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

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Keck Geology Consortium: Projects 2012-2013
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WILL BENDER, Whitman College
Research Advisor: Kirsten Nicolaysen

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MICHAEL KENNEY, University of California—Santa Barbara
Research Advisor: Phil Gans

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GEOCHEMISTRY AND GENESIS OF JURASSIC GRANITOIDS FROM THE NORTHERN SNAKE RANGE, NV

WILL BENDER, Whitman College
Research Advisor: Kirsten Nicolaysen

INTRODUCTION

Nevada's Snake Range is a classic example of a mid-crustal metamorphic core complex, exhumed by a regional-scale, low-angle normal fault, or detachment fault (Wong and Gans, this volume). Movement on the fault exposed a composite 151-160 Ma plutonic complex (Miller et al., 1988; Monroe and Gans, this volume). Previous mapping (Miller and Gans, 1999) defined four intrusive units in the northern Snake Range (NSR; Fig. 1), but the petrogenetic history that created the surprisingly extensive mineralogical and geochemical variability of the NSR complex is undetermined. We characterize rock and mineral compositions and textures for 12 samples of Jurassic two-mica granite, hornblende-rich diorite and gabbro and of 4 Tertiary dikes. Our results suggest that fractional crystallization was the major formative process involved in creating the chemical variation within this plutonic complex.

GEOLOGIC SETTING

Arc-related magmatism and volcanism occurred along the western Phanerozoic continental margin of North America starting in the Late Triassic (205 Ma) with the majority occurring in the Middle Jurassic thru late Cretaceous (e.g., Barton, 2011). By 160 Ma, back-arc igneous activity had worked its way deep into the Great Basin area, forming plutons in the Snake Range.

Three major deformational and metamorphic events (Jurassic, Cretaceous and Tertiary) have affected the Jurassic intrusions of the NSR, with a trend of increasing metamorphism from south to north (Miller et al., 1988; Lee et al., 1983 and references therein). Starting in the Cretaceous, the Snake Range was affected by crustal thickening and metamorphism associated with the Sevier fold-and-thrust belt. However, age and metamorphic fabric differences clearly separate any Sevier thrusting from the intrusion of the Snake Range plutons (Coney and Harms, 1984). Peak metamorphism during this event occurred during the Late Cretaceous and reached staurolite facies (Miller *et al.*, 1988 and references therein). In the Middle Tertiary, eastern Nevada was affected by widespread plutonism and volcanic activity (Gans *et al.,* 1989), and in the NSR several granitic and rhyolitic dikes cut through the older plutons and metasediments, providing valuable age constraints on metamorphic fabric development (Monroe and Gans, this volume).

Lee and Christiansen (1983) characterized Jurassic plutons of the southern Snake Range (SSR) plutons as tonalite to two-mica granite and attributed their formation to fractional crystallization of a lower crust-derived melt with an enigmatic contribution from the partly melted sedimentary rocks. Although the NSR complex (Silver Creek and Old Mans plutons) shows a similarly wide compositional range (tonalites, diorites and granites), our findings show that some Old Mans rocks are gabbroic.

FIELD AND PETROGRAPHIC DESCRIPTIONS

Samples were collected from the Silver Creek and Old Mans plutons and four cross-cutting dikes in an E-W transect, for a total of 12 Jurassic samples and 4 Tertiary dikes (Fig. 1). Oriented thin sections were prepared, cut parallel to lineation (generally SE) and perpendicular to the foliation.

