Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
29th Annual Symposium Volume
23rd April, 2016
ISBN: 1528-7491

IMPLICATIONS OF QUARTZ CRYSTALLOGRAPHIC PREFERRED ORIENTATIONS IN GRANITIC ORTHOGNEISS AND QUARTZITE IN THE CORE OF THE EAST HUMBOLDT RANGE METAMORPHIC CORE COMPLEX

GABRIEL CHEVALIER, Mount Holyoke College
Research Advisor: Michelle Markley

INTRODUCTION

The Ruby Mountains - East Humboldt Range (RM-EHR) metamorphic core complex in Northeastern Nevada exposes deep crustal levels associated with Tertiary extension in the modern Basin and Range tectonic regime. At least 700 m of exposures beneath the mylonitic shear zone offer a unique opportunity to study changes in fabrics, structures and deformation with depth. This study focuses on one spectacular locality, Angel Lake Cirque, that exposes a significant transition from intensely deformed mylonites at shallower structural levels to a higher temperature but more diffuse deformational regime below (Fig. 1). By applying electron backscatter diffraction analysis (EBSD) to determine bulk quartz crystallographic preferred orientations (CPOs) in quartzites and granitic orthogneisses, this study sheds light on fundamental transitions with increasing depth and temperature in deformation mechanisms, kinematics and structural style. In doing so, it relates middle crustal extension and deformation accommodated in the mylonitic shear zone to an underlying regime of deep crustal flow.

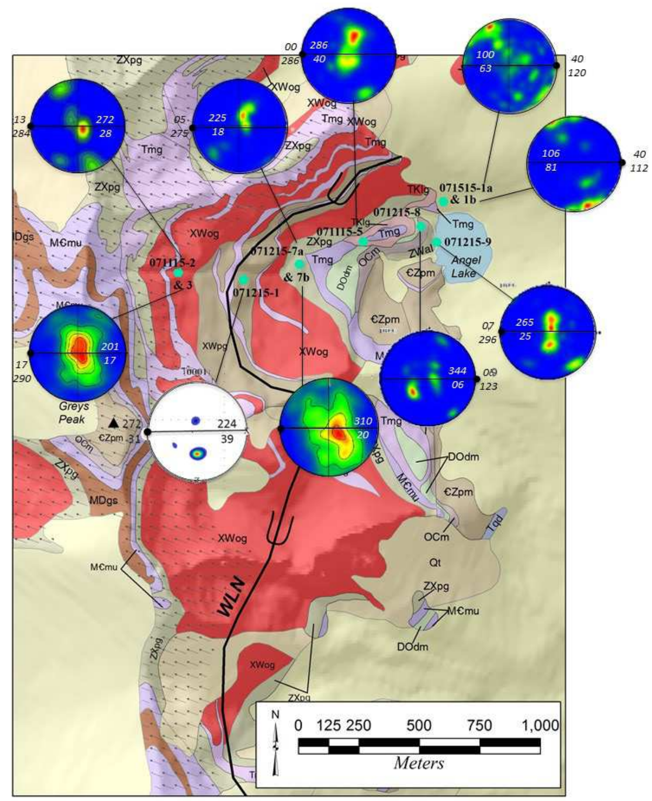

Figure 1. Composite c-axis plots for all samples in the Angel Lake transect in the RM-EHR. The samples are organized by location and overlay a geologic map of the region provided by McGrew and Snoke (2015).

