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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Research Advisor: Martin Wong

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MICROSTRUCTURAL ANALYSIS OF MYLONITIC MARBLE OF THE NORTHERN SNAKE RANGE

CASEY PORTELA, Colgate University
Research Advisor: Martin Wong

INTRODUCTION

The role of mylonite zones in the Snake Range in Nevada and in metamorphic core complexes in general remains uncertain. The mylonite zone beneath the Northern Snake Range décollement (NSRD) has been interpreted in different ways. Miller, Gans, & Garing (1983) interpreted the NSRD as a brittle-ductile transition, implying that much of the strain in the mylonitic footwall was coaxial and synchronous with faulting. Lee et al. (1987), however, presented evidence for both coaxial and non-coaxial shear in the footwall. Gaudemer and Tapponnier (1987) argued for entirely non-coaxial deformation. Cooper et al. (2010a) examined footwall fabric in Marble Wash, a location in the northern part of the range, and argue for the presence of both west and east-directed shear, indicating that the mylonite zone was a feature in the middle crust that was "captured" and brought to the surface by a moderately dipping fault.

The goal of this study is to examine mylonitic marble from the footwall of the Northern Snake Range in order to determine the kinematics of the footwall shear zone and the temperatures of ductile deformation. Petrographic observations, electron backscatter diffraction (EBSD) analyses, and calcite-dolomite thermometry are employed to better understand the nature and role of mylonitic deformation of the marble in the footwall of the NSRD. Results of this study may help constrain what model of formation best fits the Northern Snake Range and metamorphic core complexes in general.

GEOLOGIC SETTING

The mylonitic marbles of the Northern Snake Range lie directly beneath the NSRD, which generally separates the ductilely deformed footwall from the brittlely deformed hanging wall. This mylonite zone represents a >100m thick highly strained portion of the footwall. It consists of upper Precambrian to lower Cambrian metasedimentary rocks that have been penetratively stretched in a NW-SE direction. The mylonite zone contains a subhorizontal mylonitic foliation and an ESE-trending lineation (Lee, Miller, & Sutter 1987; Miller et al. 1983). The mylonitic fabric is most prominent in the eastern part of the range and decreases in intensity westward and downward away from the NSRD (Miller et al. 1983).

The focus of this study is the mylonitic marble in the structurally highest part of the footwall of the Northern Snake Range. In most areas this is correlated with the Middle Cambrian Pole Canyon Limestone. The NSRD is gently arched across the range and generally follows the top of this marble unit, except in the northern part of the range where the NSRD climbs up section and exposes the Middle Cambrian Raiff Limestone and Upper Cambrian Notch Peak Limestone in the Marble Wash area (Miller et al. 1983; Gans, Miller, & Lee 1999). The accessibility of these units throughout the Northern Snake Range make them ideal for studying variations in the mylonitic fabric.

Previous studies provide some information about the thermal and deformational history of these marble units. They were likely metamorphosed to at least upper greenschist facies conditions in the late

Cretaceous (Miller et al. 1983; Gans, Miller, and Lee 1999; Lee et al. 1999). Evidence of a complex and heterogeneous strain history is found in most areas with features including isoclinal folding and boudinage of more resistant layers (Gans et al. 1999). Limited muscovite argon geothermometry for the marbles yields generally 60-70Ma ages (Lee and Sutter 1991).

