MESO AND MICRO-SCALE ANALYSIS OF FOLIATED ROCKS OF THE SOUTHERN COAST BELT: A TRANSECT FROM WHISTLER TO LILLOOET, BRITISH COLUMBIA

by

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MESO AND MICRO-SCALE ANALYSIS OF FOLIATED ROCKS OF THE SOUTHERN COAST BELT: A TRANSECT FROM WHISTLER TO LILLOOET, BRITISH COLUMBIA

Erich Victor Zorn, M.S.

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Along Duffy Lake Road (Rt. 99) between Whistler and Lillooet, British Columbia rocks of the Coast Belt commonly record penetrative deformation. Regional stratigraphy within this transect includes rocks of the Cadwallader and Bridge River terranes, as well as units of the Gambier Group, Cadwallader Group, Chism Creek Schist, Cayoosh Assemblage, Bridge River Complex/Schist and the Brew Group. Along this 110 km transect foliation generally dips 30ºNE to vertical and strikes northwest. Down-dip lineation is common in these rocks. Although they are commonly re-crystallized, locally developed microstructures preserve shear-sense indicators in sections cut parallel to dip and perpendicular to foliation. Differences among ductile structures indicate at least five episodes of deformation. 1) Early Cretaceous plutonic rocks of the eastern Western Coast Belt, which flank both sides of the Whistler shear zone, in places have foliation which strikes northeast and dips steeply. This is interpreted to be the result of Oligocene-Miocene (~25-14 Ma) faulting (Price and Monger, 2000), that cuts across all northwest trending faults and stratigraphic units. 2) The Brew Group shows distinctly different deformation characteristics than surrounding rock units. Sub-horizontal penetrative foliation and shear bands record NW-SE extension probably related to structural exhumation of the Brew Group along the gently dipping Eocene Cayoosh Creek Fault in the footwall beneath the Bridge River Complex. 3) At Lillooet, the northeast limit of this field study, steeply dipping mylonite along the dextral, Eocene Marshall Creek Fault consists of L-tectonites with distinct sub-

horizontal mineral lineation. This penetrative deformation affects rocks of the Bridge River Complex in which left and right lateral shear sense indicators are recorded in thin section. Also affected are Eocene intrusive rocks in which only right lateral movement is observed. Therefore, the left lateral movement observed in rocks of the Bridge River Schist is older than the right lateral movement recorded by Eocene intrusive rocks. 4) Pre-85 Ma: Within the Chism Creek Schist, contact metamorphism from the 85-86 Ma Mount Rohr Pluton has completely annealed the rocks. However, mineral lineations and meso-scale asymmetric folds are preserved that give a sense of oblique left-slip and pure shear in close proximity to the Bralorne fault system. This deformation does not affect the intrusive rocks and therefore is pre-85 Ma. Both right and left lateral movement, along with flattening is observed within rocks of the Cayoosh Assemblage as well which is deformed along both the Bralorne and Downton Creek Faults. Within the scope of this field study, an upper age limit cannot be determined. 5) Post-113 Ma: Near Whistler, outcrops of strongly foliated, very fine grained volcanic rocks and meta-sediments of the Gambier Group have closely spaced and mylonitic foliation and show strong mineral lineation parallel to the dip direction. Meso-scale kink folds and asymmetric tails in thin section are interpreted to record extension whereas symmetric tails record flattening during pure shear. Late Jurassic intrusive rocks nearby to the west and east of this belt of meta-volcanics are ductily deformed.

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1. INTRODUCTION

1.1. GEOLOGIC SETTING

1.1.1. Morphogeological Belts of the Canadian Cordillera

The Canadian Cordillera is divided into five northwest trending, orogen parallel morphogeological belts (Fig. 1). Each belt displays a distinctive set of characteristics including physiography, rock types, metamorphic grade and structures which distinguish it from other belts (Dawson, 1881; Gabrielse et al., 1991). These five belts are, from west to east in the Cordillera, the Insular Belt, Coast Belt, Intermontane Belt, Omineca Belt, and Foreland Belt. This study focuses on the Southern Coast Belt of British Columbia, between 49.5º N and 51º N, and 122º W and 123º W (Fig. 3).

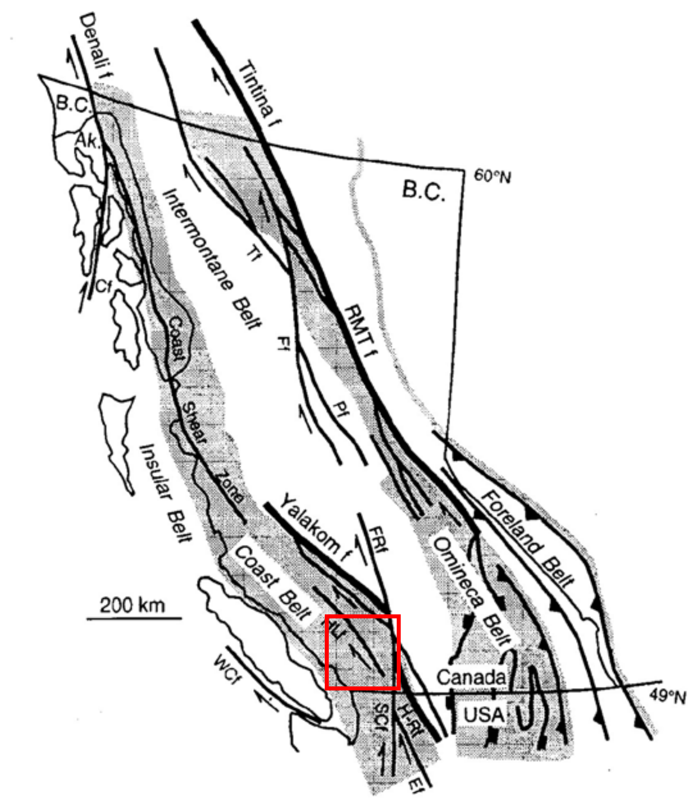

Figure 1. The five morphogeological belts of the Canadian Cordillera. The red box delineates approximately the field area of this study. Modified from Umhoefer and Schiarizza (1996).

1.1.2. The Coast Belt

Included in the Coast Belt are the Coast Mountains and the Cascade Mountains of British Columbia. The belt is characterized largely by Jurassic through Cenezoic granitic and granodioritic rocks and Paleozoic through Holocene volcanic and sedimentary rocks (Price and Monger, 2000). The volcanic and sedimentary rocks are mainly arc-derived, forming in basins and accretionary complexes, and variably metamorphosed in the Cretaceous through Cenezoic (Price and Monger, 2000). The high precipitation, at elevation (2000-3000 m), and the granitic rocks which comprise 80-85% of the Coast Belt (Price and Monger, 2000) leads to erosion and differential weathering, which create an extremely rugged landscape.

The metamorphic grade of layered rocks in the Coast Belt is mainly greenschist to amphibolite, but higher grades resulting from contact metamorphism near Late Cretaceous to Early Tertiary plutons also exist. Metamorphic grade generally decreases in the Coast Belt from south to north (Price and Monger, 2000).

East and west vergent contractional faults of Late Cretaceous-early Tertiary age are the dominant structures in the southeastern part of the belt (Varsek et al., 1993; Journeay and Friedman, 1993). Late Cretaceous-early Tertiary strike slip and extensional faults have been recognized on the east side of the belt (Coleman and Parrish, 1991 and Schiarizza et al., 1997). Journeay (1990) sub-divides the Coast Belt into three belts, the Eastern, Central and Western Coast Belts, based on structures present, metamorphism, and stratigraphic units (Fig. 2).

1.1.3. The Western Coast Belt

The Western Coast Belt comprises more than two-thirds of the total area of the Coast Belt (Journeay and Csontos, 1989), and 80% of the Western Coast Belt is underlain by granitic rocks (Monger, 1990). The strata of the Western Coast Belt are of Triassic to Late Cretaceous age and occur as pendants that rarely exceed greenschist facies metamorphism. In this study area, the contact between the Gambier Assemblage and the Cadwallader Group (Fig. 3) is the eastern limit of the Western Coast Belt. The Gambier Assemblage and other un-named meta-sedimentary rocks occur as a pendant near the town of Whistler (Friedman and Armstrong, 1995).

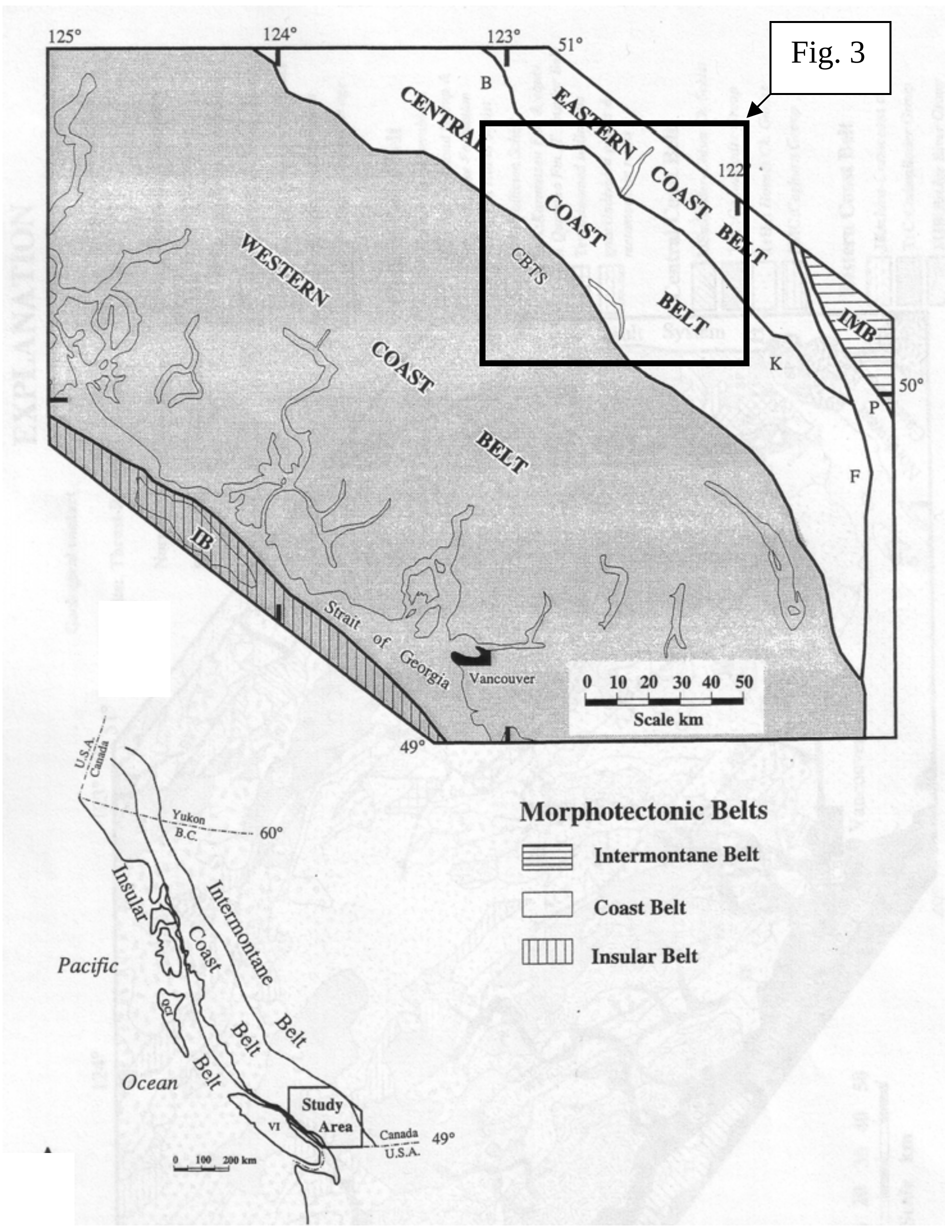

Figure 2. Simplified map of the Southern Coast Belt showing the three-fold subdivision of Journeay (1990). Modified from Friedman and Armstrong (1995).

1.1.4. The Central Coast Belt

The Central Coast Belt (Fig. 2) is bounded on the east by the oblique-slip Bralorne fault system and on the west by the Central Coast Belt Detachment (CCBD) (Friedman and Armstrong, 1995). The CCBD is the contact between the Gambier Assemblage of the Western Coast Belt and the Cadwallader Group of the Central Coast Belt. The main structural feature of the Central Coast Belt is the Coast Belt thrust system (CBTS), a series of west-directed thrusts (Friedman and Armstrong, 1995). The CCBD is an early strand of the CBTS (Journeay and Friedman, 1993). Major non-intrusive units of this field study area include the Cadwallader Group to the west and the Chism Creek Schist of the eastern Central Coast Belt (Price and Monger, 2000), both of which are intruded by Cretaceous plutons (Fig. 3). The 103Ma Spetch Creek Pluton intrudes the Cadwallader Group while the ~85 Ma Scuzzy/ Mount Rohr Pluton intrudes the Chism Creek Schist (Friedman and Armstrong, 1995). Rock units found in the Central Coast Belt are likely less metamorphosed amphibolite-facies equivalents of Eastern Coast Belt rocks (Friedman and Armstrong, 1995).

1.1.5. The Eastern Coast Belt

The Eastern Coast Belt (Fig. 2) is bound to the west by the Bralorne Fault System and to the east by the Yalakom Fault and, structurally, occupies the highest position in the Southern Coast Belt (Journeay, 1990). From west to east, the Downton Creek, Marshall Creek, Mission Ridge, and Cayoosh Creek faults cut the Eastern Coast Belt (Price and Monger, 2000). Major non-intrusive units of the Eastern Coast Belt within this study area include the Cayoosh Assemblage and Bridge River Complex (Fig. 3), both of which are cut by the 68 Ma Bendor Pluton (Friedman and Armstrong, 1995). The Brew Group, which structurally underlies the Bridge River Complex, is cut by Eocene intrusives (Friedman et al., 1995). In the Southern

Coast Belt, the Bridge River Complex occupies a large area of the Eastern Coast Belt. There are three distinct, fault bounded domains of the Bridge River (Friedman and Armstrong, 1995). The Mission Ridge Fault to the east and the Marshall Creek Fault to the west border the Bridge River Schist, a greenschist-facies member of the Bridge River Complex. To the northeast and southwest of the Bridge River Schist are more coherent prehnite-pumpellyite facies rocks of the Bridge River Complex (Schiarizza et al., 1990; Potter, 1986; Coleman, 1989).