GEOLOGIC SETTING

Located near the northern end of the EHR, the area surrounding Angel Lake cirque hosts the oldest rocks in Nevada, the Neoarchean to Paleoproterezoic gneiss complex of Angel Lake (Fig. 1) (McGrew and Snoke, 2015). This complex was thrust over a sequence of Neoproterozoic to Mississippian metasedimentary rocks before being folded into the core of the dominant structure near the northern end of the core complex. This structure, the Winchell Lake fold-nappe (WLN), is a southward-closing recumbent isoclinal fold with a 7 km lower limb. Syntectonic with emplacement of the WLN, this sequence was also subjected to migmatitic upper amphibolite facies metamorphism, recording pressures and temperatures up to >750ºC, 10 kb before experiencing continued high temperature metamorphism during a broadly decompressional unroofing path through much of the Cenozoic (McGrew et al., 2000; Hallett and Spear, 2014, 2015). The WLN is overprinted by a thick late Cenozoic high amphibolite facies, normal sense mylontic zone-- the RM-EHR shear zone. In addition to the map-scale WLN, the lower part of Angel Lake cirque exposes a cryptic, ~100 m-scale isoclinal fold of undetermined age to the west of Angel Lake that will be referred to here as the Angel Lake fold. The broader focus of the work below is to characterize deformational transitions from the deeper parts of the RM-EHR shear zone into the gneiss complex below.

QUARTZ CRYSTALLOGRAPHIC PREFERRED ORIENTATIONS (CPO'S)

Quartz is a high symmetry mineral with a large number of possible slip systems. The conditions in the crust under which quartz is deformed span the range of conditions under which the preferred slip systems vary (Nicholas and Poirier, 1976). As deformation occurs, a pattern of CPO's develops for a particular material based on the slip systems that are active in that mineral and on the geometry and the magnitude of the applied deformation (Nicholas and Poirier, 1976). The most commonly recognized slip systems of quartz are basal <a>, rhomb <a> and prism <a> (Fossen, 2010). In experimental conditions low temperature and high strain rates are the most common and activate slip along the basal plane parallel to an a-axis whereas progressively higher temperature and lower strain rates activate slip along rhomb planes parallel to the a-axes and/or the prism plane (m) parallel to an a-axis or, at the highest temperatures, parallel to the c-axis (Law, 2014). With increasing strain CPOs tend to increase in strength. Thus, quartz CPOs provide sensitive gauges of both the geometry and the intensity of strain (Law, 2014).

METHODS

Field Methods:

In the field, a suite of samples were collected between Angel Lake and Grays Peak in the northern EHR spanning a range of structural levels and a variety of rock types, including leucogranite (3), monzogranite (3), quartzite (8) and a quartz vein (1) (Table 1) (Fig. 1). Samples define an evenly spaced transect with depth beneath the RM-EHR mylonitic shear zone. In addition, at the deepest structural levels, a series of quartzite samples was collected at various points around the hypothesized Angel Lake. Cross-cutting relationships between quartzites and Oligocene monzogranitic orthogneisses were carefully documented in order to compare and contrast fabrics and quartz CPOs between them in hopes of confirming the age of deformation as being late Oligocene to early Miocene.

Laboratory and Analytical Methods:

Initial thin section analysis using an optical microscope revealed microstructures indicating shear sense and rheology; in particular, care was taken to identify deformation mechanisms in feldspar and recrystalization mechanisms in quartz. Samples were then processed using EBSD analysis to gather the bulk quartz CPOs and texture maps. EBSD is an SEM-based microstructural and crystallographic characterization technique used to understand and categorize the structure, crystal orientation and mineral phase of materials.

RESULTS AND DISCUSSION

In general the samples collected at Angel Lake Cirque produce quartz c-axis concentrations in the center of the stereonet, lying in the foliation plane perpendicular to lineation. The samples gathered at this locality are mostly high temperature rocks whose deformation was accommodated on multiple slip systems. The same CPOs that are recorded in the Oligocene granitic rocks are also seen in nearby quartzites, demonstrating that the CPOs developed after approximately 30 Ma. This confirms that the textures being described at depth are part of the Cenezoic deformational regime expressed shallower structural levels by the mylonitic zone. Given the fabrics recorded within these samples, the high temperature deformation mechanisms must have been achieved after 30 million years ago. Conversely, the cooling of these rocks through 40Ar/39Ar biotite closure temperatures (nominally ~300ºC) occurred by about 22 Ma, thus providing an approximately 8 m.y. bracket on the age of high temperature strain