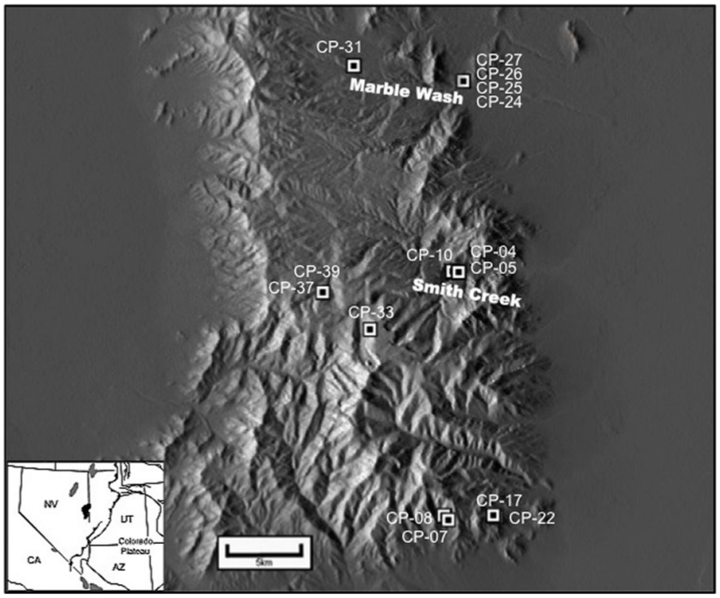

Figure 1. Sample locations (corner map from Cooper et al. 2010).

METHODS

Marble mylonite samples were collected from 7 different locations in the Snake Range (Fig.1). Thin sections were prepared from the 15 samples collected for use in petrographic study, calcite-dolomite thermometry, and electron backscatter diffraction (EBSD) analyses.

The focus of petrographic observation was kinematic indicators, grain sizes and textures. This was done to define type of deformation, sense of shear, relative amounts of strain, and what deformation mechanisms may have been active.

In order to obtain temperatures of the mylonitic deformation, calcite-dolomite thermometry was applied to the eight samples containing dolomite. Analytical work was conducted on the JEOL 8900 Electron Microprobe at Binghamton University. Two dolomite grains were chosen from each thin section and 4 calcite grains adjacent to each dolomite grain was analyzed for Ca, Mg, Fe, and Mn content. Temperatures were calculated using the calcite-dolomite solvus of Anovitz and Essene (1987). Results are presented as averages of multiple points. An uncertainty of ±48°C was found by calculating the standard deviation for all values.

EBSD analyses were carried out 8 samples selected for location and/or grain size or other defining characteristics identified with optical petrography. Analyses were done on the JEOL JSM636OLV scanning electron microscope at Colgate University. The samples were analyzed with EBSD to assess what deformation mechanism and microfabric regime (Schmid, Panozzo, and Bauer 1987) is indicated by the crystallographic preferred orientation in calcite.

RESULTS

The marble mylonite samples display a range of grain sizes and textures. Almost all samples show signs of recrystallization, and one or more samples from each general location shows a "core-mantle" structure, in which large calcite porphyroclasts are surrounded by small, equant grains. Samples from the western-central part of the range are the coarsest grained, and show more signs of annealing, such as 120° grain boundaries (Fig. 2a). Samples from Smith Creek in the eastern-central part of the range are finer grained, and all show the core-mantle structure with porphyroclasts 800-1000 microns in diameter (Fig. 2b). In locations to the north and south of Smith Creek, the fine grains are similar in size to those in Smith Creek but coarsest grains in the samples range from only ~100-600 microns in diameter (Fig. 2c and 2d). The finest grained samples are from the southernmost part of the range. Kinematic indicators, such as mica fish and delta porphyroclasts, were only visible in samples from the southern part of the range. They indicate top-to-the-east sense of shear in two samples, top-to-the-west in one sample, and both senses of shear in another sample.

