2011

Dynamothermal metamorphism of the Chiwaukum Schist in the Steven's Pass Area, Cascade Mountains, Washington

Jennifer A. Davis
Eastern Michigan University

Recommended Citation

Davis, Jennifer A., "Dynamothermal metamorphism of the Chiwaukum Schist in the Steven's Pass Area, Cascade Mountains, Washington" (2011). *Senior Honors Theses & Projects*. 271.
https://commons.emich.edu/honors/271

Dynamothermal metamorphism of the Chiwaukum Schist in the Steven's Pass Area, Cascade Mountains, Washington

Abstract

The Chiwaukum Schist in the Steven's Pass region of the North Cascade Mountains, Washington is a metamorphic rock suite of pelitic protolith bordering the Mount Steward Batholith. This clay-right parent material experienced contact metamorphism during the intrusion of the Mount Steward batholith, followed by Buchan style, dynamothermal metamorphism. The minerals produced by these early metamorphic events were later overprinted by minerals of Barrovian style, dynamothermal metamorphism. The index minerals of the contact and Buchan facies metamorphism extend into the andalusite zone, while the Barrovian facies is characterized by aluminosilicate polymorph minerals reaching the sillimanite zone. Calculation of mineral abundances and assemblages in thin section allow for the construction of a detailed petrographic analysis of the area

Degree Type

Open Access Senior Honors Thesis

Department

Geography and Geology

First Advisor

Michael D. Bradley

DYNAMOTHERMAL METAMORPHISM OF THE CHIWAUKUM SCHIST IN THE STEVEN'S PASS AREA, CASCADE MOUNTAINS, WASHINGTON

By

Jennifer A. Davis

A Senior Thesis Submitted to the

Eastern Michigan University

Honors College

in Partial Fulfillment of the Requirements for Graduation

with Honors in Professional Geology (Geography and Geology Department)

Approved at Ypsilanti, Michigan, on this date April 11, 2011

Supervising Instructor (Print Name and have signed)

Honors Advisor (Print Name and have signed)

Department Head (Print Name and have signed)

Honors Director (Print Name and have signed)

TABLE OF CONTENTS

1. Abstract……………………………………………………………………pg.4
2. Introduction…………………………………………………………………...pg.4
3. Method of Investigation………………………………………………………pg.7
4. Mount Stewart Batholith………………………..………..…………..pg.10
5. Chiwaukum Schist……………………………………………………..…pg.11
6. Conclusions…………………………………………………..……………pg.19
7. References……..……………………………………………………………pg.20

LIST OF FIGURES

Figure 1- Pressure-Temperature stability diagram for the three polymorphs:

andalusite, kyanite, and sillimanite……………………………………………..…pg.6

Figure 2- Map showing area of study……………...……………………………………pg.7

Figure 3- Detailed Sample Locality Map………………………………………………..…pg.8

Figure 4- Photograph of sample 10JDSP 5 hand specimen………………...…...……pg.10

Figure 5- Photomicrograph of sample 10JDSP5, XPL, 10X……………….………pg.11

Figure 6- Photograph of sample 10JDSP1 hand specimen……………………..………pg.12

Figure 7- Photomicrograph of sample 10JDSP1, PPL, 10X…………………………....pg.13

Figure 8- Photomicrograph of sample 10JDSP2, PPL, 10X………………………...……..pg.14

Figure 9- Photomicrograph of sample 10JDSP2, XPL, 10X….………………...…...pg.15

Figure 10- Photomicrograph of sample 10JDSP3, PPL, 10X………….…......……..pg.16

Figure 11- Photomicrograph of sample 10JDSP4, PPL, 10X….…………...…....…..pg.18

Figure 12- Photomicrograph of sample 10JDSP4, XPL, 10X…………..…………...pg.18

ABSTRACT

The Chiwaukum Schist in the Steven's Pass region of the North Cascade Mountains, Washington is a metamorphic rock suite of pelitic protolith bordering the Mount Stewart Batholith. This clay-rich parent material experienced contact metamorphism during the intrusion of the Mount Stewart batholith, followed by Buchan style, dynamothermal metamorphism. The minerals produced by these early metamorphic events were later overprinted by minerals of Barrovian style, dynamothermal metamorphism. The index minerals of the contact and Buchan facies metamorphism extend into the andalusite zone, while the Barrovian facies is characterized by aluminosilicate polymorph minerals reaching the sillimanite zone. Calculation of mineral abundances and assemblages in thin section allow for the construction of a detailed petrographic analysis of the area.

INTRODUCTION

The Steven's Pass area of Washington State lies along the border of King County and Chelan County at an elevation of roughly 4,056 feet in the northern region of the Cascade Mountain range. The rough and rugged topography shaped by Holocene glaciation provides favorable landscapes to winter sportsmen, and therefore this location is primarily known for its local ski resort. The Steven's Pass area lies on the eastern lobe of the Mount Stuart batholith, an igneous rock unit much more resistant to weathering than the adjacent Chiwaukum Schist formation. The interplay of highly competent igneous rock and less competent metamorphic rock, weathered by glacial erosion, is the underlying determinant factor in the rugged topography of the area.

The Mount Stewart batholith is a plutonic granodiorite intrusion divided into eastern and western lobes. The eastern lobe was emplaced around 95 Ma, at depths less than about 12km; whereas K-Ar dating places the emplacement of the western lobe at 82-88 Ma (Evans and Berti 1986). Regional deformation took place soon after the intrusion activity of the Mount Stewart batholiths, at which time the clay rich rocks surrounding the igneous plutons were metamorphosed into schists and gneisses.

A pelitic metasedimentary rock, the Chiwaukum Schist, has undergone multiple metamorphic events. Isotope age dating done by Magloughlin (1986), places the Chiwaukum Schist at roughly 210 Ma (±44). However, this age should be considered approximate due to isotopic disruptions potentially caused by the repeated metamorphism on the protolith. Contact metamorphism brought on by the intrusion of the Mount Stewart batholith, followed by Buchan style regional metamorphism, and at least one occurrence of Barrovian style regional metamorphism have all left their own fingerprint on the Chiwaukum Schist.