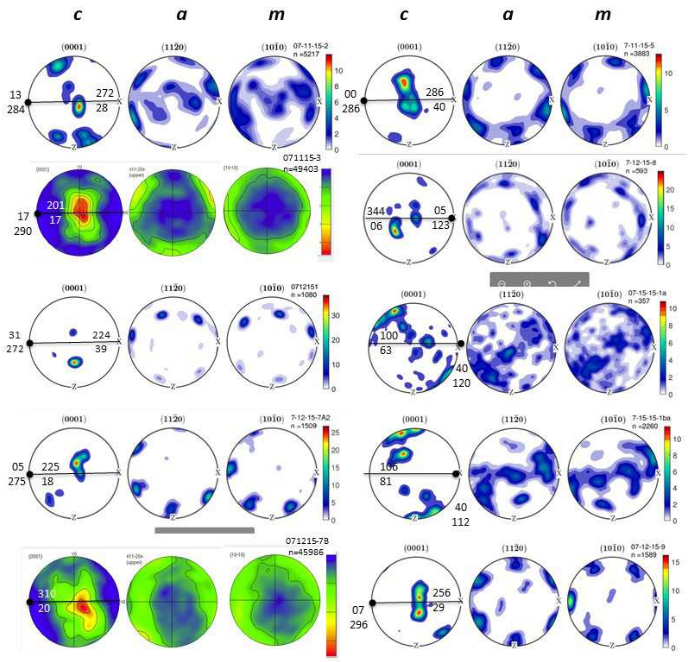

Figure 2. Composite c-axis, a-axis and m-plane plots for all samples of the Angel Lake transect in the RM-EHR. The samples are organized by elevation with the highest one (07-11-15-2) at the top and the lowest (07-12-15-9) at the base.

(McGrew and Snee, 1994). Additional constraints on the peak temperatures during deformation are provided by the observation that levels below ~9300 ft did not cool through 40Ar/39Ar hornblende closure temperatures (nominally ~490º - 580ºC) until the early Oligocene. Additionally, Dilles (this volume) reports U-Pb ages for growth of metamorphic zircon rims as young as Oligocene.

With one exception (Sample 071215-7A), the c-axis patterns show WNW sense of shear (Table 1; Fig. 1). In addition, most samples, excluding the two that were gathered from the nose of the outcrop scale fold in this region (071515-1A and 1B), have a strong central Y-axis maximum. However, many of the samples also show less pronounced but still measurable maxima that generally display along the edges of the c-axis pole figure. The following results are based on the composite pole figures illustrated in Figues 1 and 2. Each sample is discussed below, proceeding from shallower to deeper structural level.

ate	#	UTM Zone	Easting	Northing	Elev (m)	Elev (ft)	Rock_Type	Foliation	Lineation	Field context
7/11/15	2	11	659657	4543355	2941	9648	Quartzite	272, 28	313, 23	
7/11/15	3	11	659657	4543355	2941	9648	Monzogranite	201, 17	290, 17	
7/12/15	1	11	659926	4543326	2822	9257	Quartz Vein	224, 39	021, 016	
7/12/15	3(7a)	11	660157	4543390	2712	8897	Quartzite	225, 18	275, 05	Quartzite (#7a folded monzog
7/12/15	3(7b)	11	660157	4543390	2712	8897	Monzogranite	310, 20		Isoclinally fold monzogranite, bedrock surfac grainshape fol
7/11/15	5	11	660421	4543483	2661	8730	Quartzite	286, 40	286, 00	
7/12/15	8	11	660660	4543545	2590	8497	Quatzite	344,06	123, 05	Upper Limb (a
7/15/15	1a	11	660752	4543648	2560	8400	Quartzite	100, 63	120, 40	Hinge (Angel L
7/15/15	1b	11	660752	4543648	2560	8400	Quartzite	106, 81	112, 40	Hinge (Angel L
7/12/15	9	11	660725	4543480	2530	8300	Quartzite	265, 29	296, 07	Lower Limb (A

Table 1. Sample table showing date, number, elevation, rock type, foliation, lineation, field context and location of each sample.

