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Keck Geology Consortium: Projects 2012-2013
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Research Advisor: Phil Gans

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PHILIP B. GANS, University of California, Santa Barbara
MARTIN S. WONG, Colgate University

INTRODUCTION

The Snake Range, located in east central Nevada (Figure 1) is one of the archetypical examples of a metamorphic core complex, where large-scale crustal extension associated with slip on a presently low-angle "detachment" fault (the Northern Snake Range Décollement or NSRD) has juxtaposed mid-crustal, highly strained and metamorphosed rocks in the footwall against imbricately normal faulted-supracrustal rocks in the hanging wall. The Snake Range has played a central role in our understanding of extensional tectonics (e.g. Wernicke, 1981; Miller et al., 1983; Bartley and Wernicke, 1984; Gans et al., 1985 and many others), and yet many fundamental questions about the tectonic and structural development of this feature remain largely unanswered. In particular, the relationship between plutonism, metamorphism, and penetrative strain in the footwall of this complex and the exhumation and slip on the bounding detachment fault remain controversial. The goal of this project was to provide new constraints on the structural and tectonic development of the core complex by combining structural field mapping, strain analyses, and microstructural studies together with U-Pb geochronology and ^{40}Ar/^{39}Ar thermochronology. Our study focused on the lower plate of the core complex and examined spatial variations in the temperatures, magnitude, timing, and kinematics of penetrative strain, the emplacement ages of lower plate intrusions, and the exhumation (cooling) history of metasedimentary and plutonic rocks of the football.

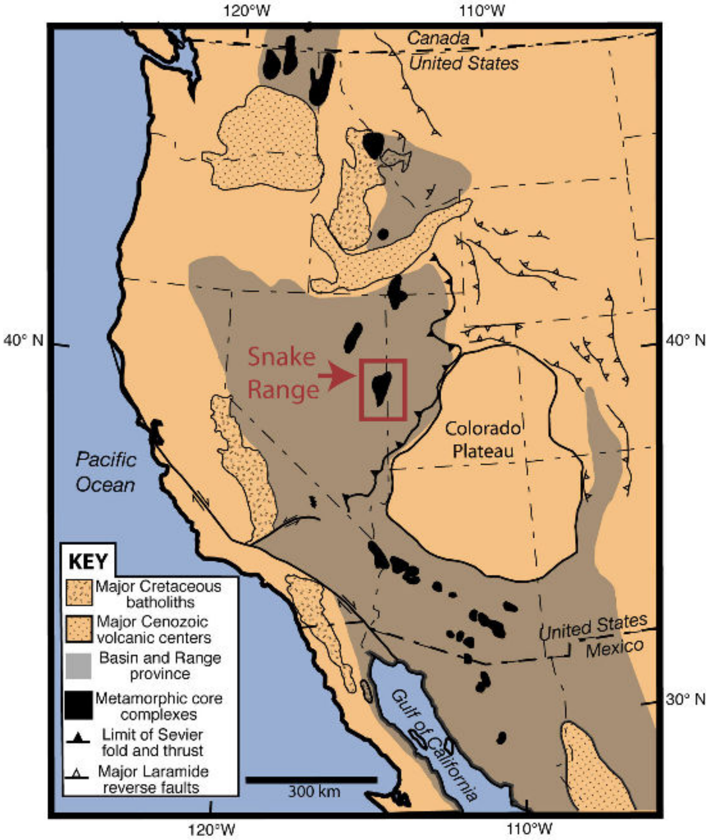

Figure 1. The extensional Basin and Range province of western North America (gray) showing the location of metamorphic core complexes (black) in a roughly north-south belt within the Cordillera. The Snake Range is located in east-central Nevada.

BACKGROUND

The northern Snake Range is an 80 km-long by 25 km-wide range in the northern Basin and Range province. The most prominent structural feature of the range is the northern Snake Range Décollement (NSRD), a low-angle fault that juxtaposes an upper plate of complexly normal-faulted Paleozoic and Tertiary strata against a footwall of highly strained metasedimentary and igneous rocks (Figure 2). Miogeoclinal strata in the footwall of the NSRD vary in age from late Precambrian to Ordovician and were deeply buried and metamorphosed to amphibolite facies during the late Cretaceous (Miller et al., 1988, Cooper et al., 2010). The footwall is relatively unfaulted but records a complex history of ductile deformation, metamorphism, and intrusion (Lee et al., 1987; Miller et al, 1988). The hanging wall or upper plate of the NSRD includes Middle Cambrian to Permian miogeoclinal rocks and Tertiary sedimentary and volcanic rocks. In striking contrast to the lower plate, these rocks are little metamorphosed but highly faulted and tilted by multiple generations of normal faults (Gans and Miller, 1983). The NSRD defines a north-trending asymmetric dome with ~ 5000 feet (1.5 km) of structural relief.

