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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INTRUSIVE AND DEFORMATIONAL HISTORIES OF THE FOOTWALL ROCKS IN THE CENTRAL PART OF THE NORTHERN SNAKE RANGE, NEVADA
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Research Advisor: Phil B. Gans

INTRODUCTION

Metamorphic core complexes are generally accepted as a manifestation of large-magnitude extension. In these complexes, low-angle (detachment) faults juxtapose a ductilely deformed lower plate against a brittley deformed upper plate. The Northern Snake Range (NSR) in east-central Nevada is considered a classic example of a metamorphic core complex (Gans et al. 1999; Miller et al 1983). The Northern Snake Range Decollement (NSRD) has been carefully mapped; however questions to its formation still remain (Fig. 1). Deeply incised canyons in the range provide superb exposures of the footwall quartzites and schist's, permitting detailed study of how footwall fabrics relate to the detachment fault.

Previous studies suggested that there are at least two major unroofing events recorded in the footwall: a late Eocene early-Oligocene event and an early Miocene event (Miller et al. 1988; Lee et al. 1987; Miller et al. 1999). Prior work done by Miller et al. (1983) on the fabrics in the footwall interpreted an early history of coaxial stretching and thinning followed by non-coaxial top-to-the-east simple shear with lesser thinning. Lee (1987) showed that quartzite from Hendry's Creek experienced intense dynamic recrystallization of quartz and that they were well developed L-S tectonites throughout the stratigraphic section. Feldspars were deforming in a brittle fashion and micas were being deformed into mica fish. Quartz petrofabrics indicated non-coaxial simple shear for samples studied from the eastern part of the range while western samples were more indicative of coaxial pure shear (Lee et al. 1987). A later study by Gebelin et al. (2010) on quartzite from Hendry's Creek that showed consistent shear sense throughout the section supported the work done by Lee (1995). Miller et al. (1983) suggest temperatures of deformation in the lower greenschist facies. The temperatures of deformation have also been estimated through microstructures under the assumption that the quartz is wet, which significantly reduces the temperatures needed for deformation (Lister & Hobbs 1980). Gebelin et al (2010) also concluded that a hydrothermal system operated along the detachment and may have added water to the quartzite.

This study combines field observations, microstructure analysis, and electron backscatter diffraction (EBSD) on quartzite to shed light on the type and temperature of deformation undergone throughout the eastern half of the range in the areas of Smith Creek, Horse Canyon, and Deadman Creek (Fig. 1). Intrusive phases were sampled to refine and clarify ages specifically of the Horse Canyon orthogneiss and a late Cretaceous swarm of aplite-pegmatite dikes and sills.

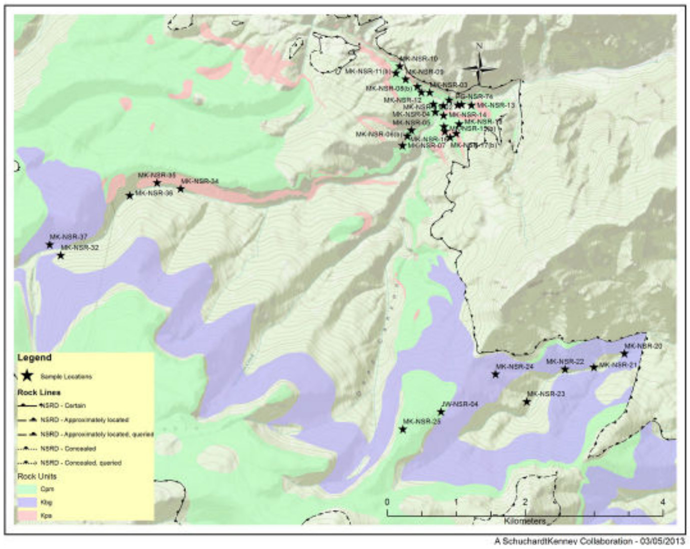

Figure 1. Geologic Map of Field Area with Sample Locations (Lee et al. 1999; Gans et al. 1999)