Barrovian style metamorphism is the most common type of dynamothermal regional metamorphism (Neuendorf, Mehl, and Jackson 2005). Two types of dynamothermal regional metamorphism exist, Buchan style and Barrovian style. Both Buchan and Barrovian metamorphism produce zones of progressively increasing metamorphic grade, identified by the first appearance of an index mineral associated with that zone. However, Barrovian type is characterized by the occurrence of metamorphic zones of the greenschist and amphibolite facies; Buchan type forms at lower pressures than Barrovian, and has a slightly different suite of index minerals. Typical index minerals of a Barrovian sequence, in order of increasing metamorphic grade, are chlorite

– biotite – garnet (almandine) – staurolite – kyanite – sillimanite; but not andalusite (Nuendorf, Mehl, and Jackson 2005). Likewise, index minerals of a Buchan sequence typically encompass the minerals chlorite – biotite – cordierite – andalusite – sillimanite. Andalusite, kyanite, and sillimanite are Al_2SiO_5 polymorphs of each other. The determinant factor as to which form will occur is pressure dependent. The stability field of andalusite takes place at pressures below 0.37 GPa. Subsequently, kyanite can only alter to sillimanite at the sillimanite isograd, above said pressure (Winter 2001).

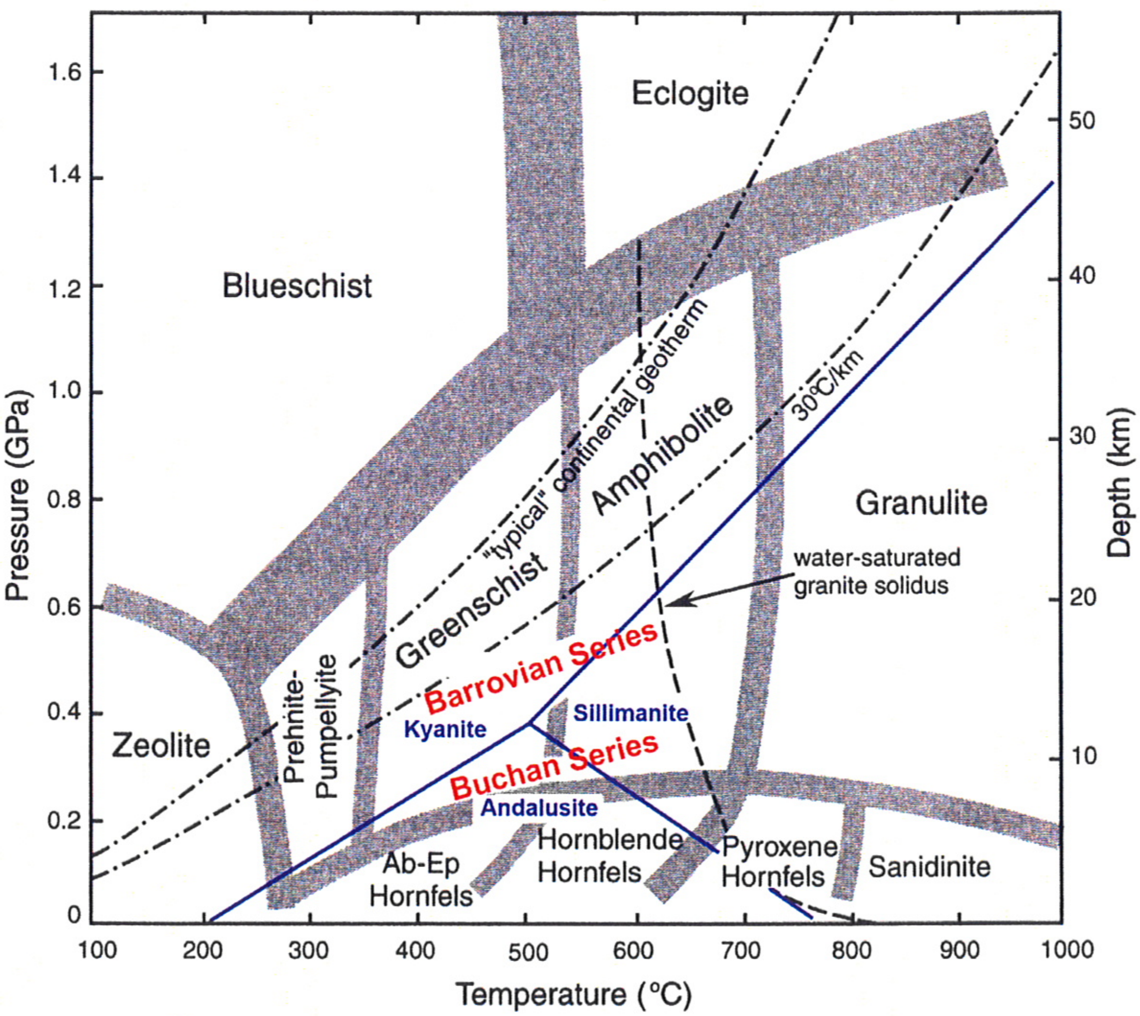

Figure 1: Pressure - Temperature phase diagram showing the P – T range of the Barrovian and Buchan series and the stability fields of the Al_2SiO_5 system for the three polymorphs: andalusite, kyanite, and sillimanite. Modified from Winter (2001).

Duggan and Brown (1994), associate the presence of relict and psuedomorphed andalusite around the perimeters of the pluton as proof of an early episode of contact metamorphism. The samples analyzed in this research reveal aluminosilicate polymorphs extending into the form of sillimanite. Results of this research concur with studies done by Evans and Berti (1986), and Duggan and Brown (1994), that the growth of Barrovian index minerals such as garnet, kyanite, staurolite, and sillimanite postdate a contact metamorphic event.