At an elevation of 9648 ft (2940 m) sample 071115-2 comes from an enclave of quartzitic gneiss on the upper limb of the WLN and is characteristic of the mylonitic zone. The c-axis pattern for this sample displays a strong Y-axis maximum but less pronounced maxima define a nearly straight girdle from the lower right to the upper left consistent with WNW-directed shear. A still weaker maximum in the lower left defines a relatively small opening angle of approximately 45º about Z, indicating temperatures of deformation in the range 350º± 50ºC according to the opening angle thermometer of Kruhl (1998). However, the strong Y-axis maximum is commonly associated with higher temperature, prism <a> slip, which is normally associated with amphibolite facies deformation. Sample 071115-3 is a monzogranitic orthogneiss collected at the same locality as 071115-2 (Table 1). The c-axis pattern shows a strong Y-axis maxima and the data are relatively symmetrical, with a slight sense of sinistral shear, supporting the WNW shear sense demonstrated in the adjacent quartzite (Fig. 1:Fig. 2). Although the CPO for the granitic rock is generally weaker, it resembles the quartzite in overall pattern and probably represents dominant prism <a> slip.

Sample 071215-1 is a deformed quartz vein found in intricately interfolded and transposed Neoarchean to Paleoproterozoic orthogneiss and paragneiss in the core of the WLN near the base of the Late Cenozoic mylonitic zone. The pole figures for sample 071215 -1 show a double maximum fabric with the dominant c-axis maxima aligned NS and relatively symmetrically disposed about the Y strain axis (Fig. 2). Though not displayed in Figure 2, the pole figure for the positive rhombs (r-planes) displays a positive rhomb strongly aligned with foliation; combined with the observation that the strongest <a> maximum parallels lineation, this configuration strongly suggests the dominance of rhomb <a> slip.

The c-axis pattern for quartzite sample 071215-7A displays a strong central Y-maximum with a smudging of data points around it and a second, less pronounced peripheral maximum on the lower left (Fig. 1). These data define an asymmetrical pattern suggesting a contribution of dextral (ESE-directed) shear with a large half-opening angle of approximately 45º relative to Z that suggests very high temperature deformation. Multiple maxima indicate an activation of both basal <a> slip and prism <a> slip. The relative symmetry of the peripheral maxima suggests a close approximation to pure shear. 071215-7B is a monzogranite sample gathered from the same locality as sample 071215-7A showing a strong c-axis maxima in the lower left which supports prism <a> slip. The strong a-axis maximum on the lower left indicates the shear direction (Fig. 2).

Sample 071115-5 originates from a Neoproterozoic paragneiss at the premetamorphic tectonic contact between the gneiss complex of Angel Lake and the upper part of the Paleozoic marble sequence; thus the Cenozoic deformation may overprint an intense older phase of mylonitization dating from Mesozoic thrust emplacement. The contoured c-axis data of quartzite sample 071115-5 show a Z-shaped skeletal outline suggesting dextral (ESE-directed) shear sense (Fig. 1). There is a strong central maximum for the c-axis data suggesting prism <a> slip, but the strongest maximum is located on the upper left portion of the net and can be associated with rhomb <a> slip. A third maximum, located on the lower left of the net is less pronounced than the first two and based on the relatively large opening angle relative to Z, may balance basal <a> against antithetic prism <c> slip.

Quartzite sample 071215-8 originates from Ordovician Eureka orthoquartzite in the core of the inferred Angel Lake fold. It produced strong C-axis maxima on the left and right sides of the Y-strain axis that define small circle girdles with a large opening angle of ~75° characteristic of constrictional strain (Schmidt and Casey, 1986). On the net representing the a-axes there is a strong maxima on the lower right edge suggesting a strong common shear direction because this <a> axis is shared for the slip systems (Fig. 2). The constrictional component in this strain path suggests constriction in the core of the Angel Lake fold, an interpretation that would imply a Cenozoic age for the fold since the CPO is inferred to be Cenozoic.