U-PB GEOCHRONOLOGY OF INTRUSIVE PHASES

Intrusive phases, the Horse Canyon Orthogneiss (Khg) and a swarm of aplite-pegmatite dikes and sills (Kpa), intrude metasedimentary rocks in the footwall in the central part of the NSR. Prior field observations and U-Pb dating by Miller et al. (1988) indicated they were largely late Cretaceous. Samples of various intrusive phases from Smith Creek, Horse Canyon and Deadman Creek were collected for U-Pb zircon dating by laser ablation multi-collector inductibly coupled plasma mass spectrometer (LA-MC-ICPMS).

Four samples of aplite-pegmatite intrusions as well as two samples of an orthogneiss intrusion were collected from Smith Creek, Horse Canyon, and Deadman Creek (Figure 2). Samples were processed using standard mineral separation techniques (milling, sieving, panning, Frantzing, and heavy liquid separation) in order to concentrate zircon grains for analysis. Roughly 80-100 zircon grains of varying size and shape were selected for mounting, with care taken to avoid metamict grains. Analysis was done in the LA-ICPMS at UC Santa Barbara. Measurements were collected for U-Pb ratios 238/206, 235/207, and 207/206 to plot along concordia diagrams and to determine the age of cooling for the zircon grain. Standards were run before and during analysis of unknown samples to enable the correction of data. A proper curve is applied to the standards after the run to observe any variations or errors that might have occurred. From this curve, corrections can be made to the unknowns. Plotted data exclude inherited ages and analyses with elevated common Pb.

Analysis of four leucogranite samples from Smith Creek, Deadman Creek, and Horse Canyon was carried out to obtain more precise ages on these intrusions (Fig. 2). Previous work presented ages for intrusions between 82-78Ma (Miller et al. 1988; Gans et al. 1999). MK-NSR-06 is a fine-medium grain leucogranite intrusion from Smith Creek. U-Pb zircon dating gave an age of 84.6±0.4Ma (n=28, MSWD=0.84). MK-NSR-23 is also a fine-medium grained leucogranite from Horse Canyon. It returned an age of 84.6±0.4Ma (n=28, MSWD=0.84). MK-NSR-12 is a medium grain leucogranite from Smith Creek. A concordant age of 84.9±0.7Ma was obtained (n=25, MSWD=1.4). MK-NSR-32 is a 2-mica leucogranite, which cross-cuts Cpm, Khg, and another aplite. A concordant U-Pb age of 76.1±1.5Ma resulted from analysis of seven zircons. Three samples are nearly identical in age while one sample is distinctly younger, indicated prolonged magmatism.

Two widely separated samples of Khg were collected to obtain more precise emplacement ages on this intrusion and to test whether the entire unit is one age (Fig. 2). Khg is a mylonitized Cretaceous granitic intrusion best exposed in Horse Canyon. MK-NSR-22 was collected near the eastern limit in Horse Canyon and yielded an age of 101.6 ±0.5 Ma (n=25 MSWD of 1.4). MK-NSR-37, the westernmost exposure of the orthogneiss was collected from upper Deadman Creek and gave an age of 100.9±0.5 Ma (n=30 MSWD of 1.4). Previous work showed an age of 100±8 Ma (Gans et al. 1999; Miller et al. 1988). This new data supports and provides more precise ages than the previous work and confirms that the Horse Canyon orthogneiss is a single intrusion.

