wernicke, B., 1985, Uniform-sense normal simple shear of the continental lithosphere: Canadian Journal of Earth Sciences, v. 22, p. 108-126.

Wernicke, B., and Axen, G.J., 1988, On the role of isostasy in the evolution of normal fault systems: Geology, v. 16, p. 848-851.

Wijbrans, J.R., and McDougall, I., 1986, $^{40}Ar/^{39}Ar$ dating of white micas from an Alpine high-pressure metamorphic belt on Naxos, Greece: The resetting of the argon isotopic system: Contriubtions to Mineralogy and Petrology, v. 93, p. 187-194.

Zeitler, P.K., 2004, Arvert 4.0.1. Inversion of 40Ar/39Ar age spectra. Users Manual.