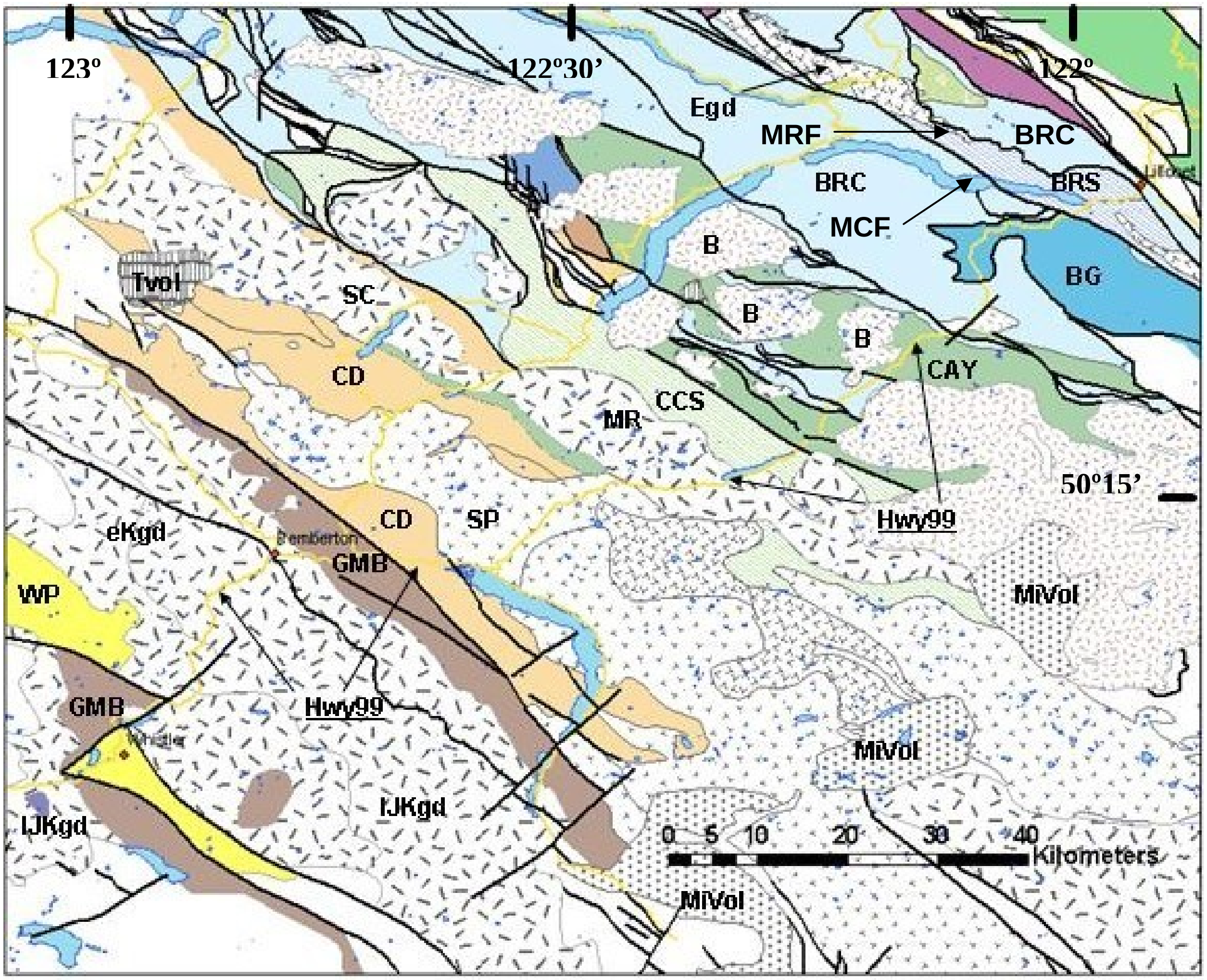

Figure 3. Detailed map of the field area of this study. GMB=Gambier Group, WP=Whistler Pendant, CD=Cadwallader Group, CCS=Chism Creek Schist, CAY=Cayoosh Assemblage, BRC= Bridge River Complex, BG=Brew Group, BRS=Bridge River Schist, gd=granodiorite, SP=Spetch Creek Pluton, SC=Scuzzy Pluton, MR=Mission Ridge Pluton, B=Bendor Pluton, vol=volcanic rocks, MCF=Marshall Creek Fault, MRF=Mission Ridge Fault. Highway 99 in yellow and labeled. Modified from Massey et al. (2005).

1.2. TECTONIC OVERVIEW OF THE CANADIAN CORDILLERA

Hypotheses that seek to explain the complex history of southwestern British Columbia include those of Monger et al. (1994) and Schiarizza et al. (1997), each of which emphasizes hundreds of km of lateral displacement along regional faults and that of Wynne et al (1995), which focuses upon dextral displacement of thousands of km..

1.2.1. Hypothesis I

Monger et al. (1994) suggest that the Gravina-Gambier arc assemblage and the Spences Bridge Group are different segments of a single arc that has been duplicated. The arc that formed along an Early Cretaceous plate margin was duplicated by sinistral faults in Early Cretaceous time. The northern Gravina-Gambier arc segment was displaced southward ~800 km to a position outboard of the Bridge River terrane that was accreted to the margin of the continent during subduction. Sinistral faulting trapped the Bridge River accretionary complexbetween the overlapping arc segments, preserving and thrusting it over top of the inboard arc segment as left-oblique convergence continued.

1.2.2. Hypothesis II

Schiarizza et al. (1997) propose a scenario very similar to Monger et al. (1994) but suggest that the western block consisting of Alexander, Wrangellia, Stikinia and Quesnellia super-terranes, arrived west of the Methow-Cadwallader Terranes as early as Late-Middle Jurassic time. They base this hypothesis on the presence of Middle Jurassic clastic overlap sequences such as the Brew, Relay Mountain and Cayoosh Assemblages deposited on top of the Bridge River Complex in possible transtensional basins. The basin development appears to be the result of the sinistral emplacement of Alexander and Wrangellia Super-terranes to the west of the Bridge River Complex prior to the complete closure of the Bridge River Ocean. The newly arrived western block served as the source rock for clastic basin fill sequences of the Bridge

River Complex. As opposed to Monger et al (1994), Schiarizza et al (1997) propose the presence of at least two distinct plutonic age groups. Jurassic-Cretaceous age plutons dominate the Western Coast Belt and shift eastward at ~100Ma. The Eastern Coast Belt contains abundant plutons of <90Ma age. This younging eastward age progression can be interpreted as the recommencement of subduction and the progressive shallowing of the subducting plate.

1.2.3. Hypothesis III

The Baja-BC hypothesis, which emphasizes between 1100 and 3500 km of dextral displacement along the coast during the Cretaceous, is based on paleomagnetic data of Wynne et al (1995) and Irving et al (1995). Using the ~85 Ma Powell Creek Volcanics of the easternmost Southern Coast Belt, Wynne et al (1995) interpreted paleomagnetic data to suggest that the rocks formed ~3500 km south of their present position, relative to the craton. Irving et al (1995) interpreted paleomagnetic results from the 105 Ma Spences Bridge Volcanics as suggesting ~1100 km of south to north displacement relative to the craton. Combining these two data sets, the Baja-BC hypothesis speculates that between 105 Ma and 85 Ma continental rocks of the southern Coast Belt and southwesternmost Intermontane Belt moved southward sinistrally, carrying the Spences Bridge Group ~2400 km. It was at this latitude the Powell Creek volcanic rocks formed. Between 85 Ma and 50 Ma, there was ~3500 km of dextral displacement which placed the Coast Belt rocks in their present location.

1.3. PURPOSE OF THIS STUDY

The purpose of this study is to characterize zones of brittle and ductile shear in the Southern Coast Belt by using the lithology, mineralogy and microstructures present in thin section. The hypothesis that lateral faulting played a key role in the tectonic history of the region stemmed in part from the recognition that the distribution of terranes and width of the Coast plutonic complex in British Columbia might be the result of overlap of magmatic belts attributable to displacement along a major lateral fault or faults. It has been recognized for more than two decades that the Insular superterrane and the Wrangellia composite terrane, composed of Wrangellia (Jones et al., 1982; Plafker et al., 1989; Plafker and Berg, 1994; Noklelberg et al.. 1994) and Alexander terrane (Schuchert, 1923; Berg et al., 1972), is separated from the Intermontane superterrane, with Stikine and Quesnellia prominent at its western margin (van der Heyden, 1992), by the pluton-rich Coast belt and diverse smaller terranes such as Harrison Lake and Bridge River (Friedman et al., 1995). Among these crustal elements in British Columbia, Monger and Price (1979) drew attention to the presence of two tectonic welts each containing abundant Mesozoic magmatic rocks. Later, Monger et al. (1982) suggested that suites of Mesozoic rocks, especially magmatic ones, distinguish major crustal welts that are sufficiently similar to suggest overlap of segments of magmatic belts (Monger et al., 1994). Explanations of the overlap of the belts fall into three general groups: 1) collisional models in which the Insular superterrane is accreted against the Intermontane superterrane during Cretaceous events (Monger et al., 1982); 2) subduction models that involve production of multiple magmatic belts during an extended period of Mesozoic magmatism (Van der Heyden, 1992) and 3) lateral faulting models that create overlap as a result of strike-slip displacements gently oblique to the strike of an Andean style Jurassic magmatic belt (Monger et al., 1994).

Tectonic activity during the Eocene has severely overprinted older structures. Analysis of microstructures revealed in thin sections from samples along a transect between Whistler and Lillooet show right lateral and down-dip movement in shear zones. By analyzing mineralogy and lithology, a better understanding of the contacts between stratigraphic units and terranes may be achieved. Shear sense indicators such as rotated grains, tail structures, stylolites and offset markers such as veins record movement patterns of the terranes that make up the West coast of Canada and the United States. The purpose here is not to present a new tectonic model for Western Canada, but only to add objective scientific observations that will contribute to the already large pool of existing data and aid in resolving the tectonic history of this complex region.

1.4. METHODS

Five weeks were spent in Southwestern British Columbia in the area between Whistler and Lillooet in the summer of 2004. Structural data, other geologic observations and oriented samples were collected from a transect along Highway 99 and surrounding roads connecting Whistler, Pemberton, Birkenhead Lake and Lillooet. The data localities are accurately located from GPS readings. At each stop, a detailed structural, lithologic and mineralogic description was completed and a sample was collected. Measurements of strike and dip of layers and foliations and lineation and fold axis orientations were collected. Digital photographs were also taken of any notable structures and outcrops. Oriented samples were collected at localities where microstructures were observed. Oriented samples from 20 outcrops were cut into 30 micron thin sections. Sections were cut perpendicular to the dip and strike of the foliation plane. If a lineation was present, a section was cut parallel to that lineation. Using a polarizing micro-scope and a digital camera, photo-micrographs were taken at 4X and 10X magnifications. Mineralogy was determined and microstructures were analyzed for shear-sense indicators. Along with photo-micrographs, a detailed 3-D block diagram (Appendix B) was constructed for each set of thin sections and strike and dip data was entered into an equal-area stereo-net for 6 areas along the 110 km transect (Fig. 15). Using a base-map published by the British Columbia Geological Survey (Massey et al., 2005), a geologic map was constructed and overlain on a Shuttle Radar Topography Mission (SRTM) dataset in order to add elevation data to the map.

2. REGIONAL GEOLOGY

2.1. TERRANES OF THE SOUTHERN COAST BELT

2.1.1. Harrison Lake

The Harrison Lake Formation within the Harrison Terrane (Figs. 4,5,6) is the largest Early to Middle Jurassic arc sequence preserved in the Southern Coast Belt. Stratigraphically, from bottom to top, the terrane contains the Middle Triassic Camp Cove Formation, Middle Jurassic Harrison Lake Formation and the Middle to Upper Jurassic Mysterious Creek and Billhook Formations (Monger, 1985; Arthur, 1986, 1987; Arthur et al., 1993). To the east, the Harrison Terrane is bounded by the Harrison Lake shear zone, which is a dextral transcurrent fault separating the greenschist-facies Harrison from the amphibolite-facies Coast Belt thrust system. The southern boundary of the terrane is the Vedder Fault, which separates the Harrison and the Chilliwack terranes. Clasts of limestone in conglomerate at the base of the Harrison Lake Fm. have been linked to the Chilliwack terrane, inferring an Early Jurassic stratigraphic link between the two terranes (Arthur 1987; Arthur et al. 1993; Monger and Journeay 1992).

The contacts between the Camp Cove, Harrison Lake, and Mysterious Creek and Billhook Creek Formations are all unconformities. The Harrison Terrane is unconformably overlain by the Lower Cretaceous Peninsula and Brokenback Hill Formations of the Gambier Group.

2.1.2. Cadwallader

Rusmore (1987) and Umhoefer (1990) describe the Cadwallader Terrane (Figs. 4,5,6) as composed of Upper Triassic rocks of the Cadwallader and Tyaughton Groups and the Lower to Middle Jurassic rocks of the Last Creek Formation and Junction Creek Unit. Most of the exposures of the terrane include the Hurley Formation of the upper Cadwallader Group, described as a turbiditic sequence of Upper Norian sandstone, siltstone, conglomerate and minor calcite (Schiarizza et al., 1997). The Hurley Formation is conformably underlain by mafic volcanics of the Pioneer Formation which are the base of the Cadwallader Group, and unconformably overlain by shale, argillite and siltstone of the Junction Creek Unit (Schiarizza et al., 1997). The Tyaughton Group and Last Creek Formation are correlative with the Hurley Formation and Junction Creek Unit respectively to the northwest (Schiarizza et al., 1997). The Pioneer and Hurley Formations are exposed in the field area of this study.

2.1.3. Bridge River

Potter (1983) describes the Bridge River terrane (Figs. 4,5,6) as being composed mainly of the Bridge River Complex (BRC), which is an assemblage of chert, argillite, greenstone, gabbro, serpentinite, blueschist, and clastic sedimentary rocks that display no coherent stratigraphy. As reported by Cordey and Schiarizza (1993) and Archibald et al. (1990), chert and limestone from the BRC range in age from Mississippian to late Middle Jurassic and blueshist metamorphism occurred in Middle to Late Jurassic time. The time-transgressive nature, complex structures and blueschist metamorphism suggest the BRC was an accretion-subduction complex. Also included in the Bridge River Terrane is the Cayoosh Assemblage. The Cayoosh is a thick succession of meta-sedimentary rocks which conformably overlies the BRC and in places is laterally continuous with the BRC (Journeay and Northcote, 1992; Mahoney and Journeay, 1993; Journeay and Mahoney, 1994)

2.1.4. Methow

The Methow terrane (Figs. 4,5,6) is an assemblage of Early Jurassic to middle Cretaceous rocks found in the northeast part of the Southern Coast Belt (Schiarizza et al., 1997). It includes the rocks of the Jackass Mountain Group.