The position of the Snake Range in the hinterland of the Cretaceous Sevier orogenic belt (Fig. 1) led Misch (1960) and later workers to relate the low-angle “décollement faulting” in the range to Mesozoic thin-skinned thrust faulting farther east. The first detailed geologic studies in the range by Miller et al. (1983) and Gans and Miller (1983) suggested that the main structural features were instead extensional in origin and Cenozoic in age. Based on stratigraphic and structural relationships, they proposed that the NSRD originated as a sub–horizontal ductile-brittle transition zone between a brittlely extending upper plate and a ductilely stretching lower plate – an interpretation that was challenged by Bartley and Wernicke (1984), who interpreted the structure as a major low-angle normal fault with 10s of km of slip.

Subsequent studies have expanded the geologic mapping and utilized structural analyses, seismic reflection profiling, metamorphic petrology,

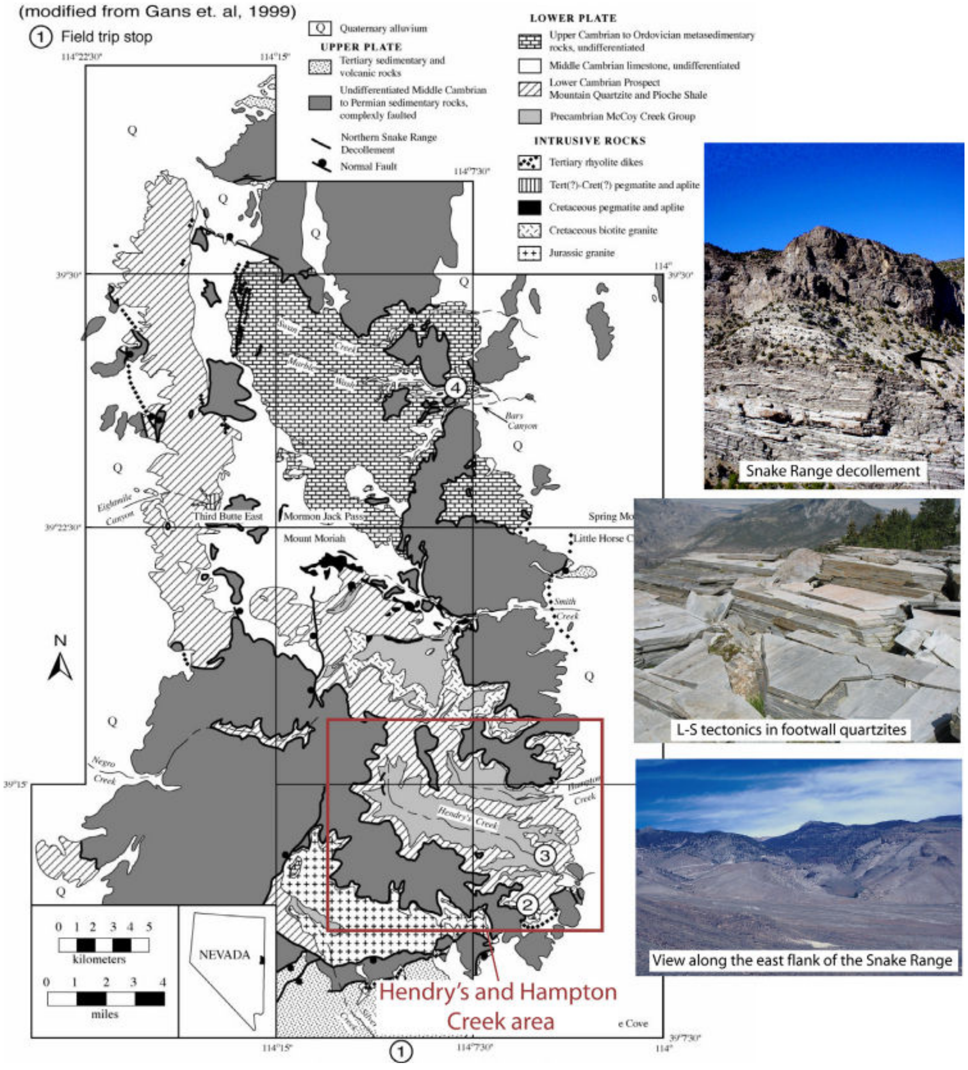

Figure 2. Simplified geologic map of the northern Snake Range. Important drainages along the southern and eastern flanks of the range include, from south to north, Silver Creek, Old Man's Canyon, Hendry's Creek, Hampton Creek, Smith Creek, and Marble Wash. Much of our work was focused near Hendry's and Hampton Creeks (red box). Photos on the right illustrate (from top to bottom) the Snake Range decollement, high strain L-S tectonites in the footwall, and the terrain along the eastern flank of the range.