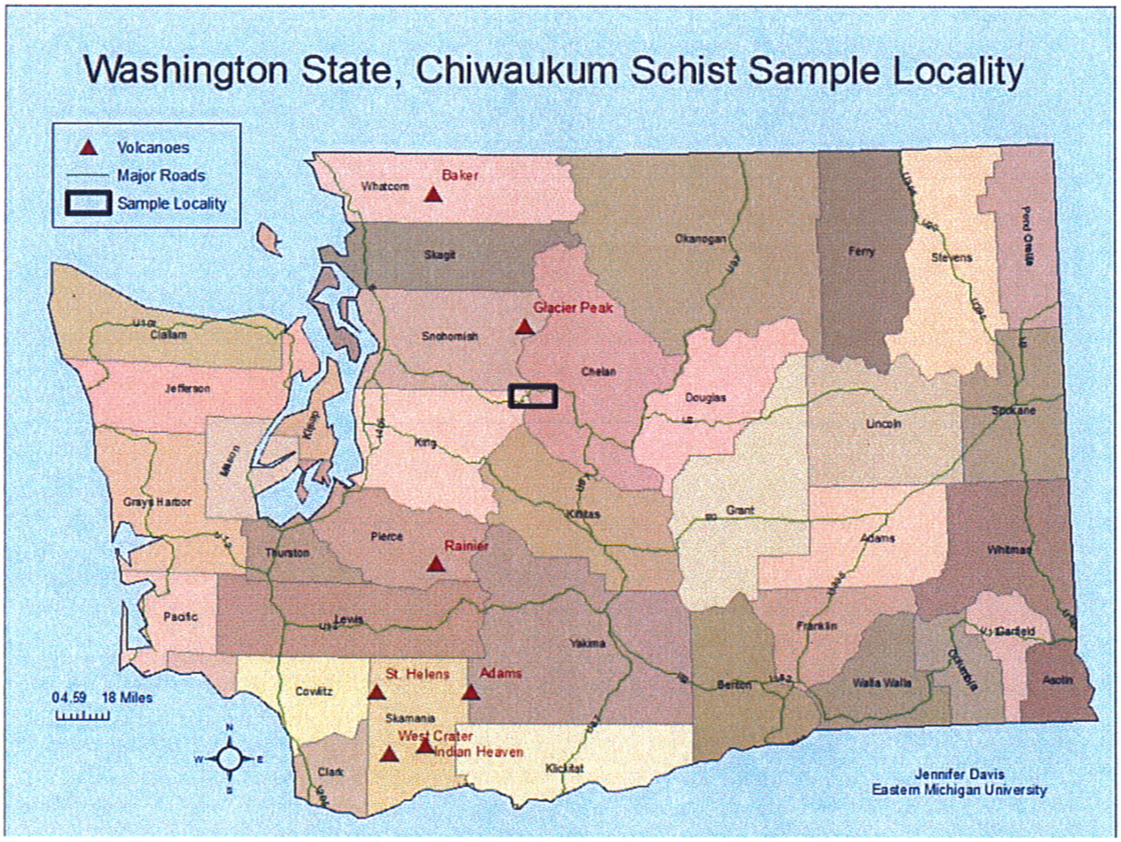

Figure 2: Map showing the area of this study.

METHOD OF INVESTIGATION

Five samples were collected from the Steven's Pass region for this research. Four reflect varying isograds of the Barrovian sequence affecting the Chiwaukum Schist, while the fifth represents the granodiorite of the Mount Stewart batholith.