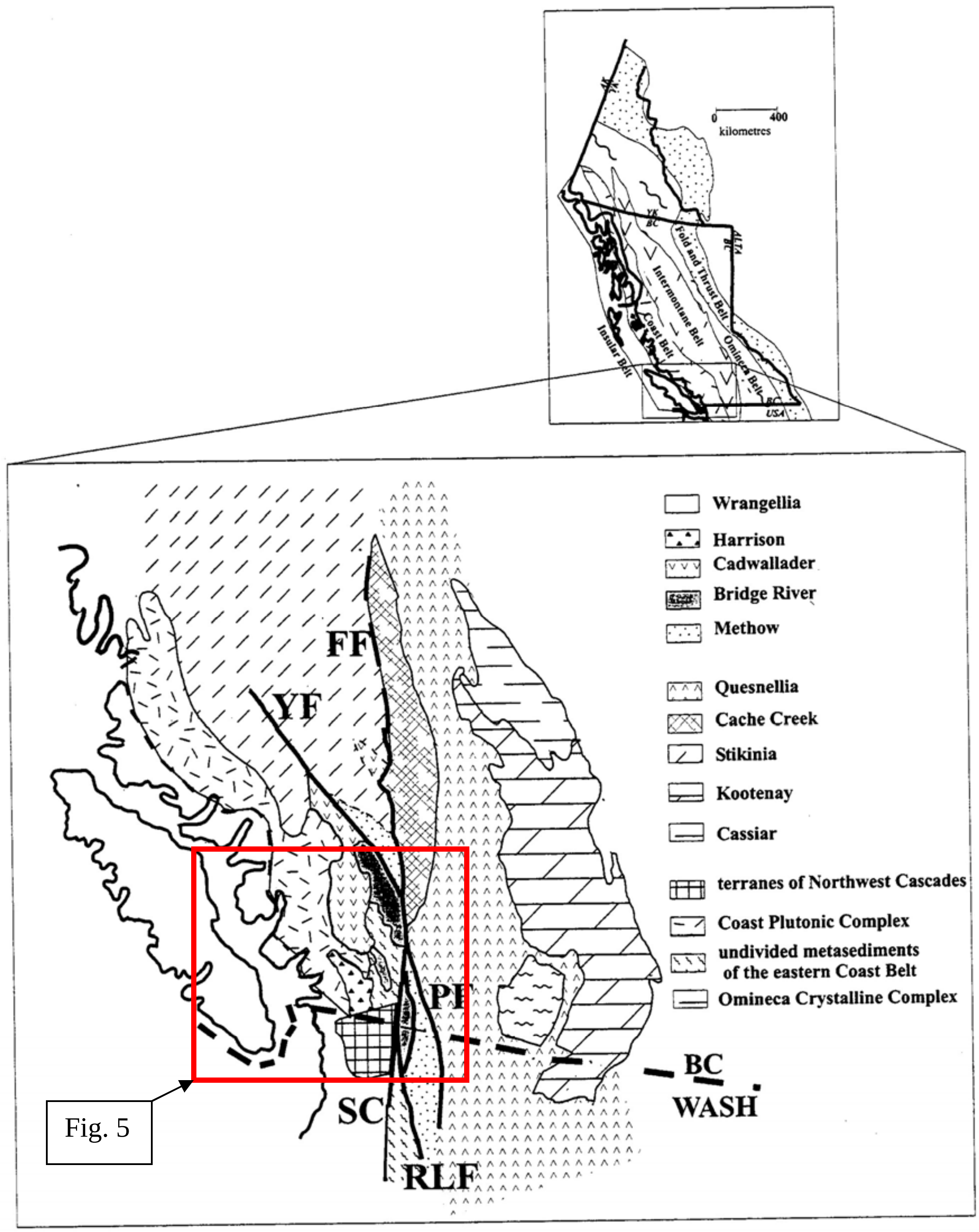

Figure 4. Terranes of southwestern Canada. Red box surrounds terranes of the southern Coast Belt. Modified from Mahoney and Haugerud (1999).

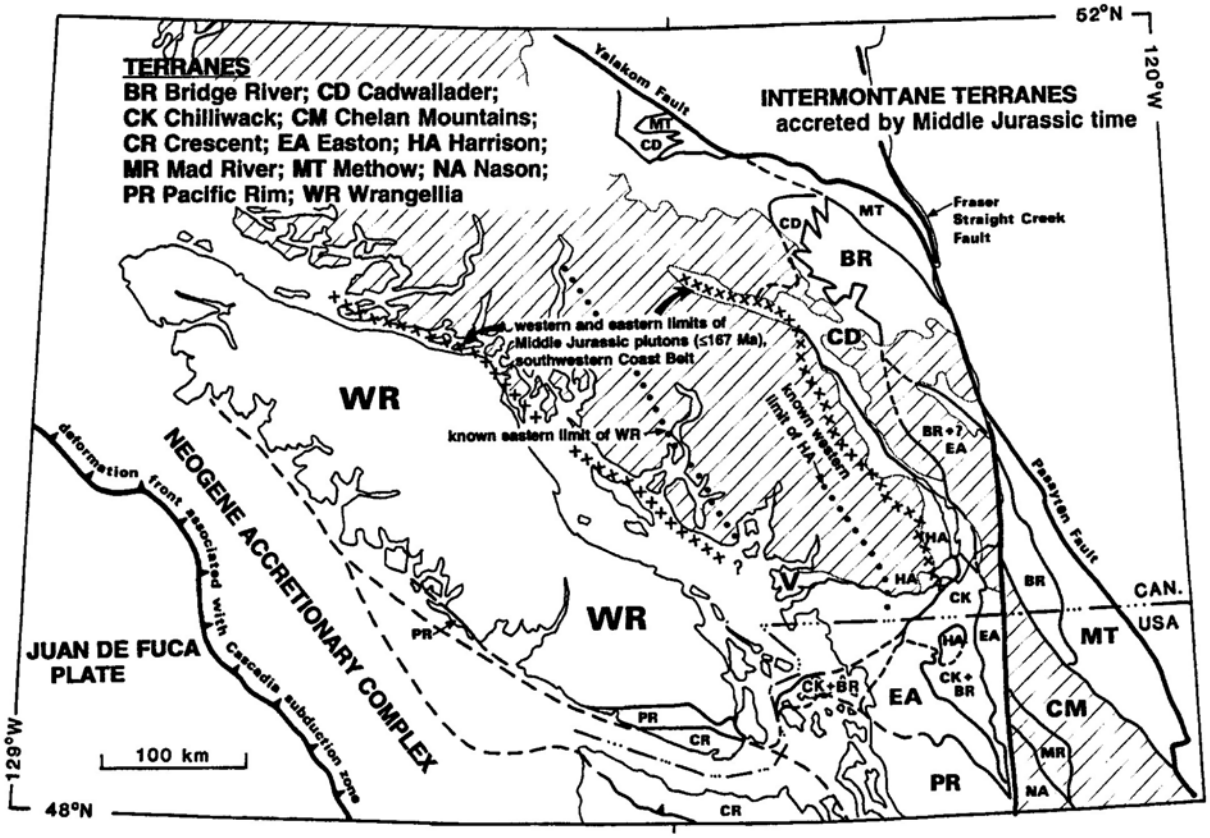

Figure 5. Terranes of the Southern Coast Belt. From Price and Monger (2000).

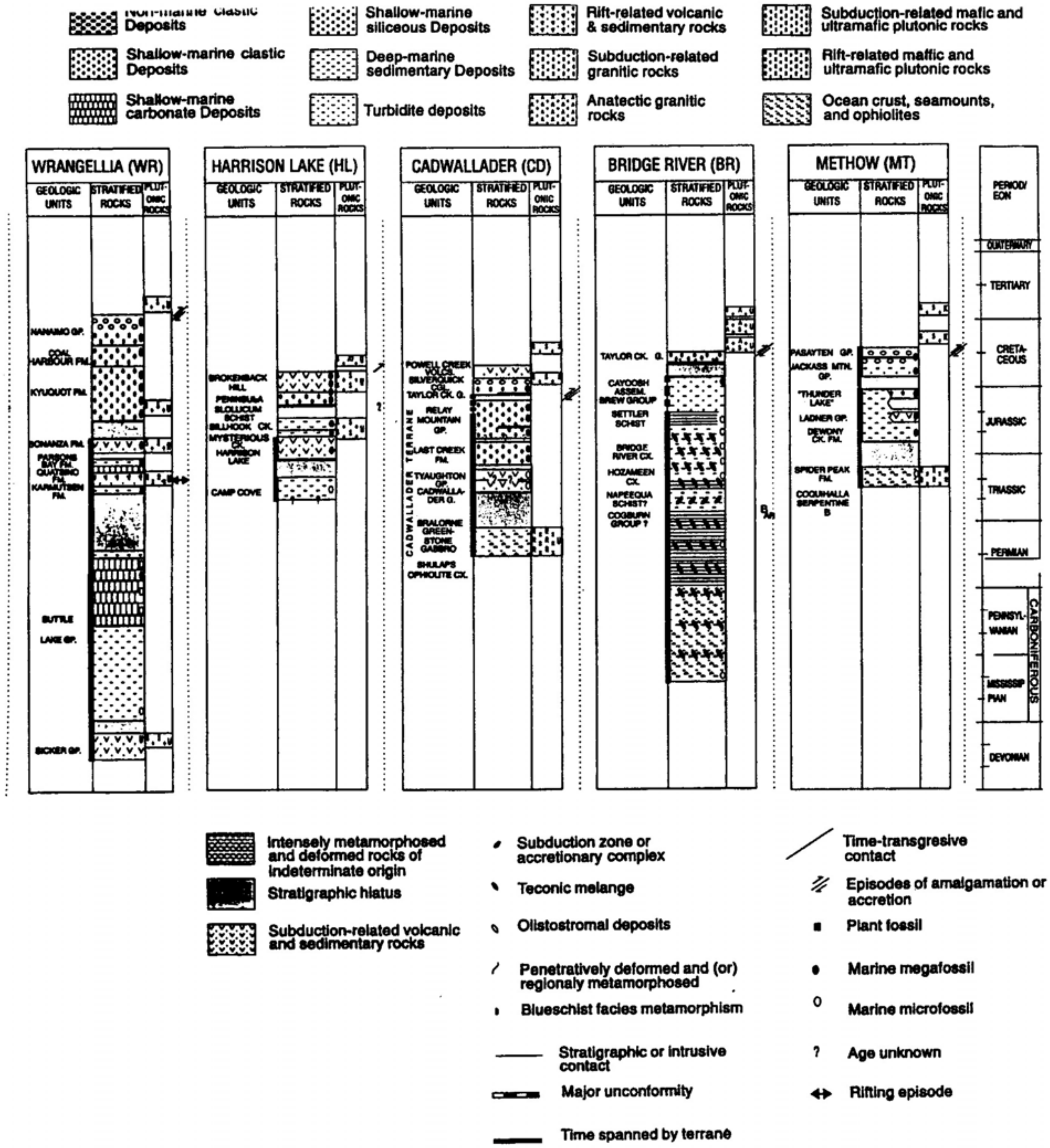

Figure 6. Stratigraphy of the five terranes of the Southern Coast Belt, showing major stratigraphic units seen within each terrane. From Price and Monger (2000).

2.2. STRATIGRAPHIC UNITS OF THE SOUTHERN COAST BELT

2.2.1. Harrison Lake Formation

The southern two-thirds of the Harrison Terrane is the Harrison Lake Formation. There are four subdivisions of the formation as established by Arthur (1986, 1987) and Arthur et al. (1993) (Fig. 7). The Celia Cove Member is exposed at the base of the anticline formed by the Harrison Lake. It is a conglomeratic rock unconformably overlying the Camp Cove Formation. The unconformity is both lithologic and angular in nature. The Celia Cove Member consists of volcanic and chert pebble to boulder conglomerate, which exhibits an overall fining upward trend with bedding becoming thinner higher up-section. The thickness varies from 10-60 meters and the contact between the Celia Cove and overlying Francis Lake Member is gradational.

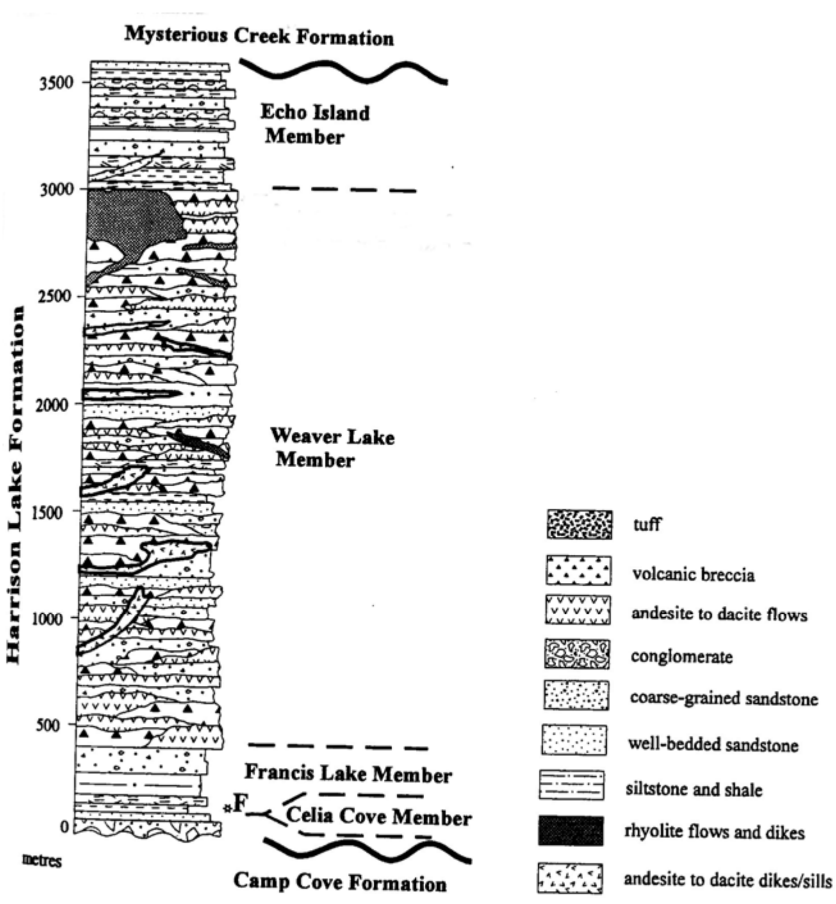

Figure 7. Stratigraphy of the Harrison Lake Formation. Modified from Mahoney et al. (1995).

2.2.2. Gambier Group

The Gambier Group (Armstrong, 1953; Roddick, 1965) consists of volcanic and sedimentary rocks from a Cretaceous arc system covering the length of the Coast Mountains (Fig. 8). Along the Lillooet River the Peninsula and Brokenback Hill Formations make up the Gambier Group in the Southeastern Coast Belt. The Peninsula Formation at the base of the Gambier Group is Early Cretaceous conglomerate and arkosic sandstone resting unconformably on the volcanic Middle Jurassic Harrison Lake Formation (Arthur et al., 1993). The Brokenback Hill Formation conformably overlies the Peninsula Fm. and is middle Early Cretaceous age. Consisting of mafic to felsic volcanic flows, the Brokenback Hill Fm. was deposited under marine and sub-aerial conditions.

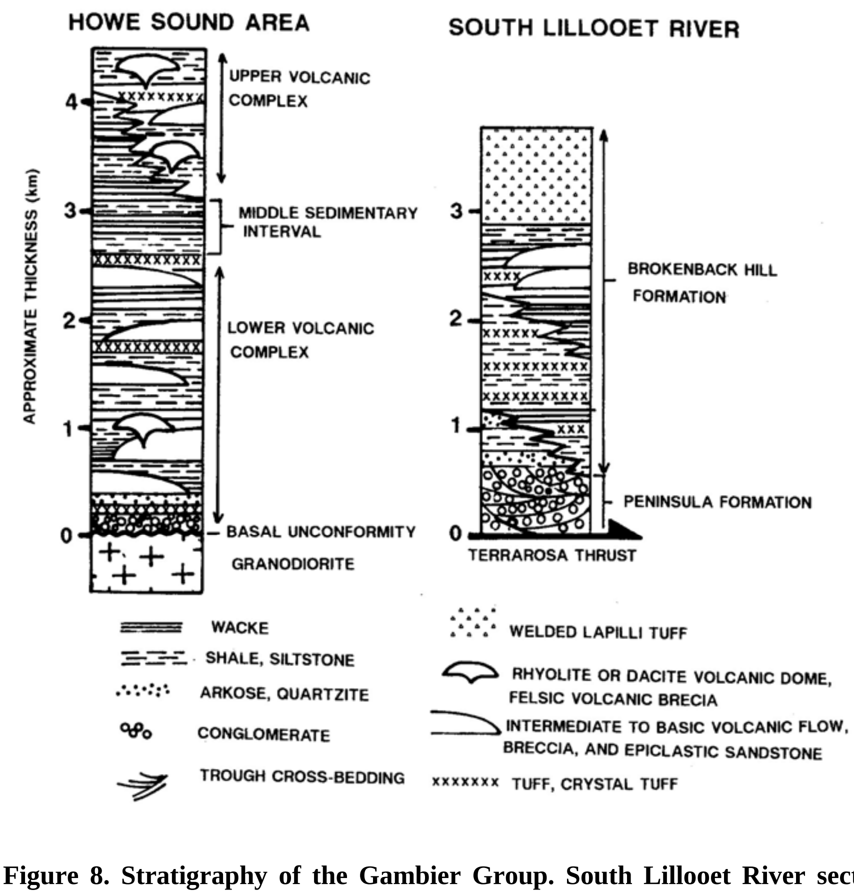

Figure 8. Stratigraphy of the Gambier Group. South Lillooet River section applicable to this field study. From Lynch (1992).