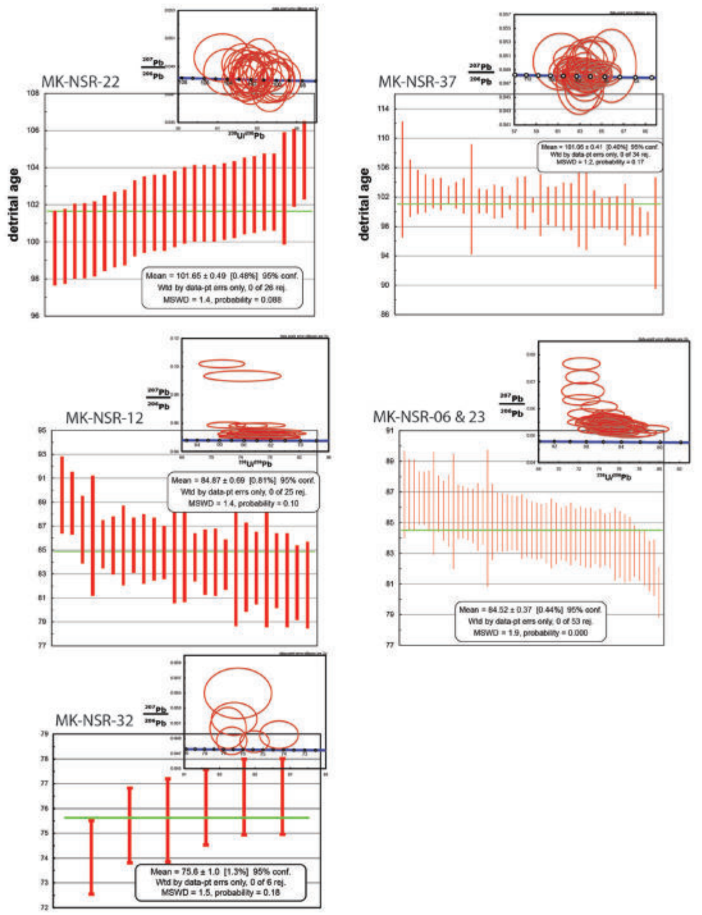

Figure 2. Weighted Mean and Tera Wasserberg graphs of U-Pb data
A. MK-NSR-12: Mean=84.9±0.7 at 95% Conf. MSWD=1.4
B. MK-NSR-22: Mean=101.6±0.5 at 95% Conf. MSWD=1.4
C. MK-NSR-23/06: Mean=84.5±0.4 at 95% Conf. MSWD=0.84
D. MK-NSR-37: Mean=101.0±0.4 at 95% Conf. MSWD=1.2
E. MK-NSR-32: Mean= 75.6±1.0 at 95% Conf. MSWD=1.5

STRUCTURAL STUDIES

Two weeks were spent in the field collecting structural data and samples from the mylonitic quartzites in the footwall in Smith Creek, Horse Canyon, Hampton Creek, and Deadman Creek.

Mylonitic foliations in the study area generally dip gently to the north or east and the poles to foliation are distributed about a NNE trending girdle that suggest folding about a ESE trending fold axis (Fig. 3) In contrast, lineations are very consistently oriented WNW-ESE (Fig. 3).