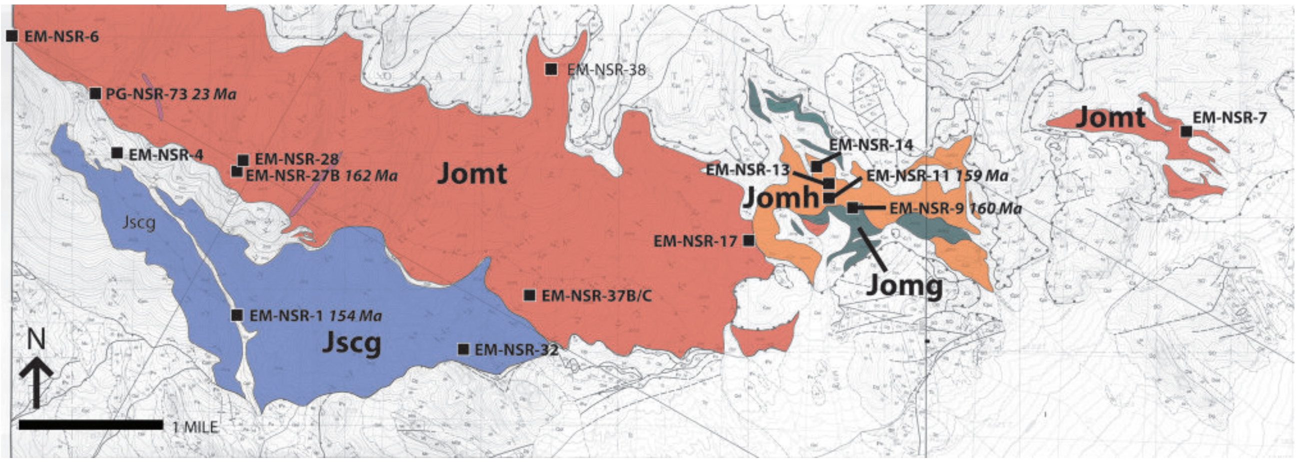

Figure 1. Location of all samples overlain on quadrangle geologic maps of Miller and Gans, 1999. Colored geologic units represent the Jurassic Silver Creek granite (Jscg, blue), Old Mans tonalite (Jomt, red), Old Mans hornblende diorite (Jomh, orange) and the Old Mans granite (Jomg, dark grey). Available zircon ages are included next to sample designation (Monroe and Gans, this volume).

The Old Mans tonalite (Jomt) is mapped as the largest intrusive unit in the NSR plutonic complex. Preliminary U-Pb zircon data from Monroe and Gans (this volume) indicate crystallization ages of different compositional phases of Jomt are within analytical error at 159 -160 Ma. This is distinctly older and unrelated to the late Cretaceous amphibolite facies the country rocks (Miller *et al.*, 1988). Mineral assemblage includes abundant plagioclase, quartz and biotite with lesser K-feldspar and muscovite (Fig. 2). Throughout the plutonic complex strain is heterogeneous with areas of high strain indicated by flaser textures, quartz ribbons, aligned and recrystallized micas, and dynamically recrystallized feldspar augen. Ubiquitous kinematic indicators consistently indicate a component of top to the E shear (Monroe and Gans, this volume).

In contrast, samples from the Old Mans hornblende-bearing diorite (Jomh), such as EM-NSR-11, show little evidence of strain, suggesting compositional resistance to metamorphic fabric development. Within Jomh, there are abundant small, ~3 m diameter blocks or enclaves of fine-grained mafic material. These blocks, such as EM-NSR-14, represent the most mafic material in the plutonic complex and appear to be cognate enclaves of a poorly-mixed mafic magma. Within the Old Mans pluton, especially in Jomh/Jomg where composition is variable from gabbro to granodiorite to granite, contacts appear to be gradational. On geochemical plots we therefore group these map units to consider their petrologic origin.