2.2.3. Cadwallader Group

Rusmore (1985) defined the Cadwallader Group as consisting of the Pioneer Formation, comprised of mafic volcanic rocks, overlain conformably by siltstone, sandstone and conglomerate of the Hurley Formation (Fig. 9). Rusmore concluded that the Cadwallader Group is Late Triassic age based on the presence of Late Carnian to Middle Norian conodonts within the Hurley formation. Mafic volcanic rocks of the Pioneer Formation consist of massive and pillowed amygdaloidal basalt, breccia and agglomerate (Schiarizza et al., 1997) that grade upward into a transitional unit of the Hurley Fm including basalt and tuff interbedded with sandstone, conglomerate and microcrystalline limestone (Schiarizza et al., 1997). Rusmore (1987) placed the Pioneer-Hurley Fm. contact at the lowest occurrence of clastic rocks. Upward, the Hurley Fm. comprises a sequence of well bedded shale, siliceous argillite and calc-arenite with local beds of polymict conglomerate (Schiarizza at al., 1997).

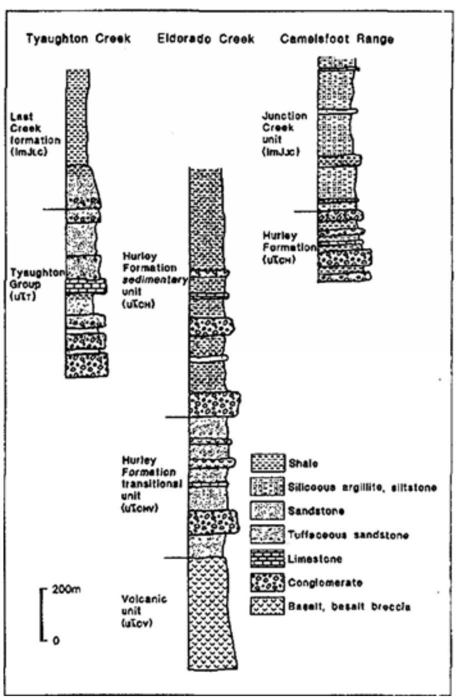

Figure 9. Stratigraphy of the Cadwallader Group, from Schiarizza et al (1997).

2.2.4. Chism Creek Schist

The Chism Creek Schist (CCS) of Rusmore (1985) is not a stratigraphic unit in and of itself, but rather a package of structurally interleaved amphibolite grade rocks found in the Eastern Cadwallader Range. Meta-chert, amphibolite, pelitic schist, mica rich quartzite, phyllitic quartzite and marble resemble units within Cayoosh Assemblage, Bridge River Complex and the Cadwallader Terrane (Price and Monger, 2000). Quartzite, pelitic schist and graphitic phyllite are the most abundant lithologies in the CCS, and point to Cayoosh rocks as the predominant parent material.

In general, metamorphosed CCS distinguishes a belt 100+ kilometers long and about 50 kilometers wide. Foliation in the rocks strikes northwest and dips steeply. The CCS is probably correlative with the Settler Schist, which is exposed east of Harrison Lake (Monger, 1991). In the Duffey Lake area, the CCS is in contact with the Mt. Rohr Pluton, part of the ~85 Ma Scuzzy Plutonic Suite (Fig. 3). The pluton is unfoliated, indicating pre-85 Ma deformation of the CCS.

2.2.5. Cayoosh Assemblage

The Cayoosh Assemblage (Journeay and Mahoney, 1994) consists of interbedded volcanic sandstone, quartzite, shale, conglomerate with plutonic clasts and volcanic layers metamorphosed to greenshist facies (Fig. 10). Fossils show that it formed during the Jurassic and Cretaceous periods. Stratigraphically, the Cayoosh Assemblage overlies the Bridge River Complex (Fig. 3). In places, contacts between the Cayoosh and Bridge River appear conformable; however, locally the units inter-finger (Monger and Journeay, 1994). This relationship indicates that the depositional environment in which the Cayoosh formed was possibly a basin within the Bridge River Complex. The conformable contact with the Bridge

River Complex is a turbidite sequence indicating deposition in an open ocean environment. Fossils found in the lower sections of the Cayoosh are Early Jurassic whereas some Middle Jurassic fossils have been found within the Bridge River (Journeay and Mahoney, 1994). This would indicate time-transgressive deposition of the Cayoosh on top of the Bridge River (Price and Monger, 2000). Overall, stratigraphy within the Cayoosh displays a change from chert-rich sedimentary facies to clastic-rich facies in Middle to Late Jurassic time, indicating a transition from oceanic to continental deposition (Price and Monger, 2000).

The Cayoosh Assemblage may be correlated with other clastic units in the southeastern Coast Belt. Price and Monger (2000) point out the close resemblance to the Brew Group (Duffel and McTaggart, 1952) in lithology and metamorphic grade. The Cayoosh may also be correlated with the Middle Jurassic-Early Cretaceous Relay Mountain Group, Gun Lake and Downton Lake units and possibly the Truax Creek Conglomerate (150-145 Ma) (Schiarizza et al, 1997). The Chism Creek Schist (Rusmore, 1985) may also be correlative. NW of Highway 99, the Relay Mountain Group overlies the Cadwallader Terrane (Schiarizza et al, 1997). The Cayoosh and correlative units may be a clastic overlap assemblage deposited on the Bridge River and Cadwallader Terranes (Price and Monger, 2000).

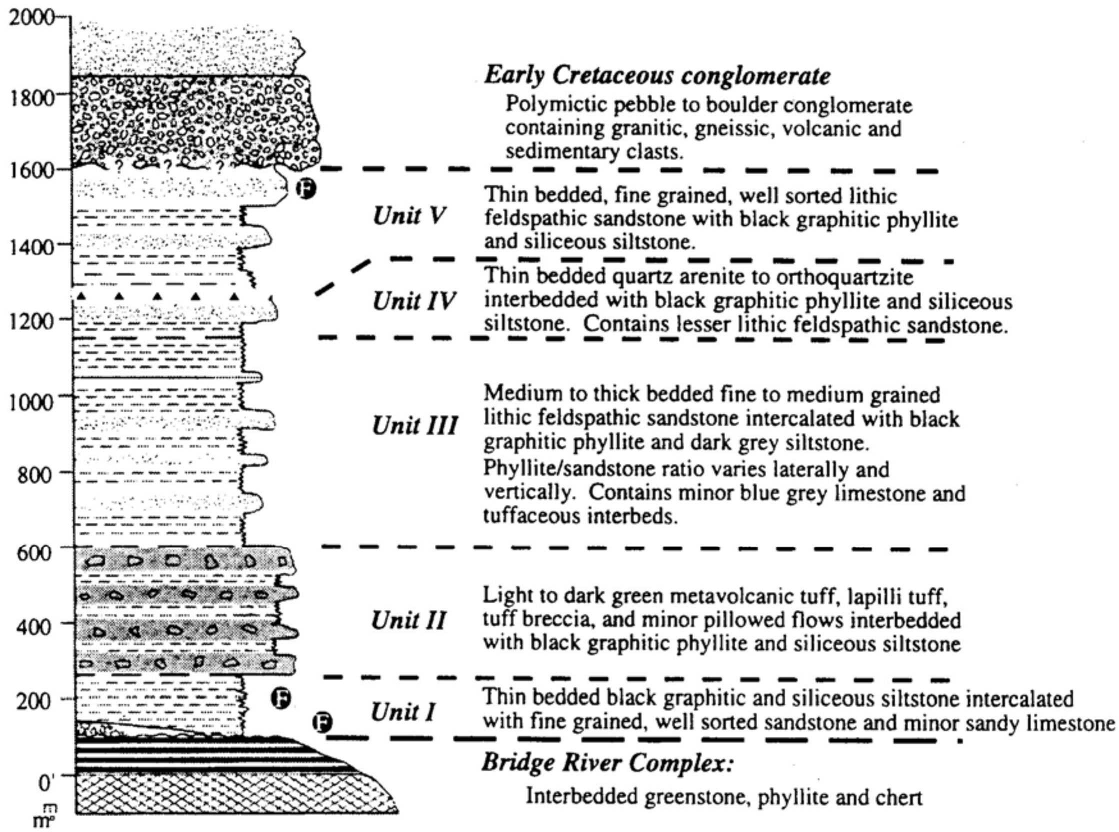

Figure 10. Stratigraphy of the Cayoosh Assemblage with unit descriptions assigned by Journeay and Mahoney (1994). Modified from Journeay and Mahoney (1994).

2.2.6. Bridge River Complex

Potter (1983) describes the Bridge River Complex (BRC), as an assemblage of chert, argillite, greenstone, gabbro, serpentinite, blueschist, and clastic sedimentary rocks that display no coherent stratigraphy. As reported by Cordey and Schiarizza (1993) and Archibald et al. (1990), chert and limestone from the BRC contain fossils of Mississippian through late Middle Jurassic ages. Blueshist metamorphism occurred in Middle to Late Jurassic time. The time-transgressive nature, complex structures and blueschist metamorphism suggest the BRC was an accretion-subduction complex.

2.2.7. Brew Group

The Brew Group of the Bridge River Terrane is a clastic succession of pelitic siltstone, volcanic rich greywacke, quartzite and matrix supported conglomerate containing argillite, granite, chert and siltstone (Duffel and McTaggart, 1952). Variably foliated and metamorphosed, it is lithologically correlative with the Cayoosh Assemblage. The Brew Group is stratigraphically below the Jackass Mountain Group and above the Bridge River Complex. Like the Cayoosh Assemblage, the Brew Group appears to have been deposited in deep water by turbidity currents. Within sandstone layers, there are shale rip-up clasts (Price and Monger, 2000). The summit of Mt. Brew, the type area of the Brew Group (Duffel and McTaggart, 1952), bivalve fossils within calcareous siltstone are Neocomian (145-127 Ma) age.

2.2.8. Jackass Mountain Group

The Jackass Mountain Group (JMG) is a member of the Methow Terrane and is Late Early Cretaceous in age, with provenance to the east. The JMG is believed to be a fore-arc complex of submarine fan deposits. Detritus was derived from volcanic rocks of the Spences Bridge Arc. The Spences Bridge Group crops out east of the Pasayten Fault, within the western Intermontane Belt (Friedman and Armstrong, 1995). Clasts within the JMG include granitic boulders of 156 Ma (U-Pb age). The lithology of the JMG is granite derived quartz and feldspar, volcanic rock, argillite and chert.

The JMG caps the Methow Terrane, unconformably overlying the fine grained clastic rocks of the Ladner Group (Jurassic-Cretaceous age). The Ladner Group in turn, unconformably overlies the mid-ocean ridge basalt of the Spider Creek Formation. The Spider Creek Fm. is of Pre-Triassic age and, along with the Coquihalla Serpentine Belt, comprises the oceanic basement of the Methow terrane.

2.3. PRINCIPAL REGIONAL FAULTS

2.3.1. Coast Belt Thrust System

The Coast Belt thrust system (CBTS) is the eastern-most edge of a system of west-vergent contractional thrust faults, which formed along the eastern boundary of the Insular Belt in late Cretaceous time (Journeay and Friedman, 1993) (Fig. 11). Rooted in the Central and Western Coast Belts, the system of east-dipping frontal thrusts imbricates Jurassic and Early Cretaceous arc sequences and plutonic suites. The Central Coast Belt detachment marks the eastern boundary of the CBTS and the border between the imbricated arc sequences of the Western Coast Belt and the folded high-pressure stack of metamorphosed island arc and oceanic rocks of the Central Coast Belt (Journeay and Friedman, 1993). A two stage history of shortening on the CBTS is recorded by structural and geochronologic data. The early stage involved the accretion of arc and basin sequences of the Insular Belt to the western margin of the Western Coast Belt. Synorogenic plutonic suites bracket the timing of these early structures to 97-96 Ma. Late stage (91-94 Ma) shortening involved fold and thrust telescoping inboard of the Western Coast Belt (Journeay and Friedman, 1993).

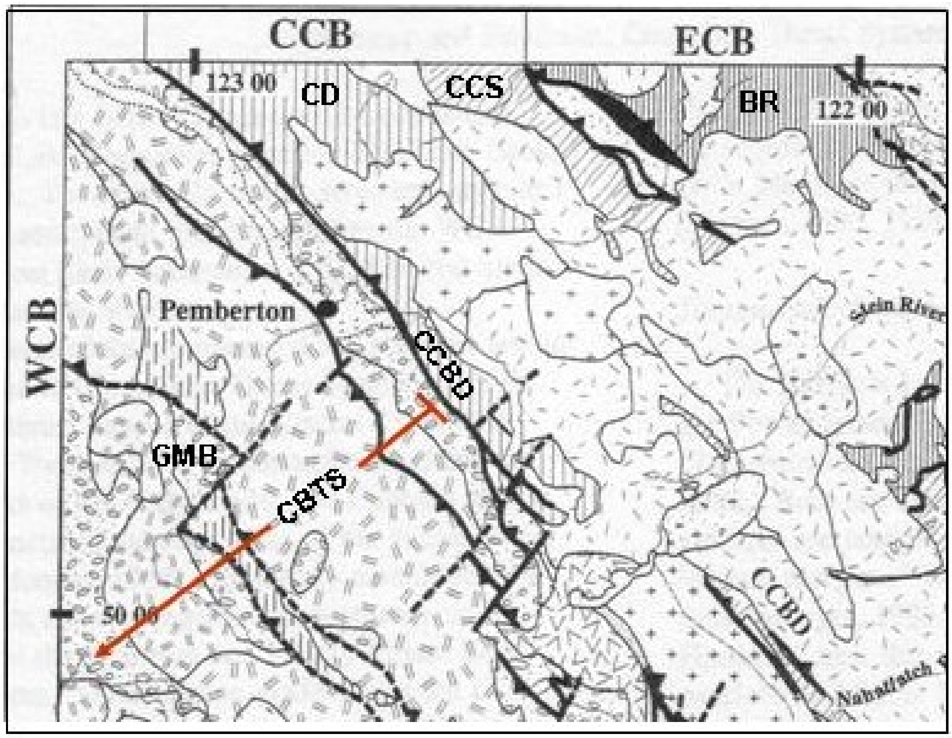

Figure 11. Simple map showing the location of the Coast Belt Thrust System (CBTS). CCBD=Central Coast Belt Detachment, WCB=Western Coast Belt, CCB=Central Coast Belt, ECB=Eastern Coast Belt, CD=Cadwallader Group, CCS=Chism Creek Schist, BR=Bridge River. Modified from Journeay and Friedman (1993).