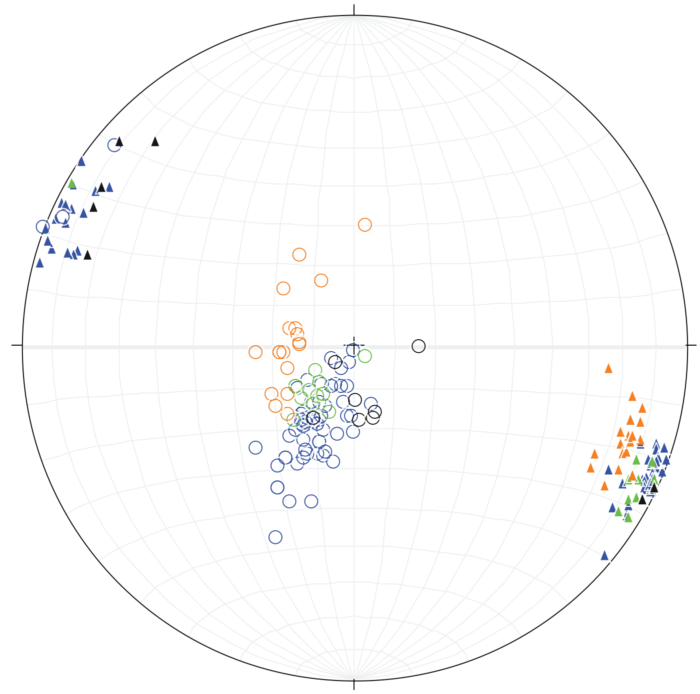

Figure 3. Stereonet of lineation and poles to foliation

MICROSTRUCTURES AND CPOS FOR QUARTZITE

Thirty-four oriented quartzite samples were collected from Smith Creek, Deadman Creek, Horse Canyon, and Hampton Creek. These samples were taken from varying depths in the stratigraphy but the majority comes from the Prospect Mountain Quartzite. Eleven quartzite samples were prepared for analysis on the SEM.

Quartzite microstructures and crystallographic preferred orientations (CPOs) were analyzed to assess the approximate temperatures of deformation and vorticities (Hirth & Tullis 1992; Stipp et al. 2002). Samples MK-NSR-11, 13, 08, 03, 05, and JW-NSR-02 were collected from Smith Creek. They all are typical L-S tectonites with ~5% mica. Quartz grains show undulatory extinction and variable amounts of deformation lamellae. Feldspar crystals are cracked and broken with small amounts of recrystallization (Fig. 4C). Quartz is ductilely deformed into ribbons and recrystallized into subgrains (Fig. 4B, D). Recrystallization and recovery textures in quartz indicate both subgrain rotation and grain boundary migration, which correlates to regime II and III (Hirth & Tullis 1992). X to Z ratios for quartz ribbons are as much as 20:1 while in recrystallized grains they are typically 4:1. Quartz grains often pinch and neck around mica, which limits the maximum recrystallization (Fig. 4D). Asymmetric mica fish in the mylonitized quartzites are abundant and consistently display top-to-east shear. Quartz ribbons and subgrains define an oblique grain shape foliation that makes an acute angle with C planes (Fig. 4B, D). The assumption is made that the fabric is entirely a product of simple shear and the angle between the grainshape foliation and C planes can serve as a proxy for the angle (Θ') between the X-Y plane of the finite strain ellipse and the shear zone boundary. Solving for the relationship (γ=2/ Tan2Θ') allows for an assessment of the overall amount of shear parallel to the shear zone boundary. A Θ' of 20° implies a shear strain of ~2.4 which is a minimum estimate given the oblique grainshape foliation is defined by recrystallized subgrains that formed after some amount of strain had already accumulated. This value multiplied by the structural thickness of the Prospect Mountain Quartzite (~0.5km) implies a minimum amount of top-to-east ductile shear of 1.2km.

Samples MK-NSR-32b, 36, 17, and JW-NSR-03, 06 are from Deadman Creek and Horse Canyon, characterized by a strong foliation and lineation, regime II and III recrystallization, and most show oblique grainshape foliation. Additionally, deformation of micas into mica fish is common. MK-NSR-36, 32b and JW-NSR-06 show a high degree of recovery compared to other samples (Fig. 4A). Similar deformation textures are observed in each sample including: undulatory extinction and less commonly deformation lamellae. Those samples that show a high degree of recovery do not provide oblique grain shape foliations; however those few samples that still retain sub grains and quartz ribbons show similar angles of intersection of ~20°.