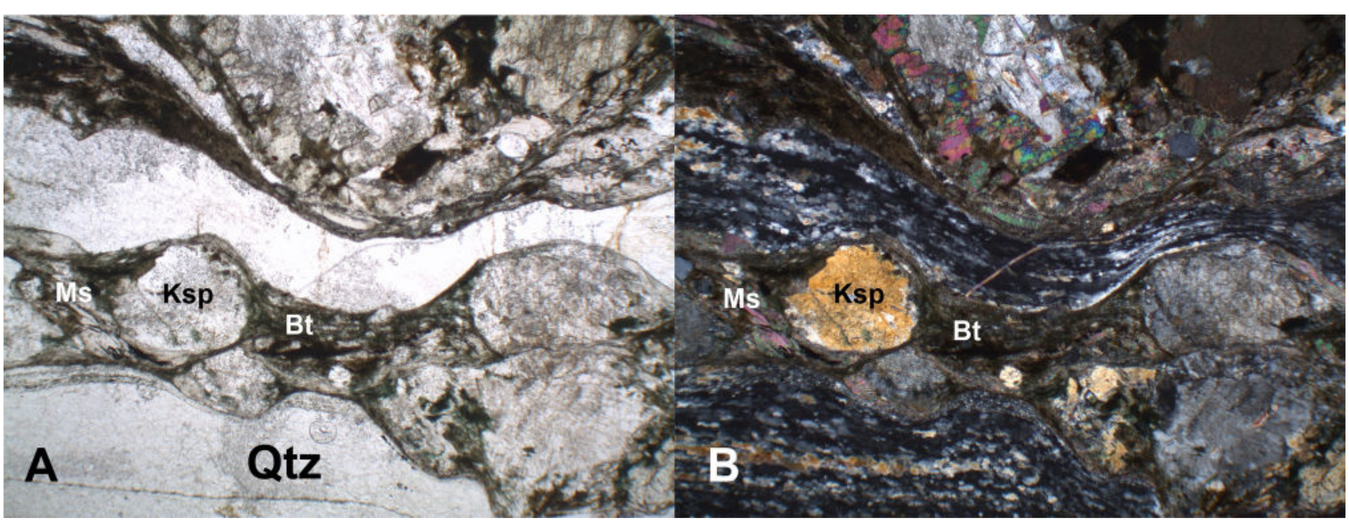

Figure 2. Photomicrographs of Old Mans Tonalite (Jomt) EM-NSR-7 in PPL (A) and XPL (B). Well-developed quartz ribbons indicate high strain environment and bands of biotite wrapping around the feldspars define the foliation. 40x magnification, FOV = 5 mm.

The Silver Creek two-mica granite (Jscg) is slightly younger, with an age of 154 Ma (Monroe and Gans, this volume) and many late-stage, garnet-bearing pegmatitic dikes and sills inject its margins. Some dikes, such as EM-NSR-27 and 28B, lie within and cut Jomt, but they are actually part of the Silver Creek pluton. Jscg is weakly to moderately foliated, with quartz recrystallization, grain size reduction and biotite-defined foliations that overall are less developed than in Jomt. Additionally, small rafts and larger pendants and screens of McCoy Creek group metasedimentary rocks are exposed along the margin between the Jscg and Jomt intrusives on the northern slope of Silver Creek Canyon. Contacts between the Silver Creek and Old Mans plutons are poorly exposed.

In both the Old Mans and Silver Creek plutons, Tertiary dikes are found cutting across the deformation fabrics. A new zircon age for a rhyolitic dike in Silver Creek Canyon is 23 Ma (Monroe and Gans, this volume). Tertiary dikes vary from rhyolitic to granitic and show fabrics distinct from those of the plutons.

ANALYTICAL METHODS

Sample preparation and analysis of all 16 NSR samples was conducted at the WSU GeoAnalytical Lab using a ThermoARL Advant'XP+ sequential X-Ray Fluorescence (XRF) spectrometer. Glass beads created from sample powders were run using a rhodium target under full vacuum at 50 kV and 50 mA. The analysis gathers data on 29 major and trace elements and precision information and operating conditions of the instrument are available online (see http://www.sees.wsu.edu/Geolab/note/xrf.html). Semi-quantitative mineral compositions were obtained using a FEI Quanta 250 SEM with a Thermo UltraDry series detector with a 30 mm^2 window operated at Whitman College. Samples were run at a working distance of 10 mm and beam conditions of 20 kV and 100 mA under high vacuum.

