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

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Keck Geology Consortium: Projects 2012-2013
Short Contributions— Snake Range, Nevada Project

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Research Advisors: Phillip Gans, Martin Wong

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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.

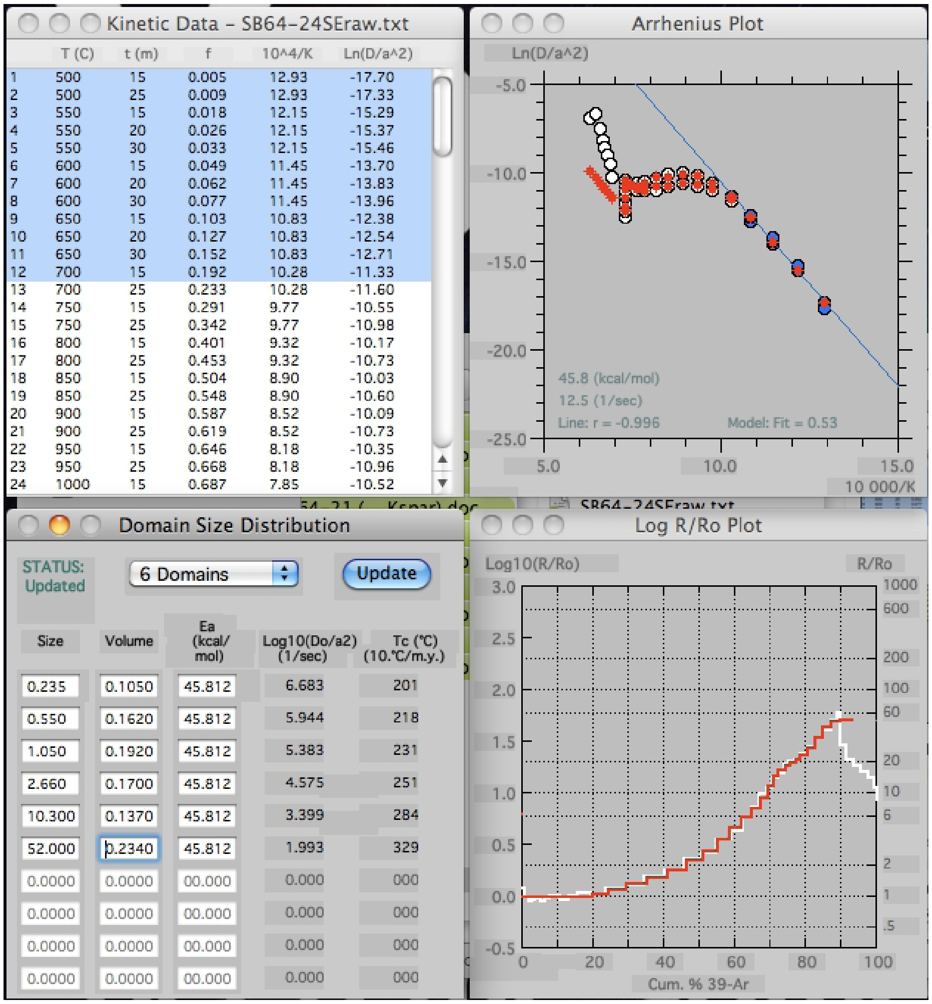
Potassium feldspar ^{40}Ar/^{39}Ar data were modeled according to the multiple diffusion domain (MDD) model to obtain model thermal histories from ~300–150° C (Lovera et al., 1991). In this study, six potassium feldspar samples were analyzed using the MDD modeling software Arvert (Zeitler, 2004).

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



Kinetic Data – SB64-24SEraw.txt

	T (C)	t (m)	f	10^4/K	Ln(D/a^2)
1	500	15	0.005	12.93	-17.70
2	500	25	0.009	12.93	-17.33
3	550	15	0.018	12.15	-15.29
4	550	20	0.026	12.15	-15.37
5	550	30	0.033	12.15	-15.46
6	600	15	0.049	11.45	-13.70
7	600	20	0.062	11.45	-13.83
8	600	30	0.077	11.45	-13.96
9	650	15	0.103	10.83	-12.38
10	650	20	0.127	10.83	-12.54
11	650	30	0.152	10.83	-12.71
12	700	15	0.192	10.28	-11.33
13	700	25	0.233	10.28	-11.60
14	750	15	0.291	9.77	-10.55
15	750	25	0.342	9.77	-10.98
16	800	15	0.401	9.32	-10.17
17	800	25	0.453	9.32	-10.73
18	850	15	0.504	8.90	-10.03
19	850	25	0.548	8.90	-10.60
20	900	15	0.587	8.52	-10.09
21	900	25	0.619	8.52	-10.73
22	950	15	0.646	8.18	-10.35
23	950	25	0.668	8.18	-10.96
24	1000	15	0.687	7.85	-10.52

Domain Size Distribution

STATUS: Updated

6 Domains

Update

Size	Volume	Ea (kcal/ mol)	Log10(Do/a2) (1/sec)	Tc (°C) (10.°C/m.y.)
0.235	0.1050	45.812	6.683	201
0.550	0.1620	45.812	5.944	218
1.050	0.1920	45.812	5.383	231
2.660	0.1700	45.812	4.575	251
10.300	0.1370	45.812	3.399	284
52.000	0.2340	45.812	1.993	329
0.0000	0.0000	00.000	0.000	000
0.0000	0.0000	00.000	0.000	000
0.0000	0.0000	00.000	0.000	000
0.0000	0.0000	00.000	0.000	000

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.