2.3.2. Oligocene-Miocene Age Faults

The Green Lake Fault cuts the Gambier Group and other rocks of the Whistler pendant (Monger and Journeay, 1994). Within the Western Coast Belt (Fig. 2), there are a series of northeast striking right lateral oblique-slip faults which offset elements of the Western Coast Belt and faults of the Coast Belt Thrust System (Fig 12). This system was active in Oligocene-Miocene age (~25-14 Ma) (Price and Monger, 2000). Within this field study area, it is believed to be responsible for northeast striking foliation within Early Cretaceous granitic rocks to the east of the town of Whistler (Coish and Journeay, 1992).

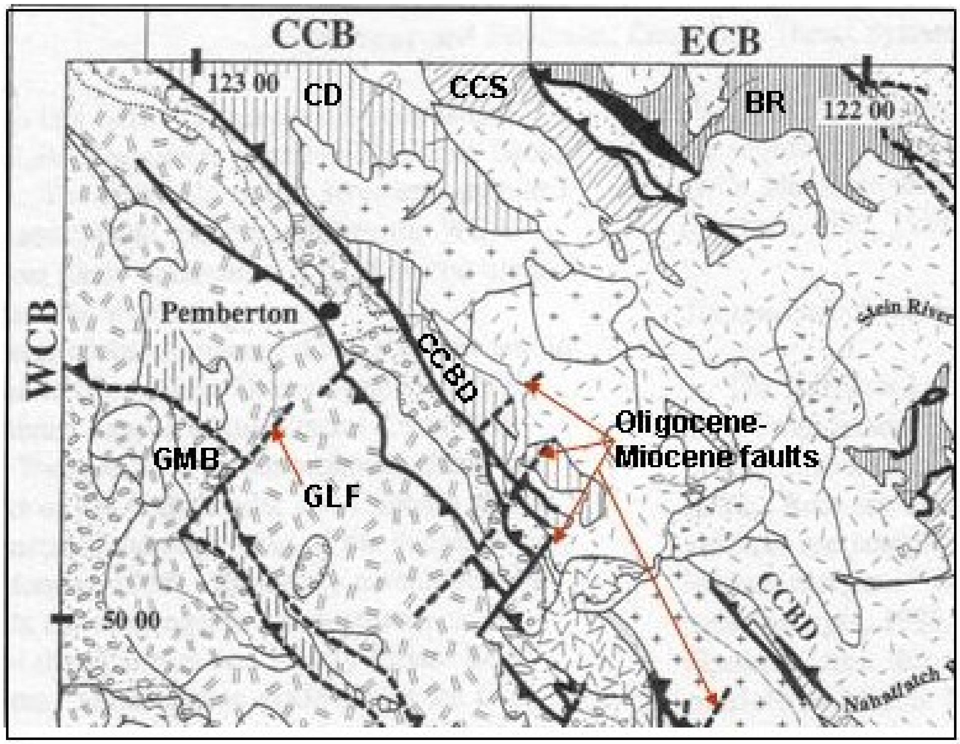

Figure 12. Simple map showing the location of major northeast-striking Oligocene-Miocene faults which cut elements of the Western Coast Belt and Coast Belt thrust system. Modified from Journeay and Friedman (1993).

2.3.3. Twin Lakes/Bralorne Fault System

The Bralorne-McGillivray Pass-Twin Lakes fault system (Figs. 13, 14) is the boundary between the eastern Coast Belt and central Coast Belt and marks the western edge of the Bridge River terrane within the Bendor/Cayoosh Range (Rusmore, 1985; Leitch, 1989; Journeay et al., 1992). It is a system of northwest-trending faults that imbricates slivers of Bridge River Complex, Cayoosh Assemblage and Chism Creek Schist, (Journeay et al., 1992). Encountered in this study is the Twin Lakes segment of the system. It consists of top to the southwest thrust faults and oblique left slip faults (Price and Monger, 2000). There are two distinct packages of rock flanking the fault system. The hanging wall is made up of imbricated Bridge River and Cayoosh Assemblage rocks and the footwall is Chism Creek Schist (Price and Monger, 2000). Age constraints on the fault system are given by the Scuzzy Pluton, U-Pb dated at 85 Ma, which cuts the fault and mesothermal gold quartz veins. These shear related veins are found along the Bralorne section of the fault system and formed between 91-86 Ma (Leitch, 1989). A hypothesis that this system is related to episodes of large-scale crustal shortening along the eastern margin of the Insular Superterrane in Late Cretaceous time (Price and Monger, 2000) is supported by this timing.

2.3.4. Downton Creek Fault

The Downton Creek Fault (DCF) (Figs. 13, 14) delineates the boundary between greenstone-chert-argillite successions of coherent Bridge River Complex to the west of the fault and sheared mélange to the east of the fault. The DCF records a complex history of top to the southwest thrusting and right-lateral strike slip movement (Journeay et al., 1992). North of Anderson Lake, the fault juxtaposes the Cayoosh Assemblage and the Bridge River Complex, with the Cayoosh in the footwall. Top to the southwest movement is recorded by asymmetric folds and shear bands in the footwall along the fault while subhorizontal lineations and asymmetric southeast verging folds record a less prominent component of right lateral displacement. The DCF cuts the Castle Pass Fault, which was dated by Garver et al., 1989 as active between 91 and 86 Ma. The Cayoosh Pluton, part of the 63-57 ma Bendor Plutonic Suite, cuts the DCF and appears to be post kinematic (Roddick, 1987). Using these relationships, the DCF is believed to have been active at ~77 Ma

2.3.5. Cayoosh Creek Fault

About 10 km southwest of Lillooet, the contact between the overlying Middle Triassic-Middle Jurassic Bridge River Schist and the Upper Jurassic-Lower Cretaceous Brew Group is exposed along the Cayoosh Creek Fault (Coleman and Parrish, 1991) (Figs. 13, 14). It is interpreted as a thrust fault because of the juxtaposition of older units above younger units

(Coleman and Parrish, 1991). Though not mapped in detail, it appears to be a shallow, northeast dipping fault. Post Mid-Eocene dextral movement on the Marshall Creek Fault may have displaced the Cayoosh Creek Fault, missing from the footwall of the Mission Ridge Fault to the east (Price and Monger, 2000).

2.3.6. Marshall Creek Fault

North of Carpenter Lake, the Marshall Creek Fault (MCF) consists of two strands. The southwest strand of the fault cuts Eocene sedimentary rocks and is mapped as a steep southwest dipping normal fault (Journeay et al., 1992). The northeast strand juxtaposes greenschist rocks of the Bridge River Complex (BRC) with prehnite-pumpellyite facies BRC rocks (Journeay et al., 1992). The proposed order of events in the Eocene on these two fault systems is dextral strike slip on the Marshall Creek Fault, followed by down to the northeast normal faulting on the Mission Ridge Fault followed by down to the southwest displacement on the Marshall Creek Fault (Journeay et al., 1992; Coleman, 1990). The Fraser River Fault, which extends to the south into Washington, is a right lateral strike slip fault active between 46-36 Ma. The MCF is truncated in the southeast by the Fraser River Fault and extends northwestward for ~135 km to its junction with the Yalakom Fault (Monger, 1989; Glover et al., 1988, Schiarizza et al., 1990) (Figs. 13, 14).

2.3.7. Mission Ridge Fault

The Mission Ridge Fault (Figs. 13, 14) juxtaposes low grade rocks of the Bridge River Complex in the hanging wall from upper greenschist-lowest amphibolite grade rocks of the Bridge River Schist in the footwall (Coleman and Parrish, 1991). It is a northeast dipping Eocene normal fault which cuts deformed rocks of the Mission Ridge Pluton (47.5 +/- 2Ma). Coleman (1990) observed a normal displacement of the Mission Ridge Fault along the Marshall

Creek Fault of ~3.5 km. This displacement may also explain the disappearance of the Cayoosh Creek Fault in the hanging wall of the Mission Ridge Fault.

2.3.8. Yalakom Fault

The Yalakom Fault (Figs. 13, 14) serves as the geologic boundary between the Coast Belt and the Intermontane Belt of Southern British Columbia. It displaces parts of the Cadwallader, Bridge River and Methow Terranes (Umhoefer and Schiarizza, 1996). In Middle Cretaceous time, the fault accommodated contractional deformation, followed by major dextral strike slip movement in the Late Cretacous and Early Tertiary (Eocene). Umhoefer and Schiarizza (1996) estimate ~120 km of dextral offset on the Yalakom Fault System, based on offset of structures on the Bridge River, Cadwallader and Methow Terranes. Umhoefer and Schiarizza also speculate that all but ~10 km of the dextral offset happened in Eocene time.

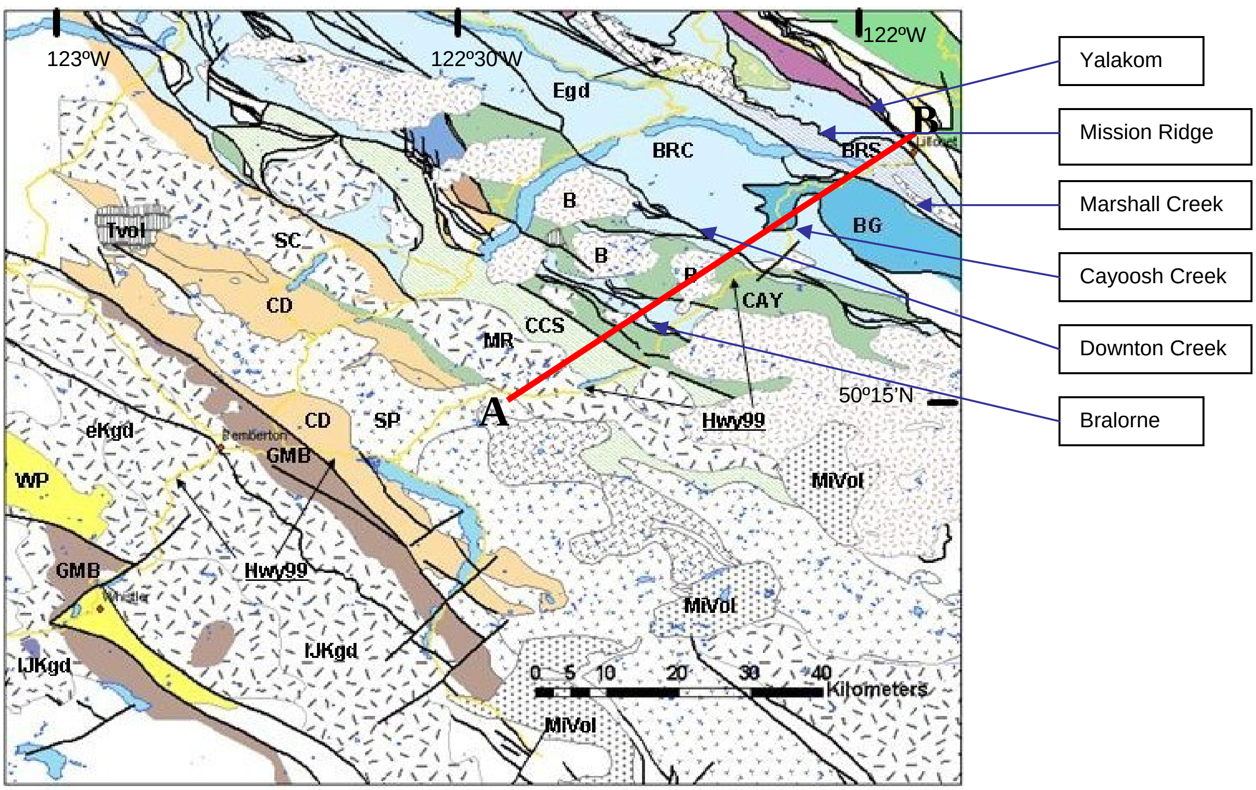

Figure 13. Map showing the cross-section transect of Fig. 14. Units labeled as in Fig. 3. Modified from Massey et al. (2005). Faults seen in Fig. 14 are labeled with arrows to the right of the figure.

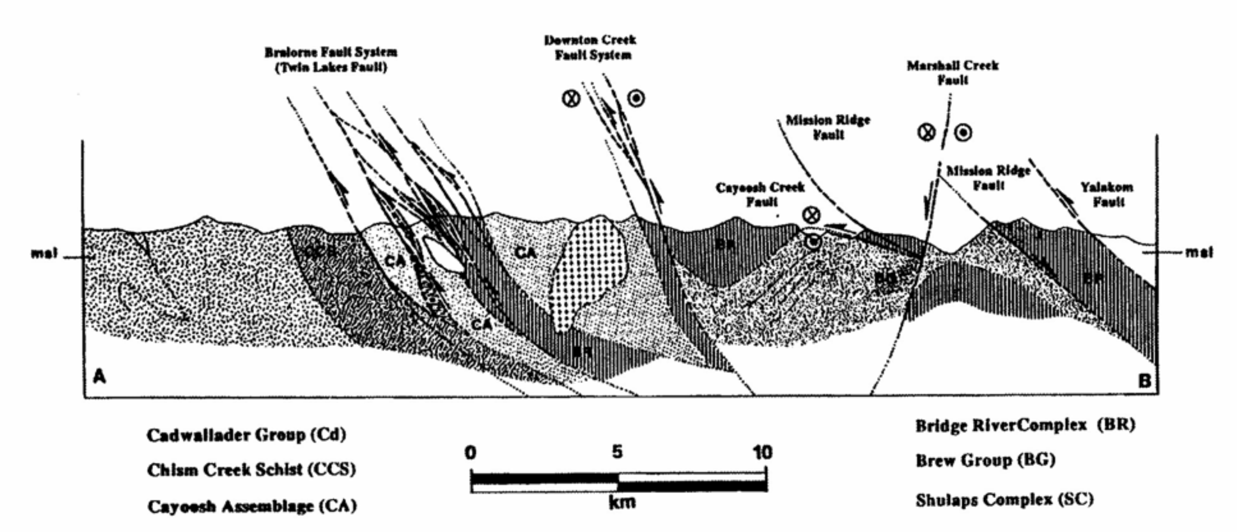

Figure 14. Cross section of Cretaceous fault systems of the Eastern Coast Belt showing the imbrication of meta-sedimentary sequences and cross-cutting relationships with early Late Cretaceous plutons. From Price and Monger (2000).

2.4. THE COAST PLUTONIC COMPLEX IN THE SOUTHERN COAST BELT

Granitic rocks of 167-145 Ma age are the oldest intrusive rocks of the Coast Plutonic Complex. Friedman and Armstrong (1995) call these rocks the Early Coast Plutonic suite. They are comprised of diorite to quartz monzonite and mafic members are common. Alteration is common in rocks of this age and penetrative fabrics are developed along discrete fault zones (Friedman and Armstrong, 1995). Late Jurassic plutons are restricted to the Western Coast Belt and provide a tie between the Southern Coast Belt (SCB) and Wrangellia by Late Jurassic time. Within the Western Coast Belt, 167-145 Ma rocks occur in two northwest trending belts. A western belt, 10-20 km wide, extends for ~130 km northwest from Vancouver. An eastern belt, 50-70 km wide, comprises much of the eastern half of the western Coast Belt (Friedman and Armstrong, 1995). Late Jurassic plutons crop out west and east of the town of Whistler in this study (Fig. 15).

Granitic rocks of 145-112 Ma age occur exclusively within the western Coast Belt and Eastern Insular Belt in a ~50 km wide, ~150 km long belt (Friedman and Armstrong, 1995).