RESULTS

Chemical compositions of the adjacent Silver Creek (Jscg) and Old Mans (Jomh and Jomt) plutons conform to a typical calc-alkaline trend expected for arc-affinity magmatism. In the rock classification diagram (Fig. 3A), it is clear that rock compositions in the plutonic complex span a broader compositional range than implied by the map units (Miller *et al.*, 1999).

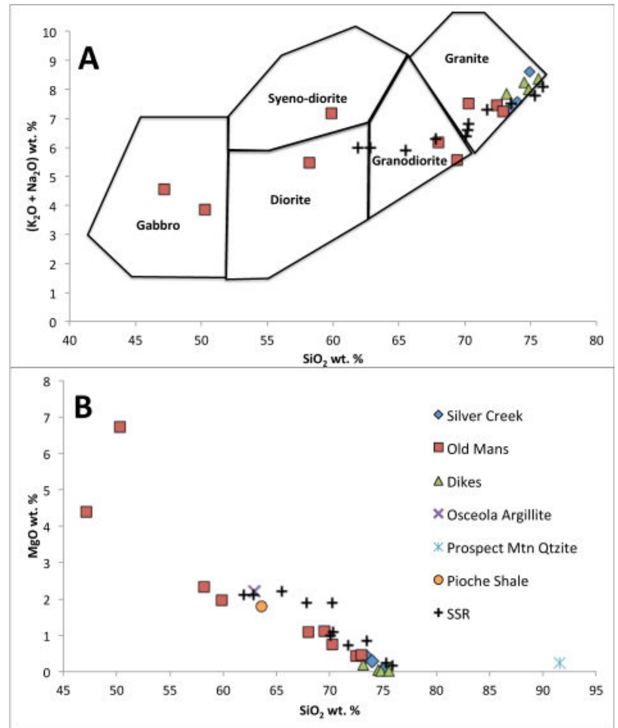

Figure 3. (A) Total alkali vs. silica classification plot for plutonic rocks (Wilson, 1989) showing the wide variety of the NSR plutonic complex. (blue diamonds= Jscg Silver Creek; red squares= Jomt + Jomh of Old Mans). Green triangles are Tertiary dikes. Black crosses are SSR plutons (Lee and Van Leonen, 1971). (B) Harker plot of MgO vs. silica for the Jurassic Silver Creek and Old Mans pluton samples, as well as country rock compositions and SSR plutons. The trend of decreasing MgO is consistent with Hb fractional crystallization.

The slightly older, 160 Ma Old Mans Jomh has SiO_2 and MgO wt. % that range from 47.2-58.2 and 2.3-6.7 respectively and consists of hornblende gabbros and diorites. EM-NSR-11, the areally widespread gabbroic sample, has Ni and Cr concentrations of 33 and 122 ppm respectively, significantly higher than all other Jurassic samples.

The majority of the Old Man pluton is mapped as tonalite (Jomt) and yielded SiO_2 contents that range from 60-73 wt. %. Al_2O_3 and MgO contents range from 14.0-16.7 and 0.4-2.0 respectively, and form a linear trend with Jomh and the Silver Creek Jscg (Fig. 3b). Within the main Jomt unit, rock types include syeno-diorite, granodiorite and granites. As expected for elements incompatible in early crystallizing minerals,

Na_2O and K_2O increase with increasing silica and P_2O_5 shows considerable scatter at the low silica end of the range. FeO, TiO_2, Sc, and V all decrease with increasing silica also defining linear trends (e.g., Fig. 4B) whereas some trace element trends show a distinct inflection (Figs. 4, 5). Overall, these geochemical results indicate that many of the mapped units could be renamed or that unit descriptions should be modified.