geochronology and thermochronology in further efforts to shed light on the origin of the NSRD, as well as on the age(s) and tectonic significance of lower plate metamorphic fabrics and its geometric and kinematic relationship to the NSRD (e.g. Rowles, 1982; Gans and Miller, 1983; Grier, 1983; Miller et al., 1983; Gans et al., 1985; Lee and others, 1987; Miller et al., 1989; Gans et al., 1989; Lee and Sutter, 1991; Lee, 1995; Gans et al., 1999a and b; Miller et al. 1999a, b, and c; Lee et al., 1999a, b, and c; Cooper et al., 2010). These studies have demonstrated a number of key relationships. Lower plate metasedimentary rocks consist of poly–metamorphosed late Precambrian to Lower Cambrian quartzites and pelites and Middle Cambrian to Ordovician marble. U-Pb dating has identified Jurassic and Cretaceous granitic plutons and Tertiary dike swarms that locally intrude lower plate units. Lower to upper greenschist-facies retrograde metamorphism and deformation of Paleocene (?) to Miocene age strongly affected much of the lower plate, causing retrogression of older peak-metamorphic assemblages. This retrograde event was accompanied by an intense penetrative strain, resulting in a subhorizontal, bedding-parallel mylonitic foliation and a WNW–trending lineation. The geometry and kinematics of this footwall strain and what relationship (if any) it has to the evolution of the NSRD were the primary focus of our multidisciplinary study.

LOWER PLATE STRAIN

A number of student projects focused on better understanding the geometry, kinematics, magnitude, and temperature conditions of lower plate strain. Four projects investigated strain conditions in footwall quartzite units across the range. Jory Lerback and Jordan Elmiger both examined strain in quartzite units in Hendry's Creek using petrographic and electron backscatter diffraction (EBSD) studies. Jory examined vertical strain gradients within quartzite units beneath the NSRD. Her work found that strain decreases in the footwall beneath the NSRD from X/Z values >>10 near the top of the footwall to values <4 in the deepest structural levels. Conditions of deformation also appear to increase downwards in the footwall. Jordan studied east-west gradients within the Prospect Mountain quartzite. His work documents a clear top-east sense of shear across the footwall, a gradual rotation of stretching lineations from N50W to S80E from west to east, and an increase in strain magnitude towards the east (confirming work by Lee, 1987?).

Michael Kenney examined quartzite units in the northern footwall (Smith Creek area) and found that deformation mechanisms were dominated by sub-grain rotation (SGR) and grain boundary migration (GBM), suggesting deformation temperatures >400°C and likely 450-550°C. Quartz lattice preferred orientation (LPO) fabrics suggest a dominance of prism <a> and rhomb <a> slip, supporting upper greenschist to lower amphibolite grade conditions during deformation. Similar results were found by Evan Monroe, who focused on deformation in plutonic rocks in the southern part of the range (Silver Creek area).

Casey Portela investigated marble mylonites across the range using a combination of petrographic and EBSD analyses as well as applying the calcite-dolomite thermometer. In contrast to the quartzite units, Casey's work revealed much greater complexity in the kinematics of the marble, as both top-east and top-west shear were evidence (see also Cooper et al., 2010). This is likely due to highly heterogeneous strain produced by flow around large dolomitic boudins. Calcite-dolomite thermometry results may indicate somewhat lower temperatures of deformation in the marbles (~350-450°C) compared to the quartzite mylonites.

TIMING OF MYLONITIC DEFORMATION

Our work on the temperatures of deformation in the mylonitic shear zone, when combined with new and existing thermochronology, provide important constrains on the timing of mylonitic deformation and whether it is related to Miocene slip on the NSRD.