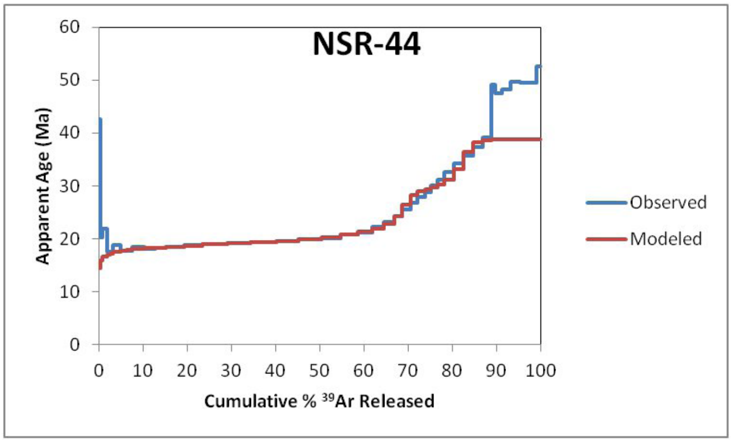


Figure 2. Age spectra from the thermal model compared with the observed age spectra.

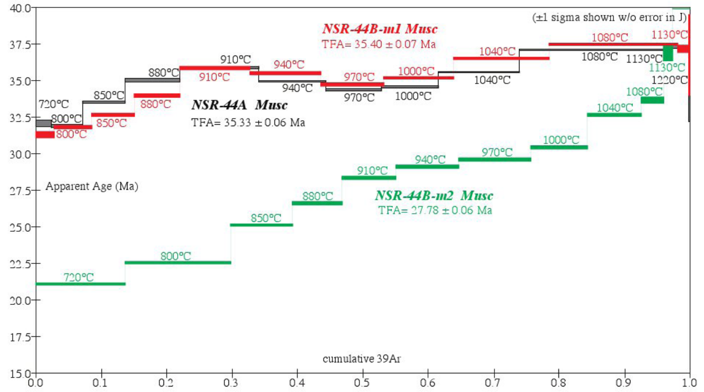


Figure 3. Age spectra for NSR-44. The black line represents the original sample, the red line represents the more magnetic fraction (m1), and the green line represents the less magnetic fraction (m2).

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% SiO_2 by weight) as well as quartz (~98% SiO_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 Miocene. In this process existing muscovite may have overgrown quartz fragments or crystals during a more recent low-temperature deformation event (Dunlap, 1997).

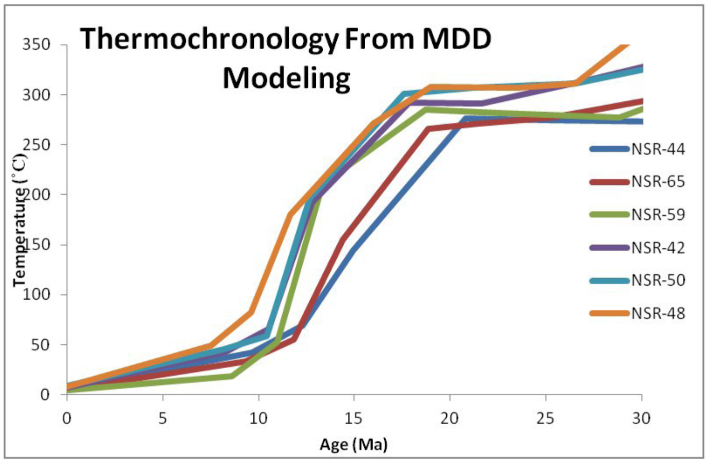


Figure 4. Composite graph of the thermal histories from the W-E transect along Hendry's Creek.

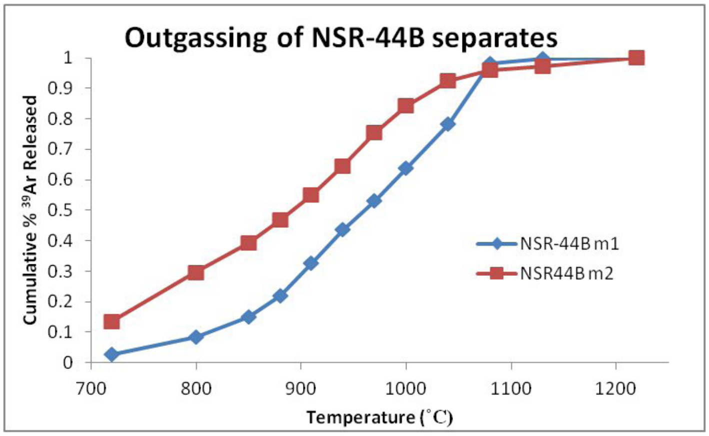


Figure 5. Graph comparing the degassing rates of the NSR-44B separates.

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.

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