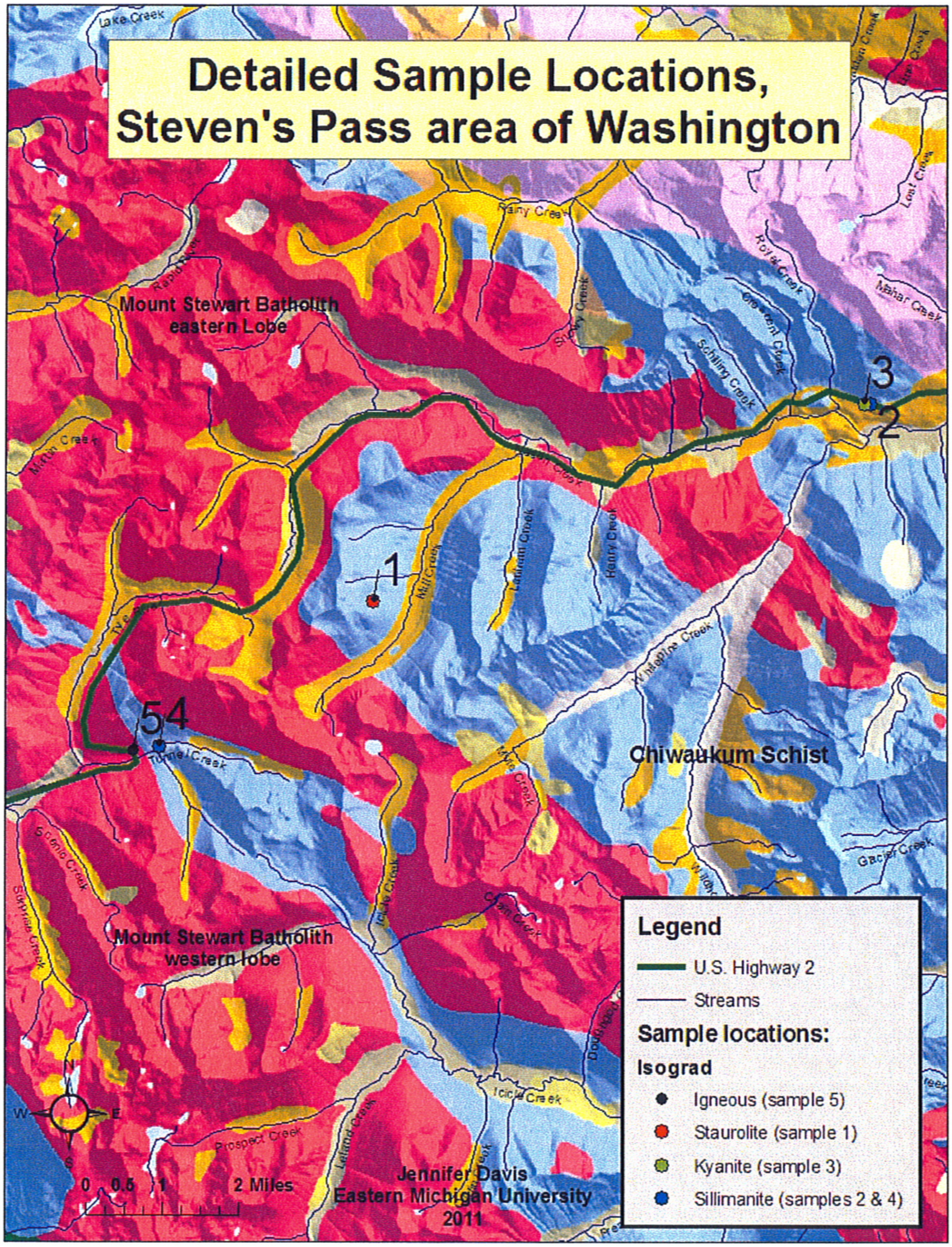

Figure 3: Map showing detailed sample locations for 10JDSP1-10JDSP5; Steven's Pass, Washington. The magenta area represents the Mount Stewart batholith, while the blue area represents the Chiwaukum Schist formation.

Sample localities were chosen to show a range of metamorphism. Important lithological characteristics were noted, including minerals visible in outcrop as well as degree of schistosity. Attitude of foliation was measured using a pocket transit; and accurate geographic coordinates were acquired using a GPS unit. Rock specimens were collected from each source to be further analyzed in the laboratory.

The five rock samples were transported to Eastern Michigan University where they were prepared for thin section production. The thin sections were produced by Applied Petrographic Services, Inc. The finished thin sections were then analyzed utilizing the methods of optical mineralogy with a Leica petrographic microscope, provided by Eastern Michigan University. Major mineral abundances and assemblages were calculated following a point-count method, allowing for the description and classification of each sample.

The point-count method used in this study consisted of 399 points counted for each sample of schist, and 209 points counted on the igneous sample. A fine grid was printed on transparent film and placed over the thin section slide. The slide with grid-film was examined, identifying each mineral that fell beneath each point on the grid within the counting field. The results from the point-counting allowed for an unbiased calculation of mineral percentages for the most abundant species in each sample.

MOUNT STUART BATHOLITH

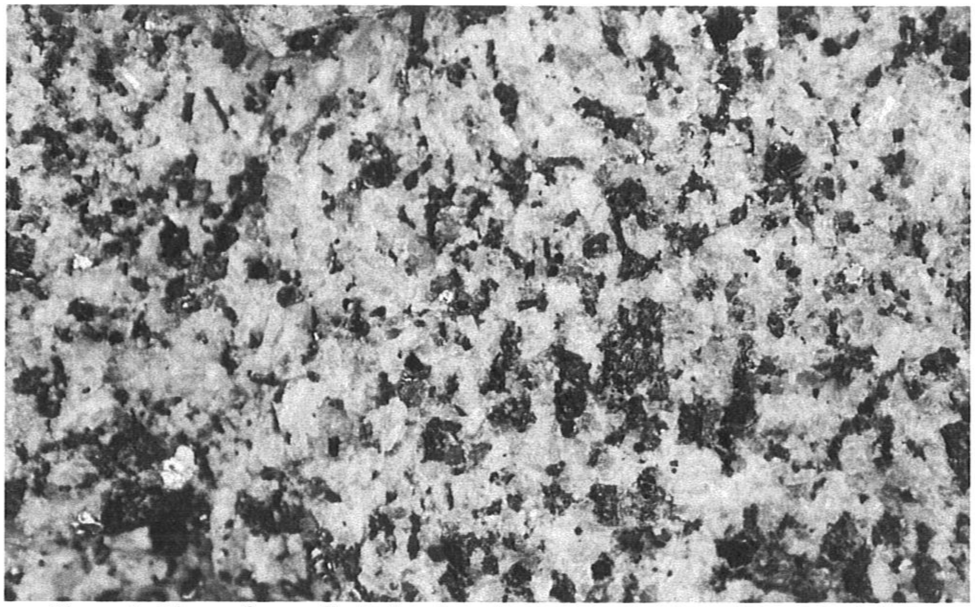

Figure 4: Photo of granodiorite hand specimen from the Mount Stewart batholith.
Dark grains are biotite and hornblende, white grains are feldspars, and the clear gray grains are quartz.
Field of view encompasses 6 centimeters.

The sample representing the Mount Stuart batholith taken for this study, was collected from a road-cut along U.S. Highway 2; N47°43.195', W121°07.494'. This light gray rock consists of white, light gray, and black minerals (Fig. 4). Grains show no preferred orientation and are similar in size. Optical analysis of thin section sample determined the most abundant minerals to be plagioclase(An_{22}) (28.71%), as well as plagioclase altering to sericite (22.00%), quartz (16.75%), biotite (14.83%), potassium feldspar (9.10%), and hornblende (8.61%). Accessory minerals consist of zircons and strongly defined prisms of apatite.