EBSD analysis of crystallographic lattice preferred orientation was carried out on eight quartz samples: MK-NSR-03, 05, 08, 13, 32, 36 and JW-NSR-04, 06 (Figure 5). For quartz, the c-axis and a-axis are of most interest because they indicate the active slip systems as well as the sense of shear. For increasing temperature or decreasing strain rate different slip systems are active: basal <a>, rhomb<a>, prism<a>, and prism <c> (Lister & Hobbs 1980). All of the samples analyzed showed strong y-axis maxima,

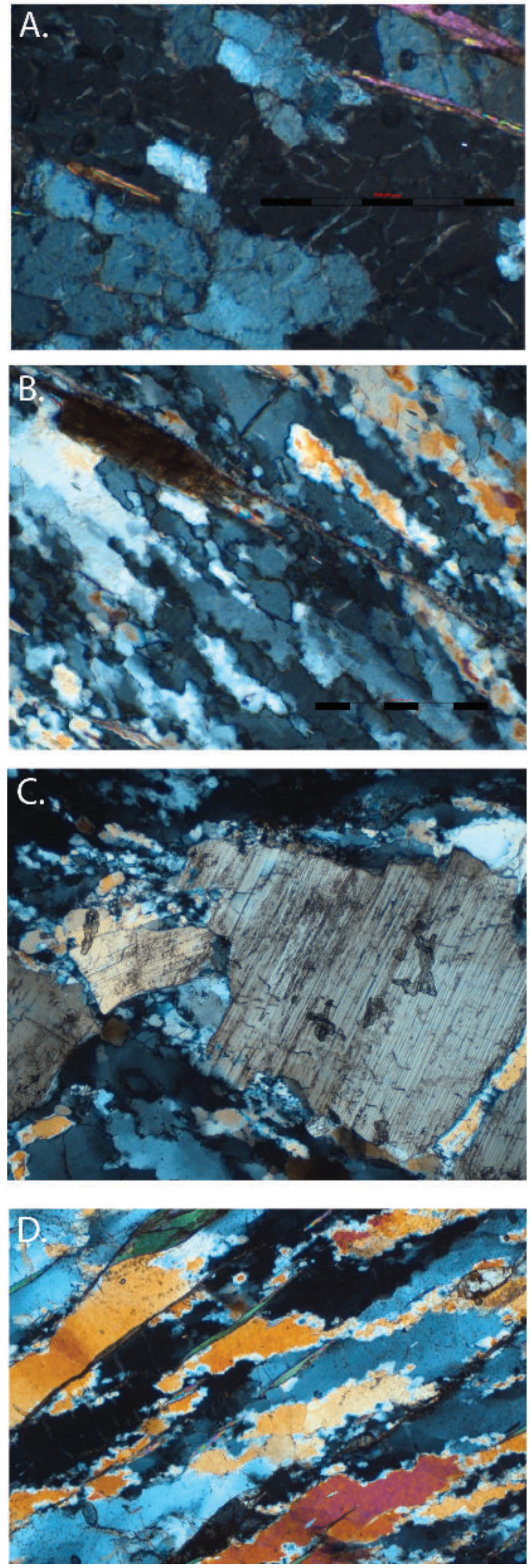

Figure 4. Photomicrographs
A. MK-NSR-36: Extensive Recovery of quartz and triple junctions of quartz beginning to form. B. MK-NSR-05: Subgrain rotation, Oblique grainshape foliation defined by quartz. C. MK-NSR-03: Brittle cracking and dynamic recrystallization of feldspar. D. MK-NSR-08: Subgrain rotation and grain boundary migration. Quartz grain growth impeded by micas

inclined a-axes, and asymmetric single girdles (Fig. 5). The strong y-axis maxima indicates prism<a> slip being the dominant slip system while the single girdles indicate rhomb<a> slip (Fig. 5) (Lister & Hobbs 1980). MK-NSR-05 (Fig. 5H) stands out because it has a high concentration of prism<a> slip with very little rhomb<a> slip and weak asymmetry. All samples, except MK-NSR-05, clearly show top-to-the-east non-coaxial simple shear based on the asymmetric single girdle of c-axis concentrations and inclined a-axis plots parallel to the lineation direction. The types of active slip systems are virtually constant with depth and laterally.