This peraluminous two-mica granite of the Silver Creek pluton (Jscg) is compositionally relatively homogenous with SiO_2 wt. % from 73.5-74.9. Jscg pegmatitic dikes and sills have similar major element compositions as the main Jscg granite. Using the SEM, preliminary results show that sample EM-NSR-1 of Jscg has accessory ilmenite, apatite and zircon and a small component of hornblende. Four Tertiary cross-cutting dikes are granitic to rhyolitic in composition and have SiO_2 wt. % from 73.1-75.6 but distinctly different abundances of some trace elements (Figs. 4, 5).

DISCUSSION

For the SSR, Lee and Christiansen (1983) proposed fractional crystallization as the formative pathway for the Jurassic Snake Creek-Williams Canyon plutons, which show less compositional variation (tonalite to 2-mica granite) compared to NSR plutons. Lee and Christiansen proposed that initially the SSR peraluminous plutons were sourced primarily from partial melting of lower crust metasedimentary rocks followed by simple fractionation to create further compositional variation within the pluton. However to account for the gabbroic phases present in the NSR Silver Creek and Old Mans plutons, their hypothesis requires modification.

Given a potentially prolonged duration of cooling and their close age and spatial relationships, Jomh and Jomt phases were nearly contemporaneous and likely closely related petrogenetically. We propose the low-silica, hornblende gabbros of Jomh (EM-NSR-14 and EM-NSR-11) exhibit low silica and relatively high compatible element compositions (Ni and Cr) suggestive of a mantle-derived (M-type) parent, though the low MgO and abundant phyric hornblende suggest the sampled enclaves are not primary mantle melts. The linear relationships of most major elements suggest fractional crystallization of hornblende to form Jomt and Jscg from Jomh with little assimilation of metasedimentary country rock (e.g., Fig. 3B).

Examination of the trace element information for the NSR intrusives elucidates the subsequent formation of the Jomt and Jscg from the most mafic Jomh compositions. First, hornblende fractionation would account for the trends seen in La/Nd and Sc relative to SiO_2 (Fig. 4). Although both La and Nd are incompatible in hornblende, Nd is slightly more compatible; thus, the four-fold linear increase in the ratio for Old Mans Jomh and Jomt matches expectations. Hornblende-rich rocks of Jomh sequester Sc causing its drop in concentration. The distinct decrease in La/Nd for a few Jomt and Jscg samples suggests saturation of a second crystallizing phase to decrease La abundance.

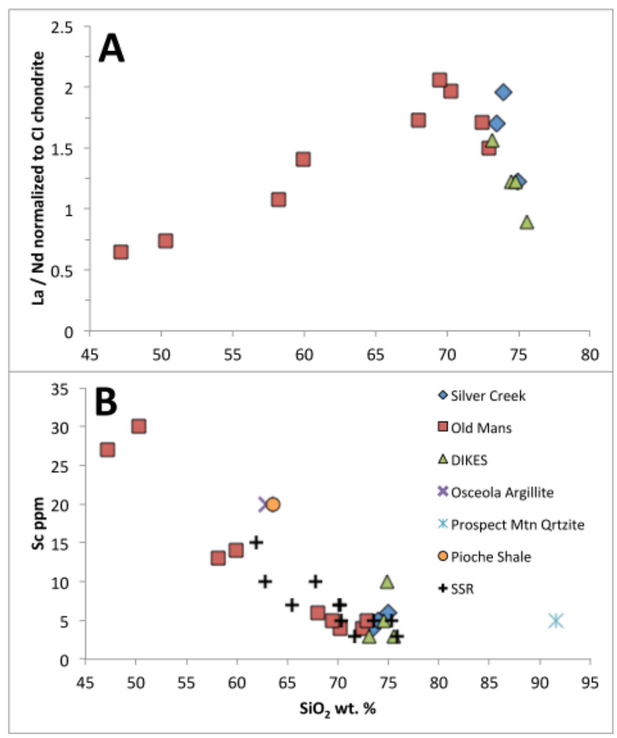

Figure 4. Silica versus (A) La/Nd normalized to CI chondrite (Palme and Jones, 1998) and Sc (B). Trends of these plots indicate hornblende fractionation. La and Nd are both incompatible in hornblende although Nd is slightly more compatible. Their ratio (La/Nd) increases as silica content increases until biotite and/or accessory minerals (eg. allanite) crystallize. Sc is compatible in hornblende which effectively incorporates most of the Sc by ~70 wt. % SiO_2.