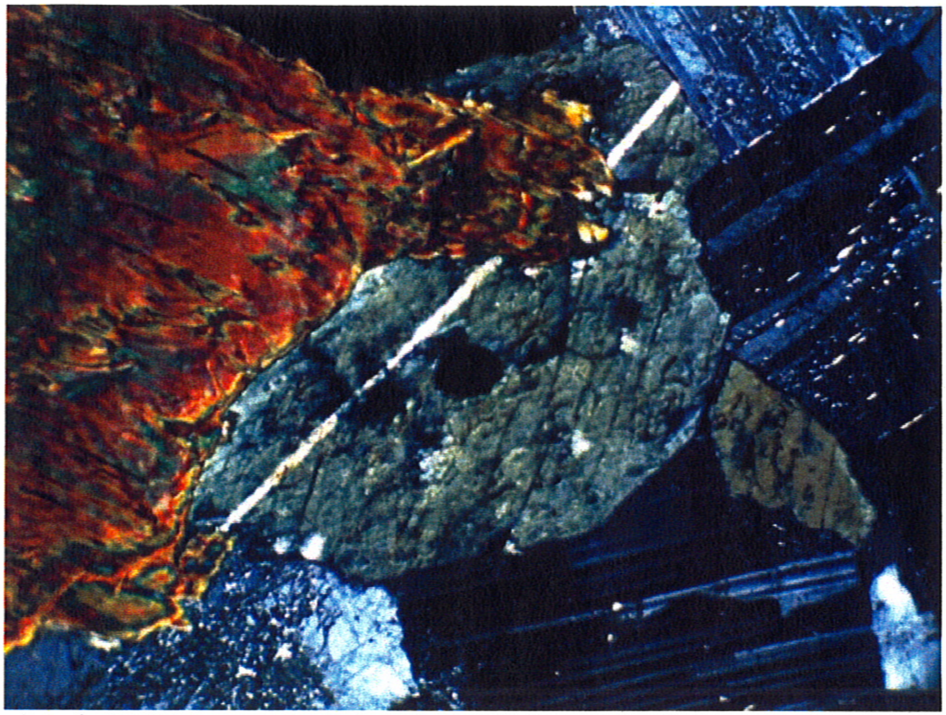

Figure 5: Sample 10JDSP5, crossed polarized light, 10X; large grain of hornblende in center of view with biotite in northwest corner of image. Hornblende and biotite are surrounded by twinned plagioclase and sericite, a fine-grained form of muscovite, visible as speckled inclusions in the plagioclase.

Many of the plagioclase grains contained well defined twins, mostly in the form of polysynthetic twinning or double twinning. The anorthite content of An_{22} was calculated using the Michel-Lévy method. Small amounts of biotite exhibited alteration to chlorite around grain perimeters. Final percentages were normalized to plot on a QAPF diagram, confirming a sample of granodiorite in composition.

CHIWAUKUM SCHIST

Four samples were collected from the Chiwaukum Schist in the Steven's Pass region. The motive for choosing the sample locations used for this research was to identify the various isograds of the Barrovian style metamorphism that took place in the area.

Figure 6: Photo of gneiss hand specimen displaying microfolding of lineated minerals. Light colored layers consist of quartz and feldspars, while dark layers are biotite and graphite. Field of view encompasses 6 centimeters.

Sample #10JDSP1 is a gneiss collected from the Mill Creek drainage, along Powerline Road; N 47°44.131', W121°03.797'. The poorly exposed outcrop was difficult to find and nearly overlooked. The attitude of foliation was 296°/12.5°NE. Large almandine garnets are visible in the rocks at this locality as well as a microfolded gneissic texture (fig. 6). Thin section point-count analysis revealed major minerals in this sample to be quartz (45.36%), biotite (32.83%), opaques in the form of graphite (14.29%), plagioclase (3.01%), and staurolite(3.01%). Plagioclase grains were too small to accurately determine anorthite content.

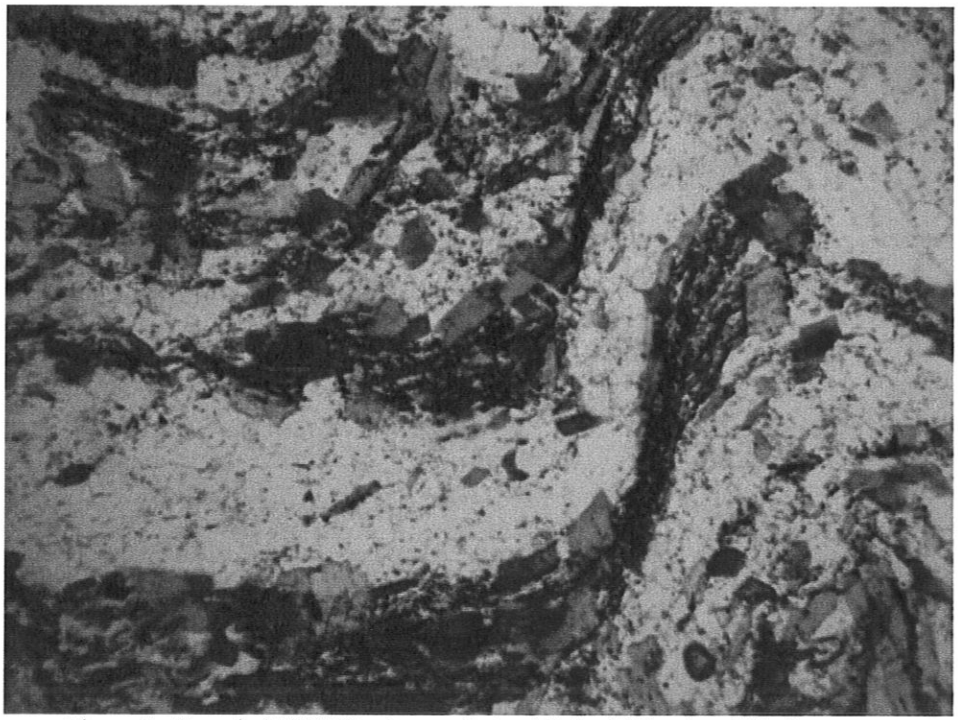

Figure 7: Sample 10JDSP1, plane polarized light, 10X; microfolded texture. Colorless layers are predominantly quartz and dark layers are of biotite with graphite.

Samples 10JDSP2 and 10JDSP3 were obtained from a road-cut along Highway 2, just east of mile marker 75. Sample 10JDSP3, collected at N47°46.866', W120°55.129, exhibited a foliation oriented 298°/66SW. This outcrop also had joints oriented 16°/84NW. 10JDSP2 was gathered roughly 30-50 feet eastward along the road-cut from sample 10JDSP3. The additional second sample was annexed on account of pronounced lithological differences over a short distance in this outcrop. The two samples differ visually; strongly defined garnets were visible to the naked eye in the outcrop source for 10JDSP3, whereas the source for 10JDSP2 did not display such obvious mineral constituents.