Rocks of this age in the study area are located near the town of Pemberton, within the Pemberton Diorite Complex (PDC) (113 Ma) (Fig. 15). Friedman and Armstrong (1995) report ductily deformed rocks within the PDC and Roddick (1965) describes the PDC as a heterogeneous assemblage of hornblende and quartz diorite, granodiorite and amphibolite. Friedman and Armstrong (1995) document the presence of Late Jurassic (164-171 Ma) granitic rocks intruded by the PDC which they assume to be pre-Gambier Assemblage. These rocks are intruded by tonalite of probable post-Gambier age. Ductile deformation affects Late Jurassic rocks

Mid-Cretaceous (112-90 Ma) plutons are some of the largest of the Southern Coast Belt. Within this field area, the 103 Ma Spetch Creek pluton falls in this age group (Friedman and Armstrong, 1995) (Fig. 15). The Spetch Creek pluton bifurcates rocks of the Cadwallader Group and is cut by Late Cretaceous plutons to the south, probably equivalents of the Mt. Rohr pluton. Located in the Central Coast Belt, the Spetch Creek pluton lies in the hanging wall of the east-dipping Coast Belt thrust system (CBTS). Timing of activity along CBTS has been constrained to 97-91 Ma by Journeay and Friedman (1993) through the dating of pre-, syn-, and post-kinematic intrusions along the thrust system. Within the study area, no foliated rocks of the Spetch Creek were encountered, lending to the conclusion that deformation within the Cadwallader Group is pre-103 Ma.

Late Cretaceous (90-65 Ma) plutons of the Southern Coast Belt are generally undeformed and post-date any deformation on the Coast Belt Thrust System. Within this field study area, the Scuzzy-Mt. Rohr plutonic suite and the Bendor plutonic suite are members of this age group (Fig. 15).

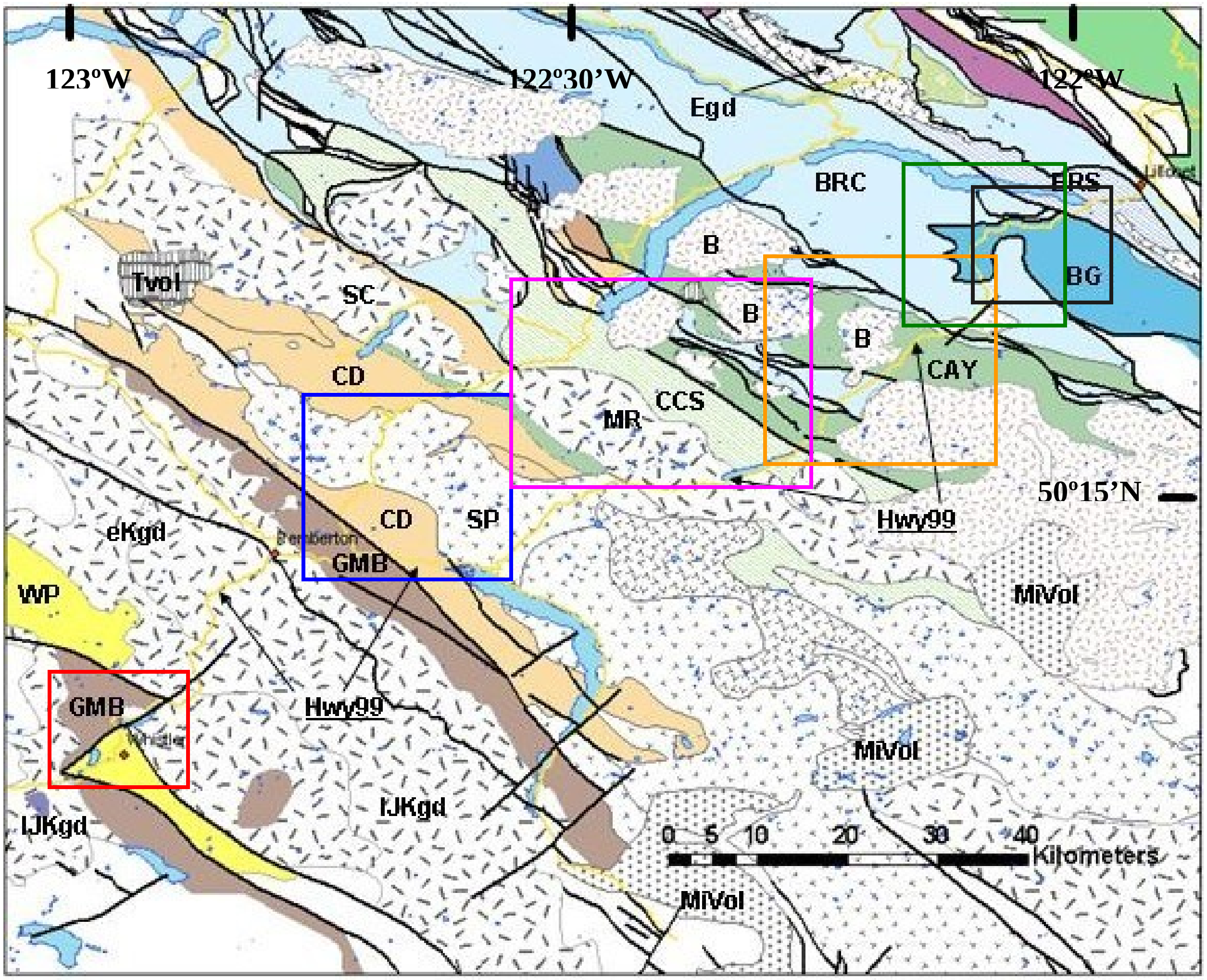

Figure 15. Detailed map of the field area of this study. GMB=Gambier Group, WP=Whistler Pendant, CD=Cadwallader Group, CCS=Chism Creek Schist, CAY=Cayoosh Assemblage, BRC= Bridge River Complex, BG=Brew Group, BRS=Bridge River Schist; Rocks of the Coast Belt plutonic complex include: lJKgd=Late Jurassic/Cretaceous granodiorite, eKgd=Early Cretaceous granodiorite, SP=Spetch Creek Pluton, SC=Scuzzy Pluton, MR=Mission Ridge Pluton, B=Bendor Pluton, vol=volcanic rocks. Highway 99 in yellow and labeled. Red box=Whistler sample area, Blue box=Cadwallader Group sample area, Pink box= Chism Creek Schist sample area, Orange box=Cayoosh Assemblage sample area, Green box=Brew Group sample area, Black box=Bridge River Complex sample area. Modified from Massey et al. (2005).

3. DESCRIPTION OF FIELD DATA

Following are detailed descriptions of separate suites of samples from the Whistler Pendant, Cadwallader Group, Chism Creek Schist, Cayoosh Assemblage, Bridge River Complex/Schist, and the Brew Group. A lithologic and mineralogic evaluation of each rock unit, followed by an evaluation of outcrop-scale structures and micro-structures found in thin-section is included in these sections. Numbers on the sample area maps indicate sampling locations.

3.1. WHISTLER SUITE

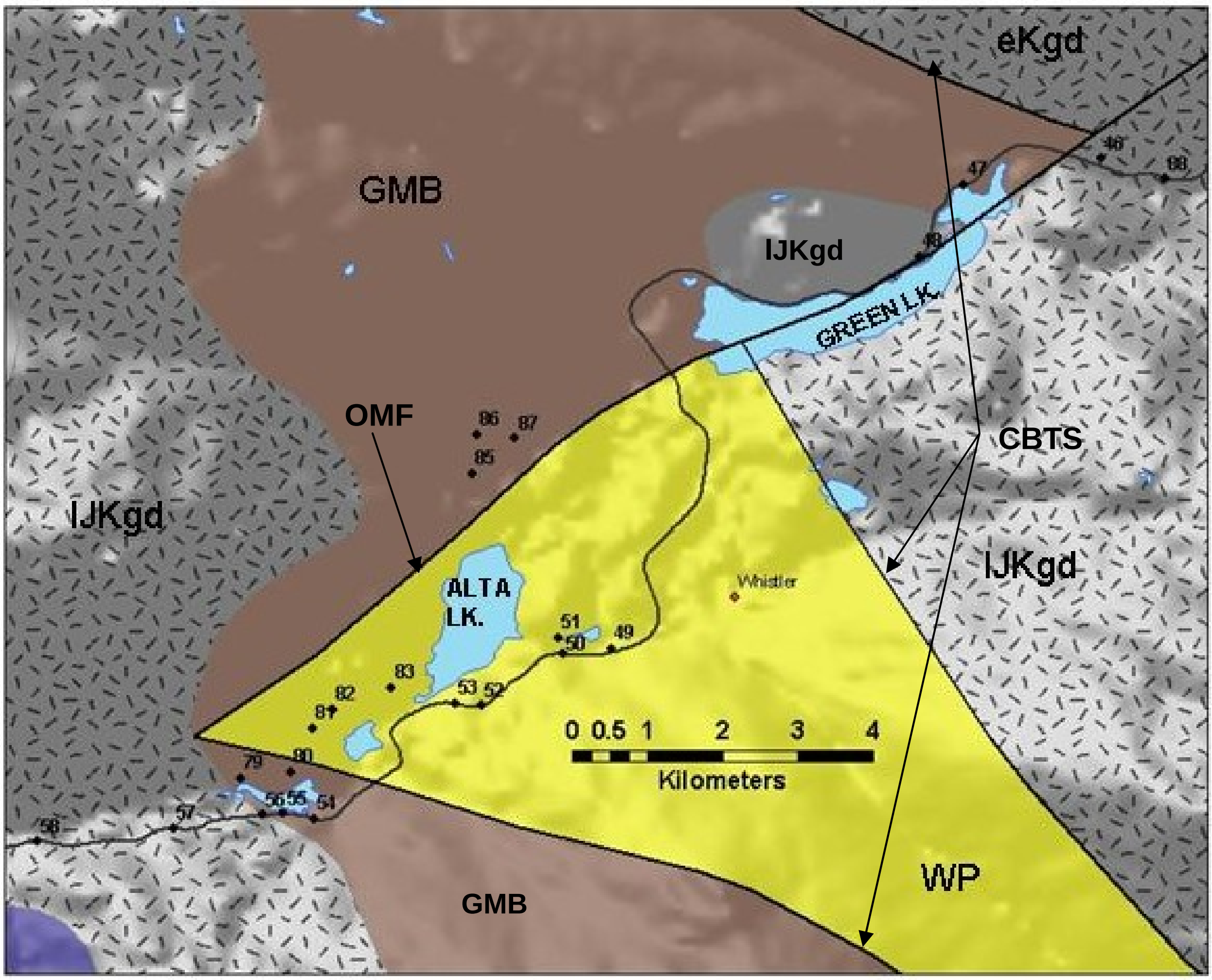

Figure 16. Detailed geologic map of the Whistler field area with Station numbers. GMB=Gambier, WP=Whistler Pendant, gd=granodiorite, OMF=Oligocene-Miocene Fault, CBTS=Faults of the Coast Belt thrust system. Modified from Massey et al. (2005).

3.1.1. Lithologic Classification

The transect through the Whistler area of southwestern British Columbia crosses plutonic and metamorphic rocks (Figs. 15, 16). The metamorphosed rocks are flanked to the west by variably foliated Late Jurassic plutons and, to the east by Early Cretaceous and undated plutons (Friedman and Armstrong, 1995). The metamorphic rocks compose fault bounded pendants of Gambier Group (GMB) and un-named rocks composed of meta-sediments and meta-volcanics (WP) (Fig. 17). Twenty-eight hand samples and 14 thin sections are included in the study of this area.

Figure 17. Steeply dipping schistose rocks typical in exposures of the Gambier Group surrounding Whistler. Notice the brittle nature of the rock and the yellow/brown weathering.

The transect begins ~10km southwest of the town of Whistler at Station #58 (Fig. 16) within coarse-grained Late Jurassic granodiorite composed mainly of quartz, plagioclase feldspar with dark minerals such as hornblende and biotite (in places altered to chlorite). Euhedral pyrite occurs as a trace mineral. The granodiorite may be foliated or unfoliated. Foliated rocks are phyllitic with micaceous minerals defining the principal foliation plane. Foliated and unfoliated rocks have similar mineralogy, and are interpreted to be of the same parent.

Northeast along Highway 99 at Station #57 (Fig. 16), the rocks are highly foliated, fine grained quartz, plagioclase feldspar, mica schist. Although much finer grained, the broken quartz and plagioclase crystals resemble the granodiorite to the southwest. Friedman and Armstrong (1995) map this area as Late-Jurassic intrusives.

A sample collected further northeast at the contact between the granodiorite and the Gambier Group displays mineralogy and strong foliation similar to the rocks to the southwest. It appears to have been a granodiorite metamorphosed to schist, with quartz, plagioclase and micaceous minerals. It shows more defined mineral segregation than samples to the southwest, and is coarser grained, with minor calcite along the foliation planes.

Within the Gambier Group (Armstrong, 1953; Roddick, 1965) samples are comprised of very fine grained rock with splintery or blocky fracture. They consist of fine grained matrix comprised of plagioclase, mica and chlorite surrounding larger grains (<1mm) of highly altered, fractured plagioclase, recrystallized aggregates of quartz and rock fragments. The mineralogy suggests volcanic porphyry of intermediate to felsic composition (Fig. 18)

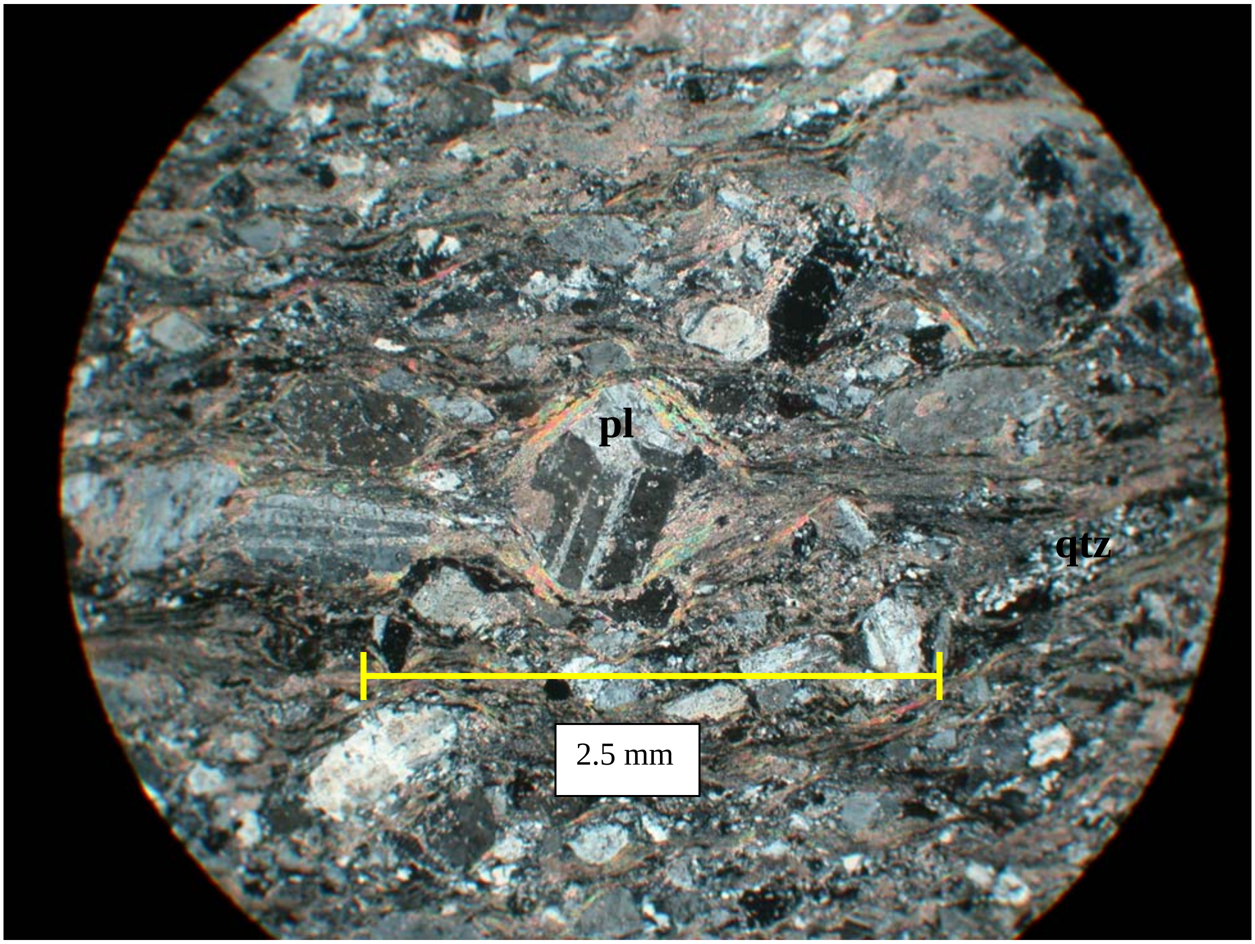

Figure 18. Photo-micrograph of sample from Station 87 cut parallel to strike and perpendicular to foliation. Photo shows large grains of plagioclase feldspar and quartz aggregates in a fine grained matrix of plagioclase, quartz, mica and chlorite. Notice the symmetric tails to the left and right of the large grain in the center of the photo, indicative of pure shear movement.