For granitic melts, Ba and Rb are both compatible in biotite and muscovite. If these minerals were fractionating, both Ba and Rb should decrease with increasing silica content (Fig. 5). However, Ba abundance increases initially and then decreases, though Rb simply continues to increase. K-feldspar fractionation can explain the pattern of decoupling between Ba and Rb with orthoclase incorporating trace amounts of Ba in its structure, but omitting Rb. The main phase of the Silver Creek granite Jscg (EM-NSR-1) and some phases of the mapped Jomt (EM-NSR-7 and 37) are K-feldspar bearing and are potential candidates for this process, whereas more mafic Jomh phases have less K-feldspar. Zr/Y ratios show trends indicating the accumulation and crystallization of zircon. Similarly early saturation of apatite and subsequent fractionation accounts for P_2O_5 trends. Both FeO and vanadium concentrations decrease linearly relative to silica indicating fractionation of titanomagnetite. In summary, fractionation of co-crystallizing phases from a mantle-derived magma seem the dominant petrogenetic process.

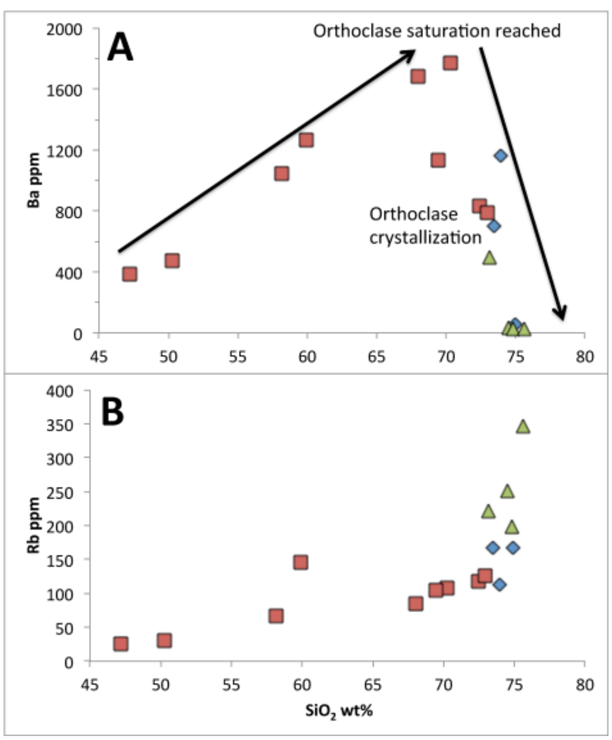

Figure 5. Ba (A) and Rb (B) ppm vs. silica. The different trends of these tracers implicate K-feldspar fractionation instead of biotite and muscovite fractionation in the melt. Symbols as in previous figures.

CONCLUSIONS

Rock compositions in the Jurassic Silver Creek – Old Mans plutonic complex vary widely from gabbro to (alkali) granite and form a calc-alkaline trend usually associated with arc magmatism, a plausible interpretation of the tectonic setting for western North America during the middle Jurassic. Gabbroic enclaves in the Old Mans pluton may represent a mantle-derived parental melt and the compositions of NSR plutons do not require significant partial melting of metasedimentary country rock. Linear trends in geochemical data support fractional crystallization, initially of hornblende followed by K-feldspar, titanomagnetite, and zircon.

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