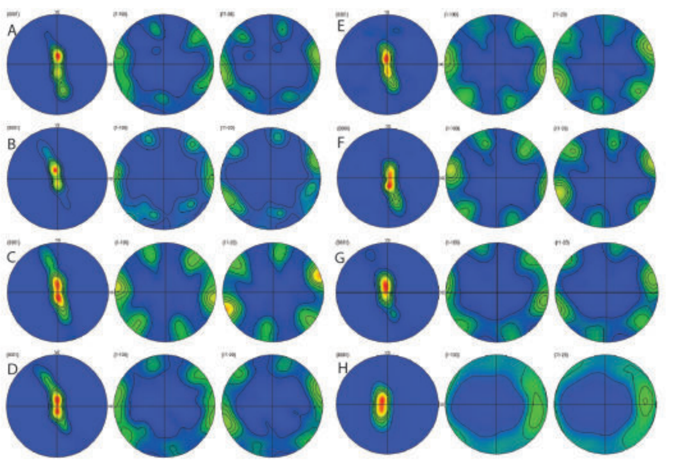

Figure 5. EBSD Pole Figures show C-axis, C-axis in the m-direction, and a-axis diagrams

All samples were placed with the Top down and East to the right. A. MK-NSR-08 B. MK-NSR-13 C. MK-NSR-32 D. MK-NSR-36 E. JW-NSR-04 F. JW-NSR-06 G. MK-NSR-03 H. MK-NSR-05

DISCUSSION

The footwall of the NSRD is comprised of mylonitized quartzites, schists, and various intrusive phases. The intrusive phases of Khg and Kpa were sampled and dated by U-Pb zircon. Two samples of Khg yielded identical ages ~101Ma supporting previous work. Kpa samples showed a range of intrusion from ~85Ma to ~76Ma. This expands upon the range previously suggested of 82Ma-78Ma. Additional dating of leucogranite sills and dikes in the NSR is needed to establish the total age span of leucogranite emplacement and whether it occurred in distinct pulses or continuously throughout the late Cretaceous.

The mylonitized quartzites of the Prospect Mountain Quartzite and McCoy Creek Group in the study are classic L-S tectonites. Recovery textures of GBM and SGR imply deformation in regime II and III (Hirth & Tullis 1990), suggesting temperature constraints of 450-550°C (Stipp et al. 2002). Additionally, EBSD analysis shows that the primary slip system active is prism<a> based on y-axis maxima plots (Fig. 5), which is a relatively high temperature slip system with lesser amounts of rhomb<a> slip (a slightly lower temperature system) active (Lister & Hobbs 1980; Lee et al. 1987). Top-to-the-east simple shear is interpreted from asymmetric single girdle c-axis orientations, mica fish, and oblique grainshape foliation. This further supports that the eastern part of the NSR last recorded simple shear; however the amount of top-to-east shearing estimated accounts for a minimum of 1.2km; pure shear, as seen in western samples, must have played a larger role then to accommodate the roughly 330% extension of Prospect Mountain Quartzite estimated (Miller et al. 1983; 1988; 1999). Overprinting of older pure shear fabrics likely occurred as deformation became progressively non-coaxial.

Cooling ages of the footwall using Ar/Ar of micas indicate that footwall temperatures had already dropped below 300°C by ~20Ma (Miller et al. 1988; Lee et al. 1987; 1995; Gans et al. 2011). Thus quartz had to cease ductile deformation by 20Ma. This is further supported by a new U-Pb zircon age (Monroe et al., this volume) of an undeformed 23Ma rhyolitic dike that cuts the southeastern part of the footwall, which is dated at 23Ma. Given the evidence that the footwall cooled below 300°C by 20Ma and an undeformed 23Ma dike cut lower plate fabrics, the strain recorded in the area of Smith Creek, Horse Canyon, and Deadman Creek must be older than 23Ma and younger than the 76Ma deformed dike swarm. Thus none of the top-to-east shearing can be coeval with the Miocene slip event.

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