After completing a point count analysis, major minerals in 10JDSP2 were quartz (24.56%), plagioclase (19.80%), plagioclase weathering to sericite (11.03%), kyanite, including kyanite altering to sillimanite (24.82%), and biotite, including altered biotite

(13.28%). Accessories entail opaque minerals, rutile, and sillimanite. The presence of sillimanite, although slight, places this sample in the sillimanite zone of a Barrovian sequence. Almost half the kyanite in this sample exhibited alterations to sillimanite, with growth being predominantly in the form of fine, needle-like inclusions within the cleavage planes of kyanite.

Other signs of degradation in this rock are seen in the weathering of plagioclase. Thin section observations identified intergrowth of sericite within plagioclase grains. Also, grains of biotite exhibit signs of potential hydrothermal alteration, displaying reaction rims around the preferentially aligned elongate minerals in thin section. Many aggregates of kyanite, sillimanite, and biotite take on an "imperfect diamond" shape. This shape has been interpreted to represent relict or polymorphed andalusite crystals.

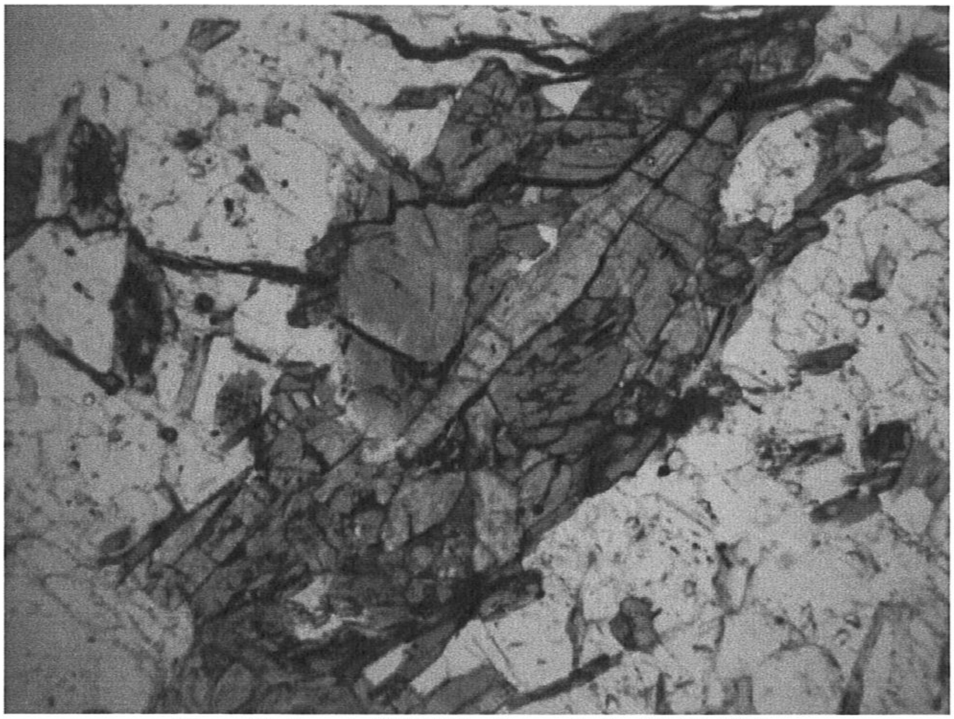

Figure 8: Sample 10JDSP2, plane polarized light, 10X;
aggregate of kyanite, sillimanite, and biotite, surrounded by grains of quartz and feldspar.

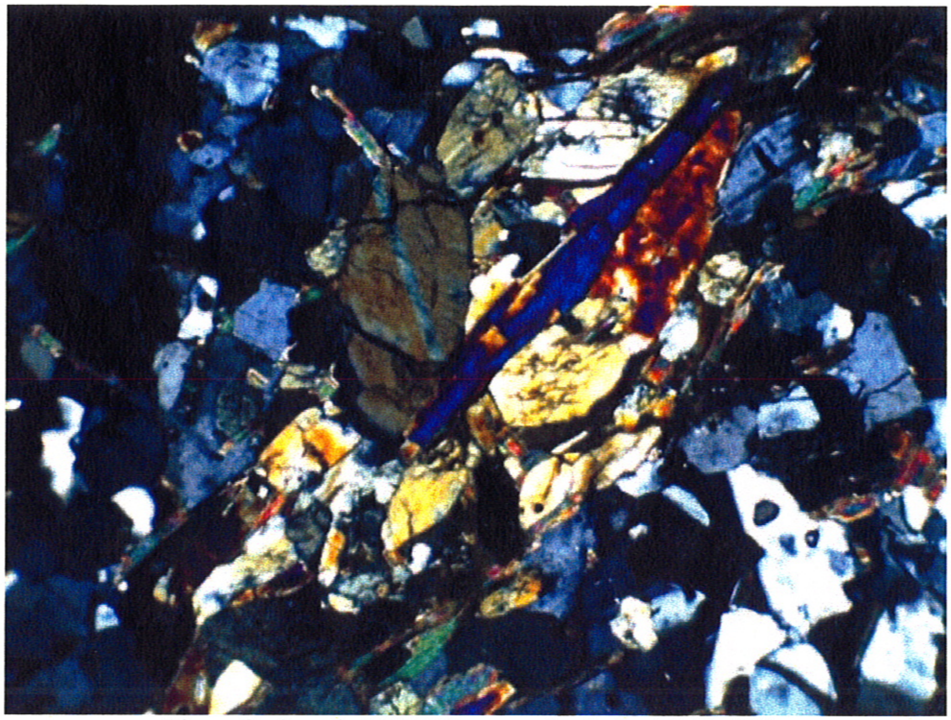

Figure 9: Sample 10JDSP2, crossed polarized light, 10X;
aggregate of kyanite, sillimanite, and biotite, surrounded by grains of quartz and feldspar.