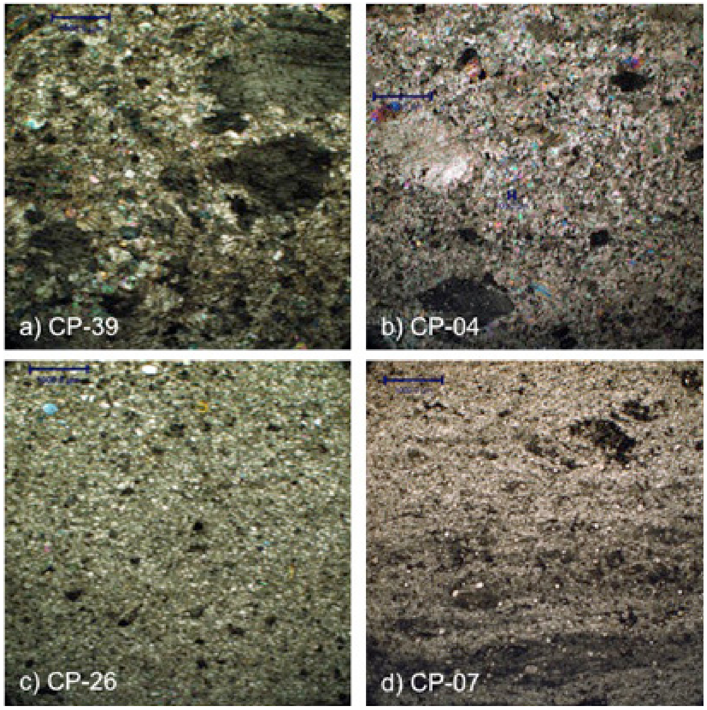

Figure 2. Photomicrographs of samples. Scale bars represent 1000microns. a) Coarse-grained sample from the western-central part of the range. b) Fine grained sample with large porphyroclasts from eastern-central region. c) Fine grained sample from the northernmost location. d) Finest-grained sample from the southernmost part of the range.

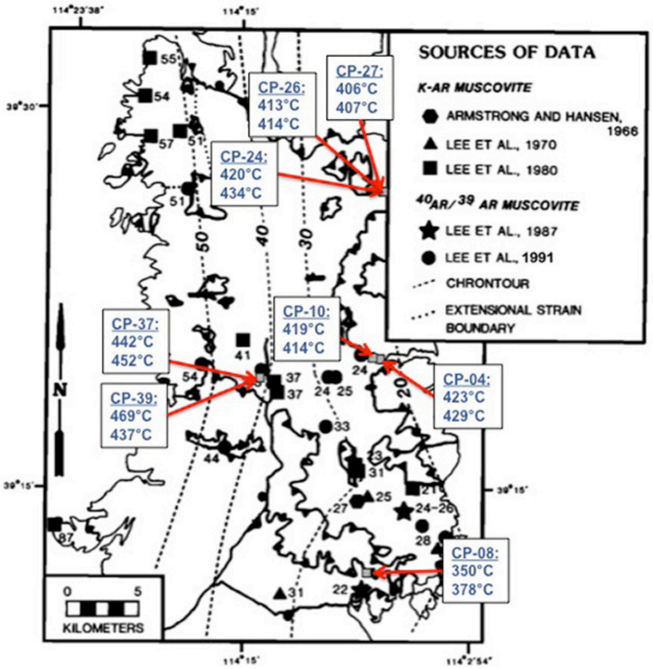

Figure 3. Calcite-Dolomite Thermometry results. Each temperature shown is the average of twenty measurements. The uncertainty for each temperature is ±47°C. Figure is from Lee and Sutter (1991) and shows N-S trending contours based on published K-Ar and $^{40}Ar/^{39}Ar$ muscovite cooling ages. Contours and corresponding muscovite cooling ages show evidence of differential cooling, but ages are from structurally lower units and are likely not directly applicable to the marbles.