3.1.2. Field Measurements and Structural Analysis

Highway 99 and Alta Lake Road (Fig. 16) pass through the Gambier Group and un-named arc-derived sediment consisting of mineralogy very similar to rocks of the Gambier Group, before crossing the eastern contact with Early Cretaceous and un-dated intrusions. The average orientation of foliation within the Whistler pendant is N38ºW, 82ºNE (Fig. 19). Northeast and northwest striking faults cut the pendant. Along the northeast striking faults, foliation commonly strikes northeast with top-down to the southeast, normal sense of movement. Foliation is consistently stronger in the dip direction, indicating dip-slip movement to be the dominant mode of transport. In domains of northwest striking foliation, asymmetric tails on euhedral pyrite crystals are present in thin sections cut parallel to the dip and perpendicular to foliation (Station #53) (Figs. 20, 80-App B). At Station #51, kink folds on the foliation plane are oriented paralle to the strike direction (Fig. 21). The average fold-axis orientation at this location is 0º, N22W. Foliation at this location is N32ºW, 64ºNE. The asymmetry of the folds gives the sense of top-down to the northeast extensional movement.

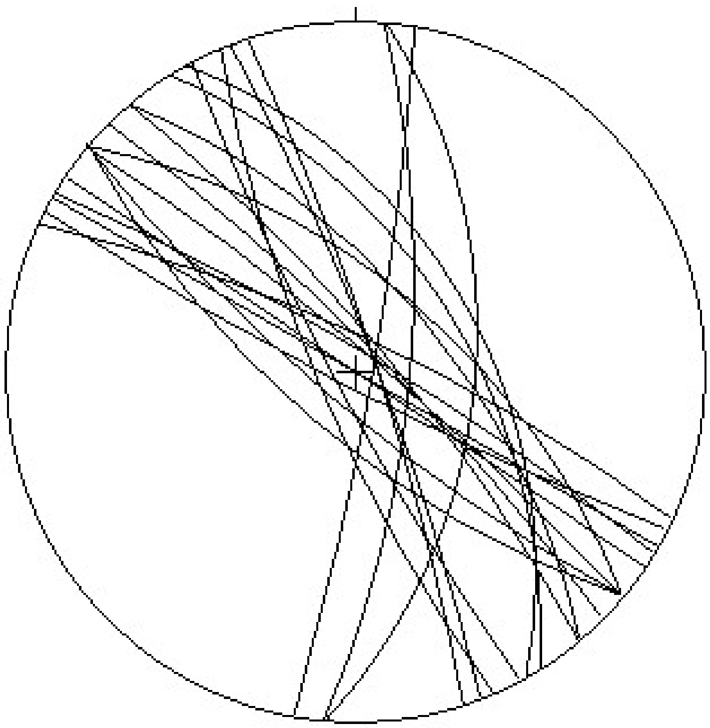

Figure 19. Equal area plot of 22 foliation planes within the Whistler Pendant. North is oriented to be at the top of the equal area plot. All equal area plot are oriented in this manner.

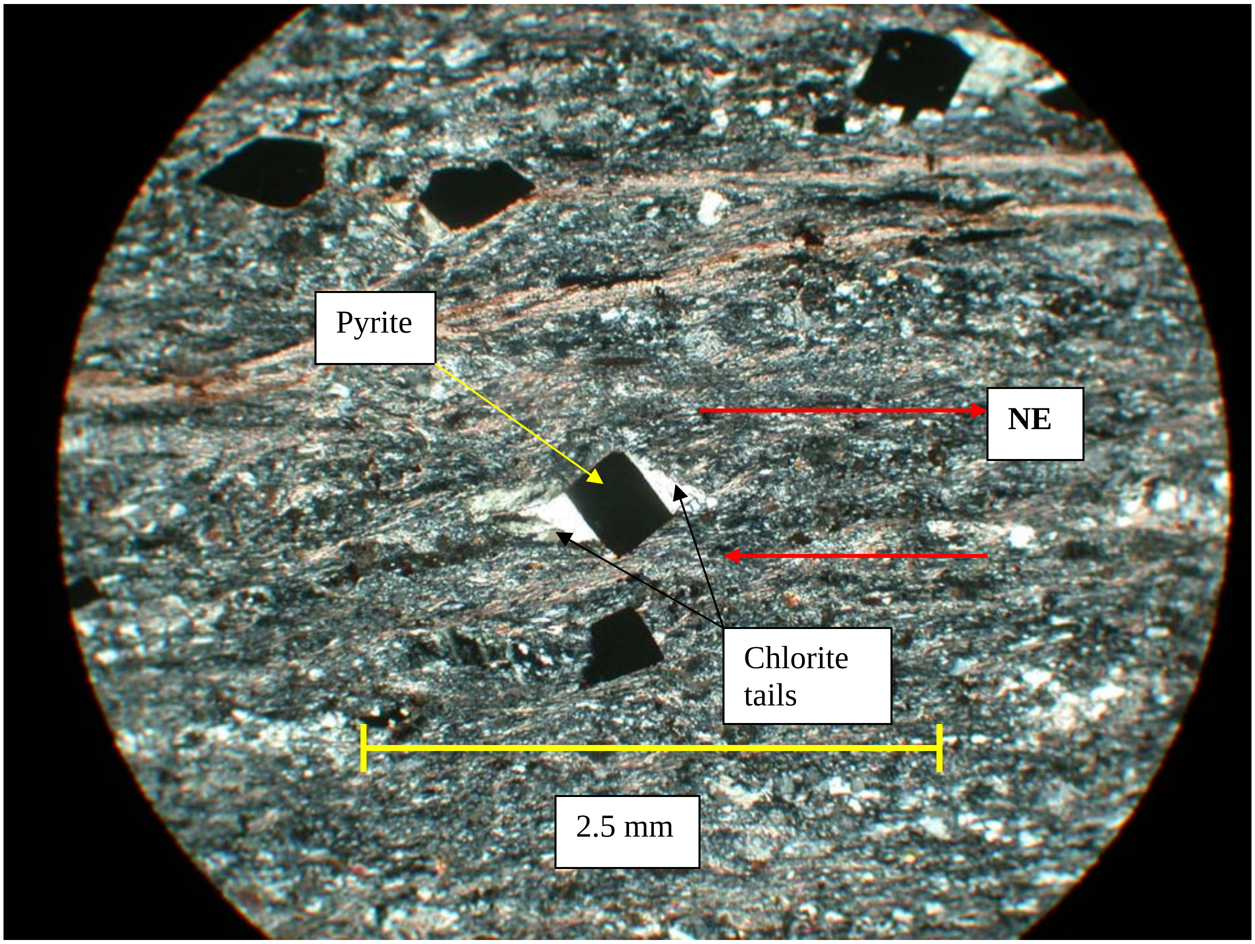

Figure 20. Photomicrograph of sample from Station #53 showing asymmetric tails on a pyrite crystal. Sample was cut parallel to dip direction and perpendicular to the foliation plane. Sense of movement is top-down, to the northeast. Arrows indicate the sense of movement.

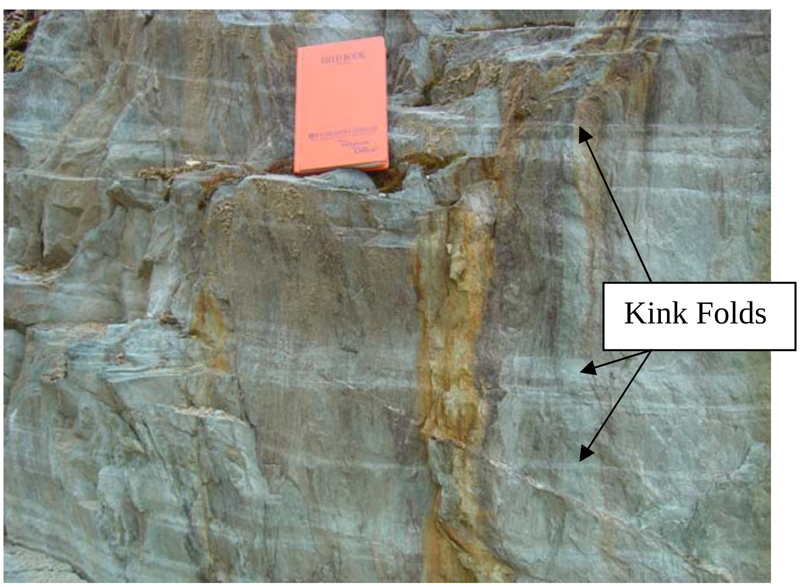

Figure 21. Horizontal mono-clinal kink folds in the Whistler Pendant indicative of dip-slip movement.

3.2. CADWALLADER SAMPLES

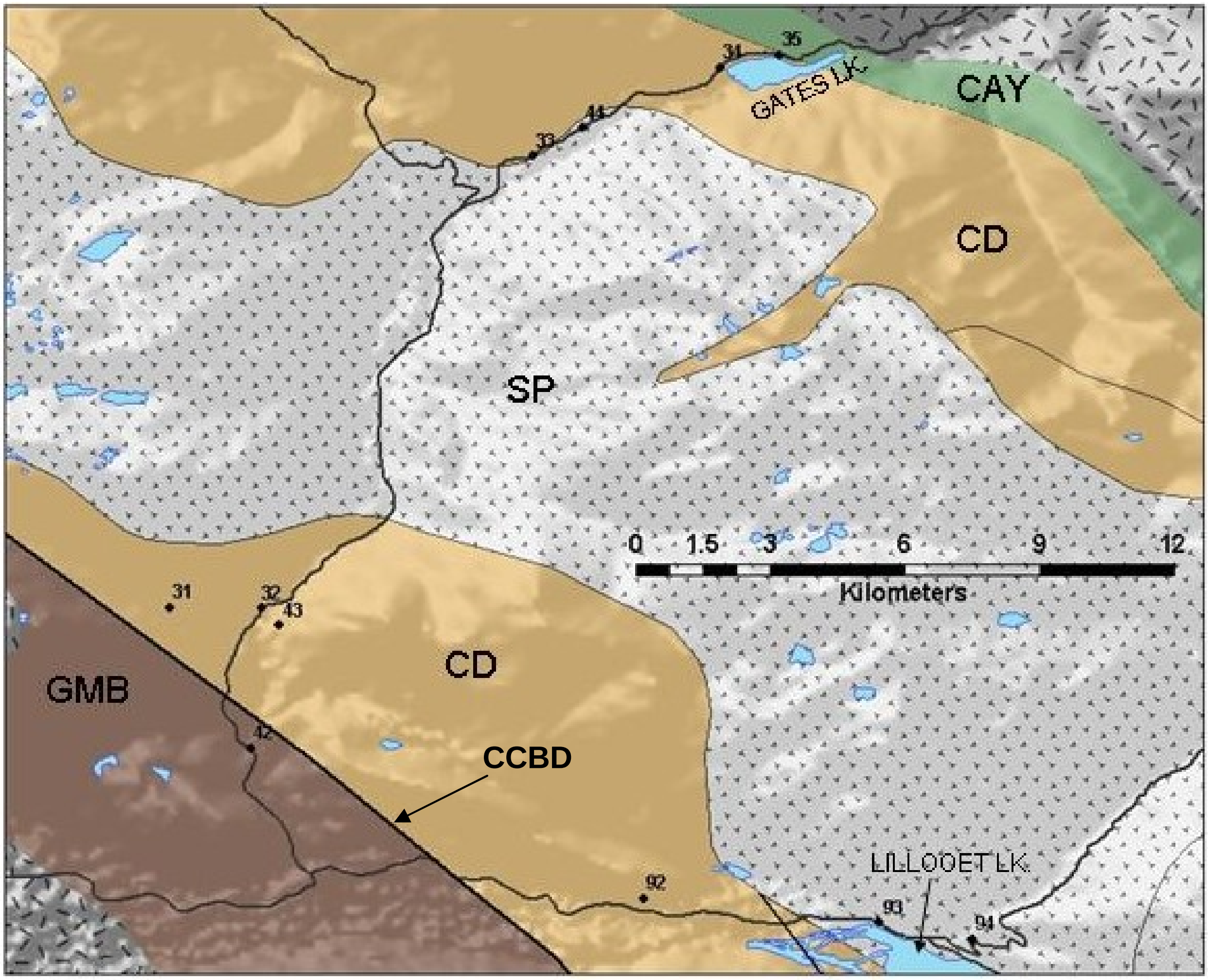

Figure 22. Detailed geologic map showing the locations of samples from the Cadwallader Group. GMB=Gambier Group, CD=Cadwallader Group, SP=Spetch Creek Pluton, CAY=Cayoosh Assemblage, CCBD=Central Coast Belt detachment. Modified from Massey et al. (2005).

3.2.1. Lithologic Classification

The Cadwallader Group crops out at multiple locations in the Southern Coast Belt as shown by Friedman and Armstrong (1995). Within the field area, exposures compose an elongate panel bound on the southwest by the Gambier Group and to the northeast by the Cayoosh Assemblage and Scuzzy Pluton (Fig. 22). The Spetch Creek Pluton intrudes the Cadwallader, splitting it into northeastern and southwestern belts (Friedman and Armstrong, 1995) (Figs. 15, 22). The Cadwallader includes the mafic volcanic rocks of the Pioneer

Formation conformably underneath the interbedded clastic rocks and volcanics of the lower transitional unit of the Hurley Formation. The upper Hurley is clastic with no volcanic members (Rusmore, 1985). Among the exposures of Cadwallader rocks, four samples were collected and Sample #33 was thin-sectioned. One sample was collected along Hwy 99. Heading north out of the city of Mount Currie toward Birkenhead Lake yielded three samples.