Joe Wilch analyzed muscovite and K-feldspar $^{40}Ar/^{39}Ar$ thermochronologic data originally presented by Gans et al. (2011 and unpublished work). Multiple diffusion domain (MDD) modeling of K-feldspar results suggest a period of rapid footwall cooling beginning at ca. 20 Ma and continuing until at least 15 Ma at cooled the footwall from ~300 °C to <100 °C. These results match well with prior fission track results (Miller et al., 1999) and document rapid top-east (normal) slip on the NSRD. The $^{40}Ar/^{39}Ar$ results document a ~150-200 °C temperature difference between the crest and eastern flank of the range at ca. 20 Ma, suggesting that the NSRD initiated at a significantly steeper dip. Joe's analysis of muscovite $^{40}Ar/^{39}Ar$ results indicate complexity in the age spectrum of most samples, likely as a result of mixtures of different compositions of muscovite in the samples. However, the generally older ages (>20 Ma) given by muscovite and the high temperature steps of K-feldspar samples suggest the entire range had cooled below 400°C well before 20 Ma (largely by 30-50 Ma). Given the petrofabric work described in the previous section, this result suggests that most, if not all, of the footwall strain occurred prior to the Miocene and is therefore unrelated to Miocene slip on the NSRD. It is possible that the geometric similarity of the NSRD to the underlying footwall shear zone is a result of the NSRD reactivating the older mylonitic shear zone rather then the features being coeval.

AGE AND PETROLOGY OF LOWER PLATE PLUTONS

Several student projects focused on refining our understanding of the character, petrology, and age of plutonic units in the lower plate.

Michael Kenney conducted U-Pb zircon geochronology by LA-ICPMS in the central/northern part of the range in Smith Creek. His work on the Horse Canyon Orthogniess, previously dated at ~100±8 Ma (Gans et al., 1999; Miller et al., 1988), produced a much more precise age of 100.9–101.6 ± 0.5 Ma. He also dated several leucogranite bodies in the area, with concordant U-Pb ages that are dominantly 84–85 Ma, with one yielding a concordant age of 76.1 ± 1.5 Ma. These results are also consistent with previous geochronology (Miller et al., 1988; Gans et al., 1999) but greatly improve the precision. The younger age suggests a more protracted phase of leucogranite generation than previously recognized.

Evan Monroe conducted U-Pb zircon geochronology by LA-ICPMS on plutonic units in the southern part of the Northern Snake Range. Previous work on these units (Miller, et al., 1988) suggests that both the Silver Creek and Old Mans Canyon plutons are approximately 160 Ma and subsequent TIMS dating (J.E. Wright, unpub. data, referenced in Miller et al., 1999) concluded both plutons were emplaced 155±5 Ma. Evan's work precisely dates the Old Man Canyon pluton at 160 ± 1 Ma and indicates that the wide range of compositional variations in this mapped unit are all the same age. Evan also found that the Silver Creek pluton is modestly but distinctly younger and was emplaced at 154-152 Ma. Evan's work on dikes in the Silver Creek provide important constraints on the timing of fabric formation. A ~35 Ma dike cuts the main sub–horizontal foliation in the Silver Creek granite, but the dike has a well developed fabric internally – perhaps indicating that mylonitization was still ongoing at this time, although the fabric in the dike is quite discordant to the host rock fabric, suggesting the dike fabric may be highly localized and younger than the main fabric here. A 23 Ma rhyolite dike cuts sharply across the mylonitic fabric in Silver Creek and is entirely undeformed, which provides a firm minimum age for the fabrics in this area. This interpretation is consistent with our results combining the petrofabrics and thermochronology that much of the footwall fabrics may pre-date Miocene slip and exhumation on the NSRD.

Will Bender conducted a detailed petrographic and major and trace element geochemistry study of the intrusive phases in the Old Man and Silver Creek plutons. His work demonstrates that the compositions range continuously from gabbro to two mica granite (basalt to high silica rhyolite). Analysis of the major and trace element variation diagrams indicate that these are fairly typical calc-alkaline magmas and can be explained largely by fractionation of a mantle derived basaltic parent (i.e. the gabbroic end member).

CONCLUSIONS

A variety of evidence supports the conclusion that the lower plate fabrics in the Snake Range core complex at least partly (and perhaps mostly) pre-date Miocene slip and exhumation on the brittle NSRD (ca. 20 Ma). The geometric similarities between the ductile fabrics and brittle fault may be a result of brittle reactivation of the older ductile shear zone. Most models of core complex formation view the ductile shear zone as the mid-crustal manifestation of the brittle detachment fault. However, our results call into question that model. The exact timing of this older ductile footwall deformation remains unclear, as does its tectonic significance, although given its similarity to the geometry and kinematics of Miocene slip on the NSRD, these ductile fabrics may document a pre-Miocene extensional event. At the inception of rapid Miocene slip on the NSRD, the eastern flank of the range was 150-200°C hotter than the crest of the range, suggesting the presently low-angle NSRD initiated at a steeper dip rather than initiating at a mechanically unfavorable shallow dip.

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