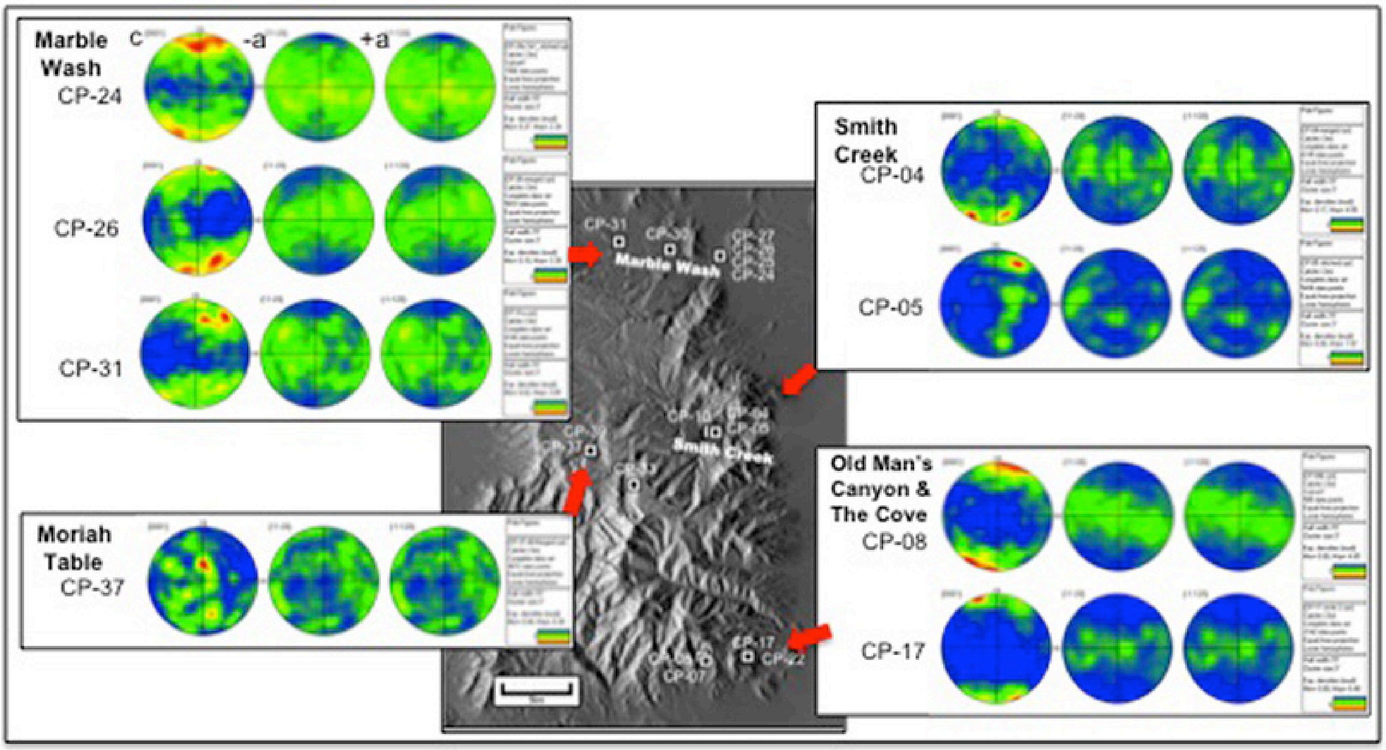

Figure 4. Calcite EBSD data grouped by location. Contoured equal area, lower hemisphere projections. The horizontal axis (x-strain axis) is parallel to the main mylonitic foliation and stretching lineation. The right side of the pole figure is east and the top of the figure represents up.

Calcite-dolomite thermometry yielded temperatures that ranged from 350–469 ± 47°C (Fig. 3). The lowest temperatures were obtained from The Cove area in the southern part of the range, while the highest temperatures were obtained from the Moriah Table area in the central-western side of the range. Temperatures from the central-eastern Smith Creek location and northeastern Marble Wash were all within 14° of 420°C.

EBSD results (Fig. 4) reveal that all samples do show a crystallographic preferred orientation (CPO), with multiple of uniform density (m.u.d.) values greater than 1. This indicates that the fabrics are non-random, and so were deformed by dislocation creep rather than by brittle processes such as cataclasis. With the exception of sample CP-37, all c-axis (0001) pole figures show a maximum parallel or slightly oblique to the z-strain axis, and the two different a-axes (-a [11-20] and +a [-1-120]) show a girdle parallel or nearly parallel to foliation in the samples. The a-axis girdle for most samples is asymmetric and tilted top-to-east while others are more symmetric and one (CP-26) is tilted top-to-west. The CPO present in sample CP-37 differs from the other samples and appears closer to a random fabric.

DISCUSSION

Thermometry results indicate a northward and westward increase in temperature within the marble units, and can be interpreted in one of three ways. The first possibility is that all temperatures have been reset by slow cooling from peak metamorphic conditions. Thermobarometry results for deeper schist units suggest peak metamorphic temperatures reached ~600°C within at least that level of footwall (Lewis et al. 1999; Cooper et al. 2010b). The ~350-450°C temperatures calculated in this study may be much lower as result of retrogressive resetting, which the calcite-dolomite thermometer is prone to (Essene 1982). Some degree of resetting is also likely since the westward increase in temperature across the range is incompatible with existing thermochronology that indicates that the western flank of the range was cooler than the east from at least the middle Eocene (Lee 1995).