Specimen 10JDSP3 compositionally differs from 10JDSP2. 10JDSP3 is comprised of the major minerals biotite, including altered biotite (37.34%), quartz (27.57%), plagioclase(An_{40}) (22.06%), garnet (4.26%), opaques (4.26%), and kyanite (3.26%). Accessory minerals in this sample consist of potassium feldspar, rutile, and staurolite. A prominent dissimilarity between samples 10JDSP2 and 10JDSP3 is the large, porphyroblastic almandine garnet and kyanite crystals, commonly surrounded by smaller, lineated biotite grains that are found in 10JDSP3. Although not as dominant, the primary difference between these two samples is the absence of sillimanite in 10JDSP3. This places 10JDSP3 in the kyanite isograd while just a short distance away, 10JDSP2 represents the higher metamorphic sillimanite isograd. The variance in index mineral constituents over such a diminutive distance means either this outcrop is precisely along the kyanite-sillimanite isograd, or an undocumented fault has displaced material from one index zone to abut the other. Although the initial conjecture was that the samples were collected along an isograd, the many small, scarcely recognized fault structures in the region make the latter of the above mentioned possibilities a feasible supposition.

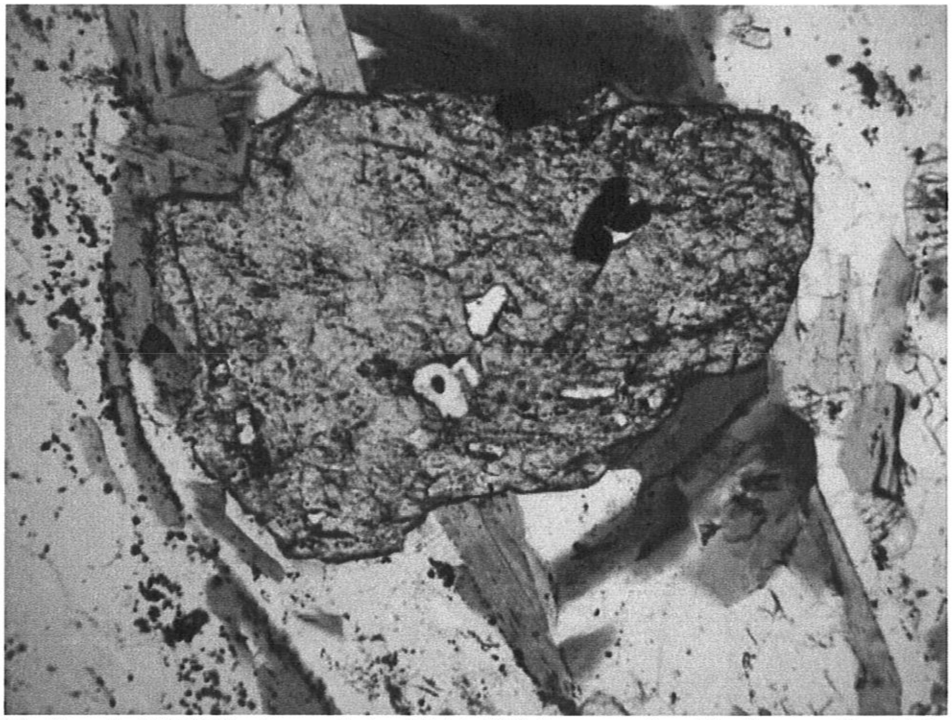

Figure 10: Sample 10JDSP3, plane polarized light, 10X; large porphyroblastic garnet has high relief in plane polarized light, and is surrounded by grains of biotite, quartz, feldspar and opaques.

The final sample of schist acquired, 10JDSP4, was retrieved from a road-cut on Forest Road 6095, alongside Tunnel Creek. This location of N47°43.233', W121°7.067' lies between the two lobes of the Mount Stewart batholith, and has foliation of 313°/83°SW. Thin section point counts determined major minerals in this specimen are quartz (23.31%), kyanite (23.31%), biotite (22.06%), plagioclase(An_{48}) (15.04%), kyanite altering to sillimanite (7.52%), plagioclase altering to sericite (3.51%), opaques (2.26%), and sillimanite (1.00%). Apatite and perthite make up the accessory minerals in this piece. Commonly found were aggregates of kyanite, sillimanite, and biotite in the form of an andalusite. Several pleochroic grains were determined to be kyanite altering to sillimanite, psuedomorphed after andalusite containing organic inclusions. However, the inclusions do not occur in the typical cross-like pattern characteristic of chiastolite. Rather, these needle-like inclusions form along the insides of grain boundaries in a zonal arrangement. Further inspection of the ambiguous pleochroic mineral revealed many grains possessing an inclined extinction angle of 17° and interference colors reaching first-order red. This led to the identification of this mineral to be kyanite, psuedomorphing an andalusite. Additionally, grains that did not exhibit inclined extinction had interference colors that stretched into the second order blues. When found, optic axis figures showed a smaller 2V angle than one would see with an andalusite. These minerals are interpreted to be sillimanite. Similar observations and conclusions were applied to grains within 10JDSP4. So, although 10JDSP4 and 10JDSP2 were collected miles apart, 10JDSP4 resembles 10JDSP2 more than one would predict.