Quartzite samples 071515-1A and 071515-1B contrast with the other samples in that both originated from steeply inclined foliation forming the outer arc of the Angel Lake fold. They were cut parallel to the 40º ESE-plunging lineation and perpendicular to foliation, and thus in geographic coordinates the plane of section is gently dipping, nearly orthogonal to the other sections. In this orientation, both place the greatest c-axis maxima on the outer periphery of the pole figure instead of in the center, creating a single girdle c-axis skeleton (Fig. 1). In the reference frame of foliation and lineation these CPO's are consistent and can be interpreted as suggesting basal slip with a WNW-directed shear sense priot to folding. However, due to the complexities of the frame of reference, at present the interpretation of the data remains uncertain.

Quartzite sample 071215-9 originates from the deepest structural level in the cirque and shows a relatively symmetrical cross-girdle skeleton with an ~85º opening angle about the Z strain axis (Fig. 1). The greater intensity of the maximum in the lower right of the c-axis pole figure suggests a component of sinistral (W-directed) shear, but in other respects the relatively high symmetry of the skeletal outline and the balanced distribution of <a> axes suggests a closer approximation to pure shear than observed in most other CPOs. The maxima in the lower right and in the lower left define the nearly symmetrical crossed girdle skeletal outline with an opening angle of nearly 90° suggesting temperatures in the range of 600º - 700ºC. A decreasing non-coaxial contribution to the overall strain path seems to characterize deeper structural levels, representing a fundamental transition away from simple shear toward a more nearly pure shear strain regime at depth.

CONCLUSIONS

The samples collected at Angel Lake cirque in the East Humboldt Range document the transition from the mylonitic zone to the core of the complex. With depth beneath the mylonitic zone there is a measured increase in the temperature of deformation mechanisms and a generally decreasing asymmetry in CPOs (compare with Plummer, this volume). Taken together, these observations suggest that Cenozoic extensional mylonitization was superimposed on a weak deeper crust undergoing more nearly coaxial homogeneous stretching. The agreement between the CPOs of the quartzites and the late Oligocene monzogranitic orthogneiss confirms the late Oligocene to earliest Miocene timing of the extensional deformation.

ACKNOWLEDGMENTS

I would like to thank the KECK Consortium, Dr. Allen McGrew, University of Dayton, and Jeffery Rahl, Washington and Lee University for the opportunity to conduct research and for their guidance through the process. I would like to thank Peter Crowley at Amherst College for the use of his EBSD instruments and Michelle Markely at Mount Holyoke College for her guidance and support.

REFERENCES

Fossen, Haakon. Structural Geology. Cambridge: Cambridge UP, 2010. Print.

Hallett, B.W., and Spear, F.S. (2014) The P-T history of anatectic pelites of the northern East Humboldt Range, Nevada: Evidence for tectonic loading and anatexis. Journal of Petrology, 55, 3-36.

Law, R. D. (2014). Deformation thermometry based on quartz c-axis fabrics and recrystallization microstructures: A review. Journal of Structural Geology, 66, 129-161.

McGrew, A., Peters, M. and Wright, J. (2000) Thermobarometric constraints on the tectonothermal evolution of the East Humboldt Range metamorphic core complex, Nevada. Geological Society of America Bulletin. 112, no.1;45-60

McGrew,A. J., and Snee, L. W., (1994) 40Ar/39Ar thermochronologic constraints on the tectonothermal evolution of the northern East Humboldt Range metamorphic core complex, Nevada: Tectonophysics v. 238, p. 425–450.

McGrew, A., and Snoke, A., (2015) Geologic map of the Welcome quadrangle and an adjacent part of the Wells quadrangle, Elko County, Nevada. Map 184.

Nicholas, A. and J.P. Porier (1976). Crystalline plasticity and solid state flow in metamorphic rocks. New York: Wiley.

Schmid, S. M., & Casey, M. (1986). Complete fabric analysis of some commonly observed quartz c-axis patterns. Geophysical Monograph, 36, 263-286.

Snoke, A. W. (1980). Transition from infrastructure to suprastructure in the northern ruby mountains, nevada. Memoir - Geological Society of America, (153; 153), 287-333.