However, the possibility still remains that these temperatures do record Cretaceous peak metamorphic conditions. Mineral assemblages suggest metamorphic grade decreases at structurally higher levels of the footwall (P.B. Gans, personal communication, 2013) and suggest lower peak metamorphic temperatures in the marble units (Cooper et al. 2010a). It is then possible that peak metamorphic conditions for the lower schist units do not reflect peak temperatures in the marble, possibly due to extensive thinning of the footwall (Miller et al. 1983) resulting in a collapsed metamorphic gradient and/or simple shear of highest structural levels down to the east juxtaposing the less metamorphosed rock against more intensely metamorphosed lower structural levels. The northward increase in temperature found in this study reflects the northward increase in metamorphic grade observed in the range (Lewis et al. 1999), and may support this argument for the thermometry results of this study recording peak or near-peak metamorphic temperatures in the marbles.

The final, and most likely, interpretation of thermometry data is that the results reflect a combination of mechanisms depending on location. The samples from the western part of the range are coarser grained, show more evidence of annealing, and have a more random CPO while those from the east show more signs of grain size reduction and have stronger CPOs. This may suggest that the samples from the western part of the range were not deformed during Miocene deformation and record peak or near peak metamorphic temperatures, while the finer grained eastern samples may have been reset during Miocene deformation and record the temperatures of that event.

A study by Cooper et al. (2010a) also applied calcite-dolomite thermometry techniques to the Snake Range. They obtained temperatures of 433°± 33°C and 351°C± 20°C and interpreted the different temperatures from the two samples as representing separate top-to-east and top-to-west deformation events. That interpretation may be accurate but that amount of local variation in temperature was not seen in this study. This may indicate that such variation does not exist everywhere in the range and is only applicable to

Marble Wash, or perhaps that the ~350°C temperature found by Cooper et al. (2010a) is anomalous.

From petrographic observations it is clear that most samples show evidence of dynamic recrystallization, which indicates deformation at temperatures above 250°C (Ferril et al. 2004). Subgrain formation at grain boundaries seen in most samples indicates deformation occurred by intracrystalline slip (Schmid et al. 1987)

The EBSD pole figures show that most calcite c-axes are oriented perpendicular to the foliation plane or are at a slightly oblique angle to it. This obliquity is sometimes unreliable as a shear sense indicator (e.g. Bestmann, Kunze, & Matthews 2000), but has been used as a reliable shear sense indicator in carbonates (e.g. Wenk et al. 1987). Two samples that were analyzed with EBSD also contained kinematic indicators. In both the c-axis is rotated opposite the sense of shear. If this trend is consistent then c-axis obliquities indicate top-to-west sense of shear in some samples from all locations on the eastern side of the range, and top-to-east sense of shear as well in the southernmost and northernmost parts of the range. There does not appear to be any strong link between sense of shear indicated by EBSD and temperatures obtained with calcite-dolomite thermometry. The variation in sense of shear may be due to the heterogeneous flow of highly ductile marble in these folded and boudinaged units.

CONCLUSION

Results of this study indicate that the ~350-450°C temperatures obtained with calcite-dolomite thermometry may be either completely reset, record peak or near-peak metamorphic temperatures, or may reflect one or both depending on location. Petrographic observations and EBSD results indicate that the third possibility, that of variation depending on location, may be most likely, with temperatures from the west side of the range recording peak or near peak metamorphic conditions and temperatures from the east recording temperatures completely or partially reset during Miocene deformation. The lack of strong variation in temperature within any one location calls into question the interpretation of Cooper et al. (2010a) that two distinct deformation events recorded in the marbles suggest the initial formation of the mylonite zone is unrelated to the NSRD. Kinematic Indicators and EBSD results indicate both top-to-west and top-to-east sense of shear throughout the eastern side of the range. This indication of widespread simple shear deformation eliminates interpretations like that by Miller et al. (1983) that interpret the shear zone as a ductile-brittle zone with pure shear deformation only. This study does not eliminate the possibility of some pure shear deformation in addition to simple in the Snake Range. The variation in sense of shear seen in this study does not show a strong trend associated with location or temperatures obtained with calcite-dolomite thermometry and may be due to heterogeneous flow of highly ductile marble.

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