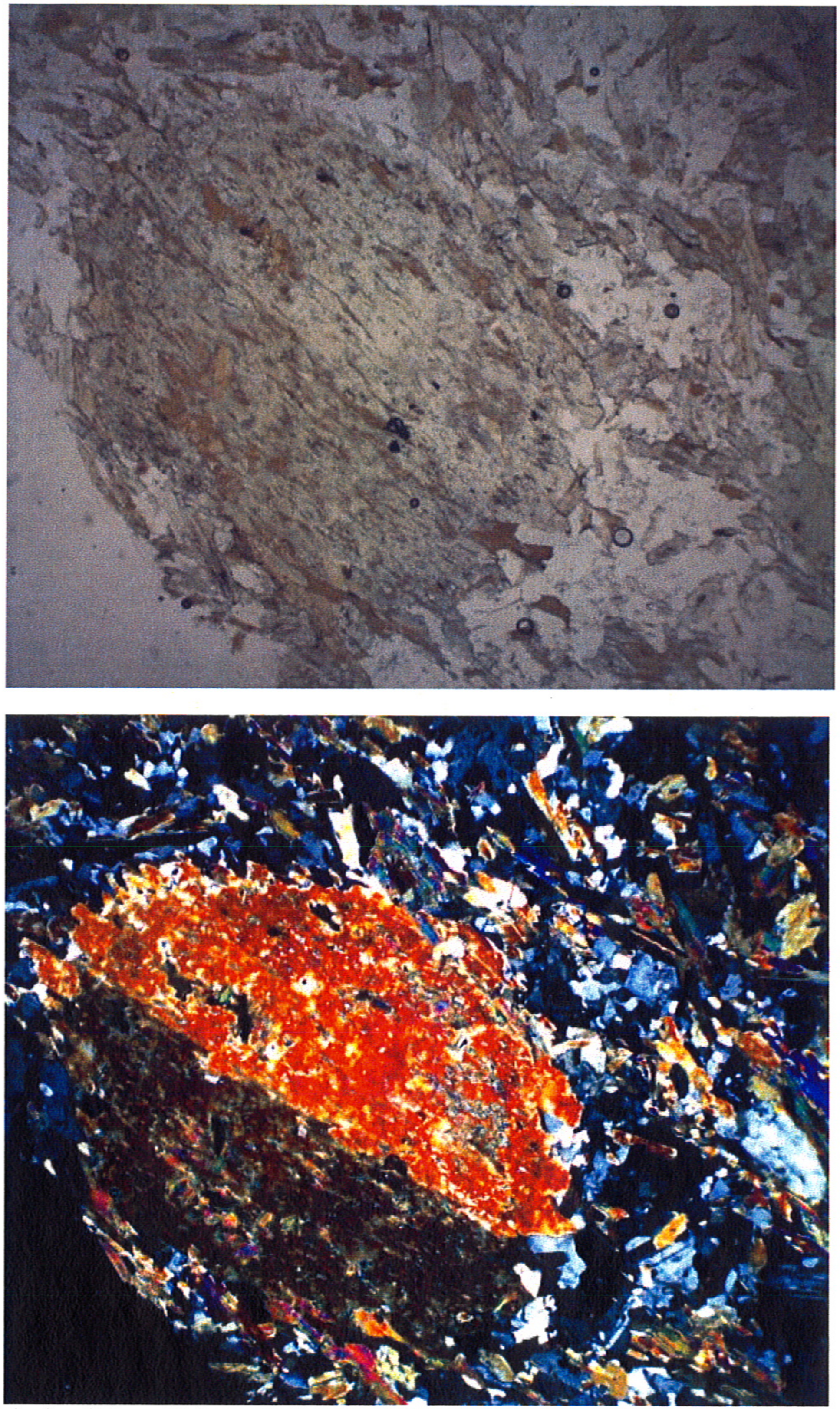

Figure 11 (top) and Figure 12 (bottom): Sample 10JDSP4, plane polarized light (top) and crossed polarized light (bottom), 10X; relict andalusite- aggregate of kyanite, biotite, and opaques; surrounded by grains of quartz, biotite, and feldspar.

CONCLUSIONS

The Chiwaukum Schist in the Steven's Pass region of the Northern Cascade Mountains, Washington, is a pelitic metasedimentary rock that has endured multiple metamorphic events. A clay rich protolith is apparent through the high abundance of aluminum, potassium, and silica bearing minerals present in the samples. The existence of the Barrovian style index minerals staurolite, kyanite, and sillimanite, prove the material has undergone temperature and pressure regimes characteristic of Barrovian style, dynamothermal regional metamorphism reaching the amphibolite facies. Sample 10JDSP1 is of the staurolite isograd, sample 10JDSP3 represents the kyanite isograd, and samples 10JDSP2 and 10JDSP4 are from the sillimanite isograd.

Persistence of andalusite crystal structures, although replaced by higher metamorphic grade polymorphs, provides evidence of at least one previous metamorphic event having taken place in the area. Considering andalusite forms in lower pressures than what is required to form Barrovian index minerals, the preceding metamorphism was most likely either contact metamorphism from the intrusion of the Mount Stewart batholith, Buchan style metamorphism, or both. The processes necessary to yield kyanite and sillimanite in the shape of andalusite, as seen in the samples for this study, entail the formation of andalusite first, providing the initial structure for its polymorphs to amass in its place. The dynamic metamorphic history that this paper describes is typical of an orogenic environment. Supplemental chemical analysis of the specimens examined, would help validate and expand upon identifications made in this study.

REFERENCES

Duggan, K.M., and E.H. Brown. "Correlation of the Tonga Formation and the Chiwaukum Schist, North Cascades, Washington: Implications for Late Cretaceous orogenic mechanisms". *Tectonics* 13.6 (1994): pp. 1411-24. Web. 12 Nov. 2010.

Evans, Bernard W., and John W. Berti. "Revised Metamorphic History for the Chiwaukum Schist, North Cascades, Washington". *Geology* 14 (1986): pp. 695-8. Web. 12 Nov. 2010.

Gordon, Stacia M., Samuel A. Bowring, Donna L. Whitney, Robert B. Miller, and Noah McLean. "Time Scales of Metamorphism, Deformation, and Crustal Melting in a Continental Arc, North Cascades USA". *GSA Bulletin* 122.7/8 (2010): pp. 1308-30. Web. 12 Nov. 2010.

Magloughlin, J.F. "Metamorphic petrology, structural history, geochronology, tectonics, and geothermometry-geobarometry in the Wenatchee Ridge area, North Cascades, Washington". *M.S. thesis, University of Washington, Seattle.* (1986): pg. 344. Web. 12 Nov. 2010.

Neuendorf, Klaus K.E., James P. Mehl, Jr., and Julia A. Jackson. *Glossary of Geology – Fifth Edition.* Virginia: American Geological Institute. 2005. Print.

Perkins, Dexter, and Kevin R. Henke. *Minerals in Thin Section.* New Jersey: Pearson Education, Inc. 2004. Print.

Plummer, Charles C. "Dynamothermal contact metamorphism superposed on regional metamorphism in the pelitic rocks of the Chiwaukum Mountains area, Washington Cascades: Summary". *Geological Society of America Bulletin* Part 1, 91 (1980): pp. 386-388. Web. 12 Nov. 2010.

Winter, John D. *An Introduction to Igneous and Metamorphic Petrology.* New Jersey: Prentice-Hall Inc. 2001. Print