Outcrops of the western belt of the Cadwallader are composed of generally unfoliated and fine grained rocks of intermediate to mafic composition. North of Mount Currie and east on Hwy 99 are unfoliated, fine grained dark andesite crops out at Stations #31, 32, 43 and 92. These rocks match the lithology of the Pioneer Formation of Rusmore (1985). The northeast belt of the Cadwallader exposes very fine grained (<.1mm), highly foliated rock comprised of plagioclase feldspar, hornblende, chlorite, quartz and clino-zoisite (Sample #33) and also unfoliated siliceous argillite (Sample #34). Within Sample #33, chlorite and hornblende form thin, dark laminae among the crystals of plagioclase and quartz. This sample may have been derived from a sandstone or tuffaceous sandstone of Rusmore's lower Hurley Formation based on its felsic mineralogy. The lithology and mineralogy of Sample #34 correlates with rocks found in the clastic upper Hurley Formation (Rusmore, 1985).

3.2.2. Field Measurements and Structural Analysis

Overall, the average foliation in deformed rocks of the Cadwallader Group measures N12ºW, 86ºNE (Fig. 23). Rusmore (1985, 1987) and Schiarizza et al. (1997) do not report any zones of brittle or ductile deformation within the Cadwallader but two discrete zones were encountered north of the town of Mount Currie. Rocks at Stations #31, 32 and 43, within the southwest belt of the Cadwallader, show brittle and ductile deformation. The average foliation within zones of brittle deformation at these three stations measures N42ºW, 65º SW to NE. Sub-horizontal lineations within the brittle shear zone at Station #32 suggest strike-slip movement. A discrete ductile shear zone at Station #32 is 2-3m wide and the average foliation measures N27ºE, 90º. A sub-horizontal lineation within this ductile deformation plunges 3º, S30ºW. This ductile shear zone is flanked by unfoliated mafic feldspar porphyry.

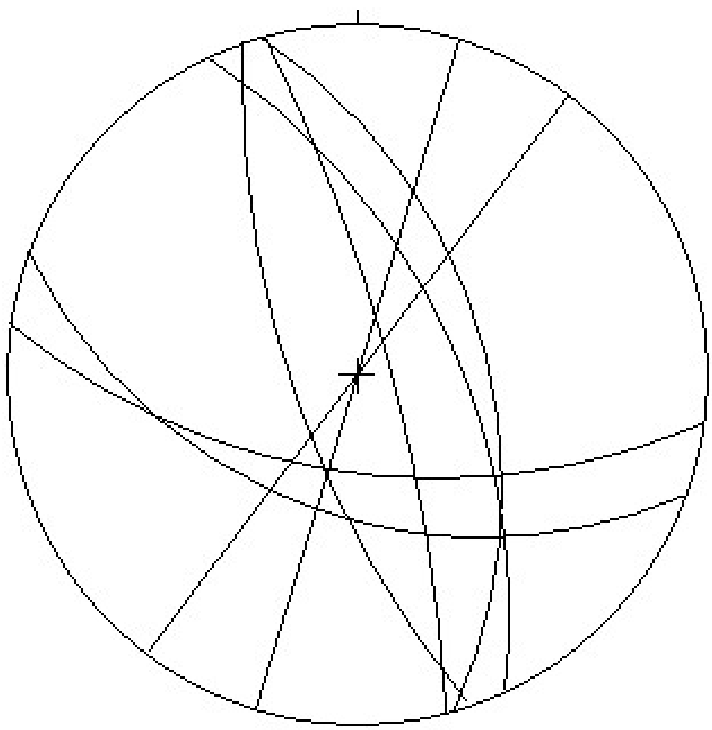

Figure 23. Equal area plot of 8 foliation measurements within the Cadwallader Group

At Station #33, in the northeast belt of Cadwallader, foliation in plagioclase feldspar-hornblende-quartz rich mylonite is N15ºW, 82ºNE (Figs. 24, 25, 82-App B). In thin section, parallel to strike and perpendicular to the foliation plane, the foliation is difficult to distinguish. Compositional layering is present but there are no flattened or aligned grains which delineate the foliation plane (Fig. 26). In contrast, a section cut parallel to the dip direction and perpendicular to the plane of foliation shows flattened, elongate grains of feldspar, quartz, hornblende and chlorite which are aligned with the foliation plane, lending to the conclusion that pure shear was not the dominant mode of transport at this location (Fig. 27). The minerals are recrystallized as a result of the close proximity to the Spetch Creek Pluton, so it is difficult to pick out shear-sense indicators, but the elongate grains are suggestive of dip-slip movement. At Station #33, the thinly banded texture and tightly folded, recrystallized mineralogy suggest that the rock was partially melted and began to take on a migmatitic texture (Figs. 24, 25). The down-dip lineation could be the result of upward movement of the Spetch Creek Pluton and partial melting of country rock at its boundaries.

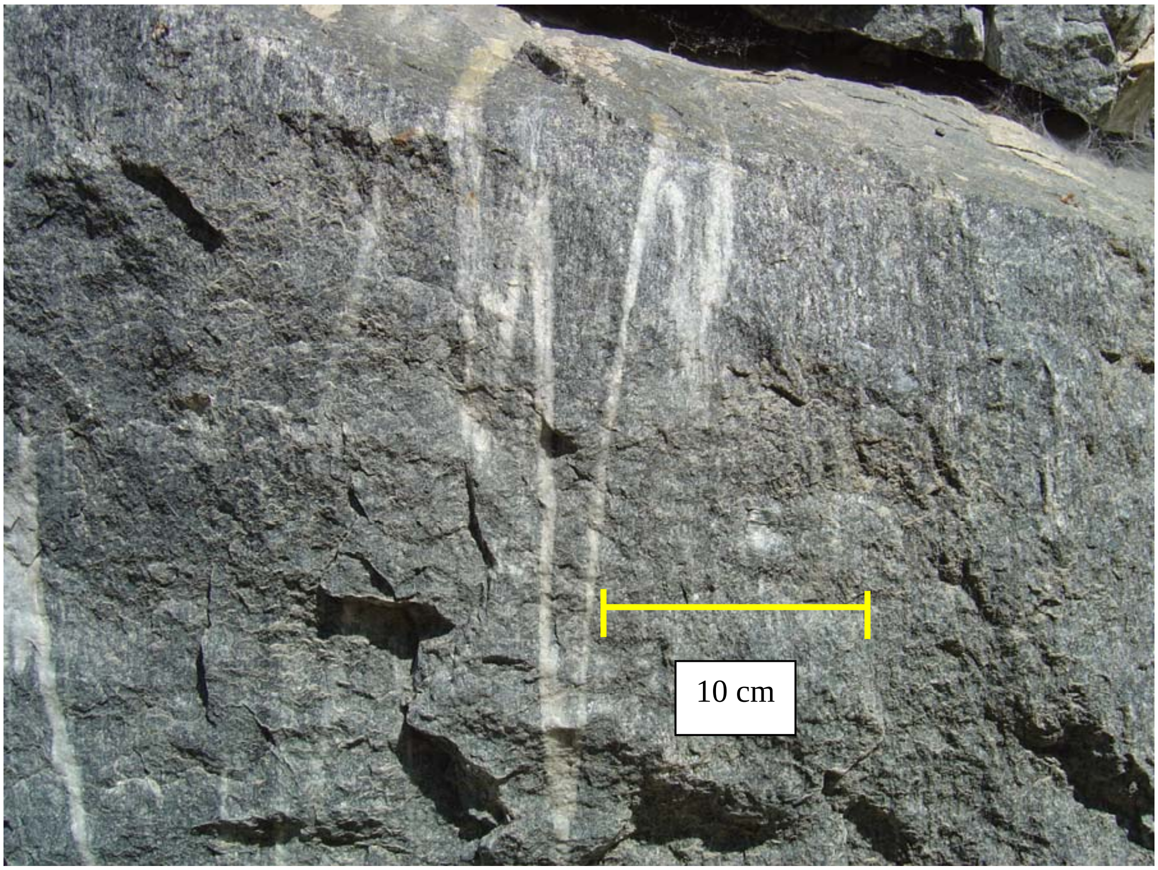

Figure 24. Mylonite within the northeastern belt of Cadwallader Group rocks at Station #33.

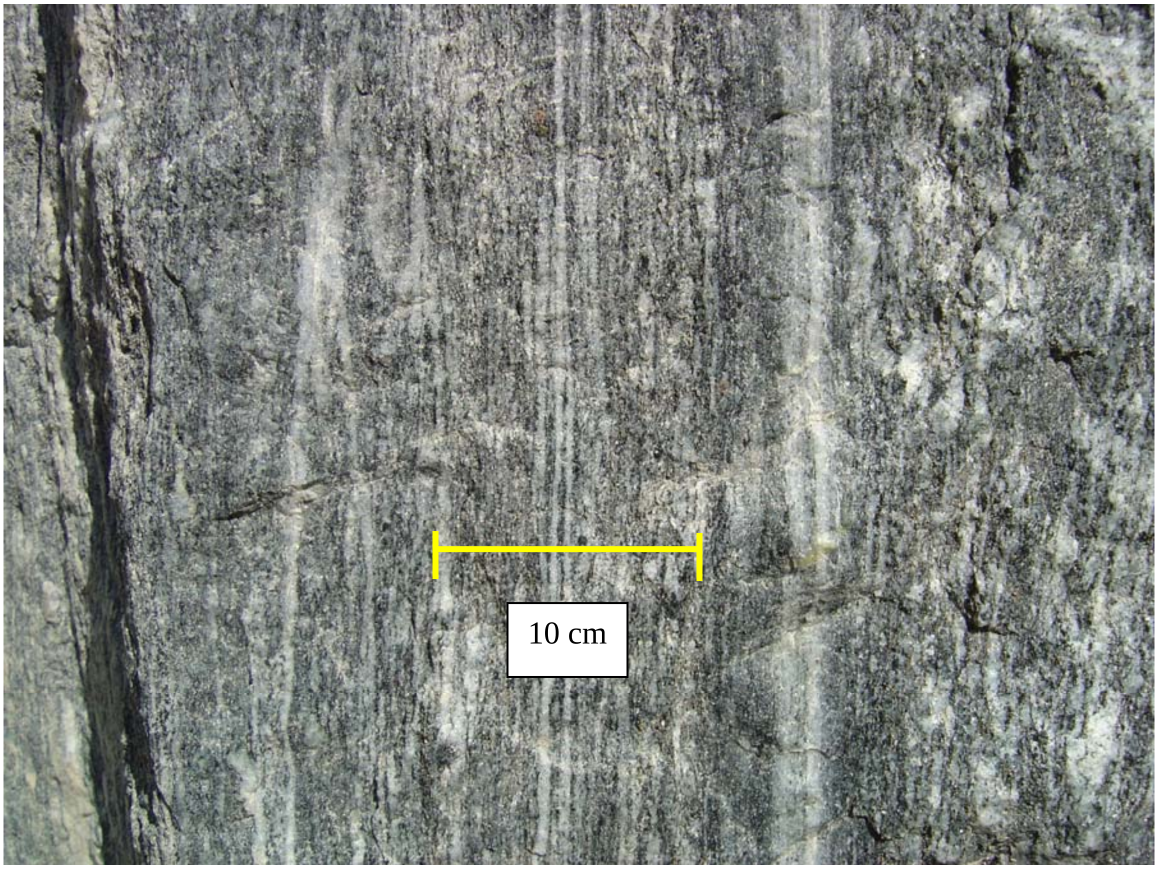

Figure 25. Mylonite within the northeastern belt of Cadwallader Group rocks at Station #33.

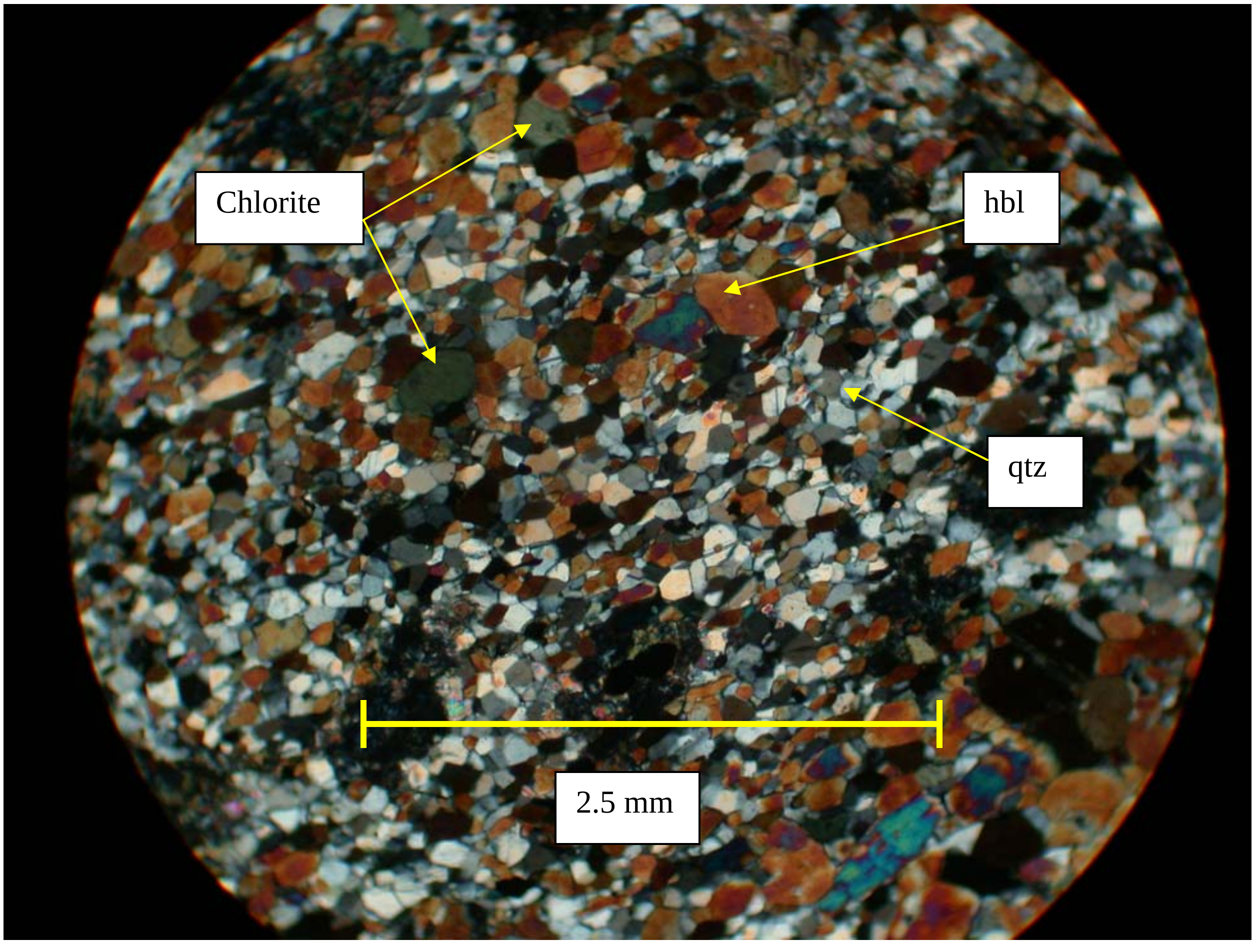

Figure 26. Photomicrograph of sample from Station #33 within the Cadwallader Group. This thin section was cut parallel to the strike direction and perpendicular to the foliation plane. Notice the six-sided relatively undisturbed quartz grains and euhedral hornblende crystals. Compositional layering and the properties of the foliation are difficult to distinguish.

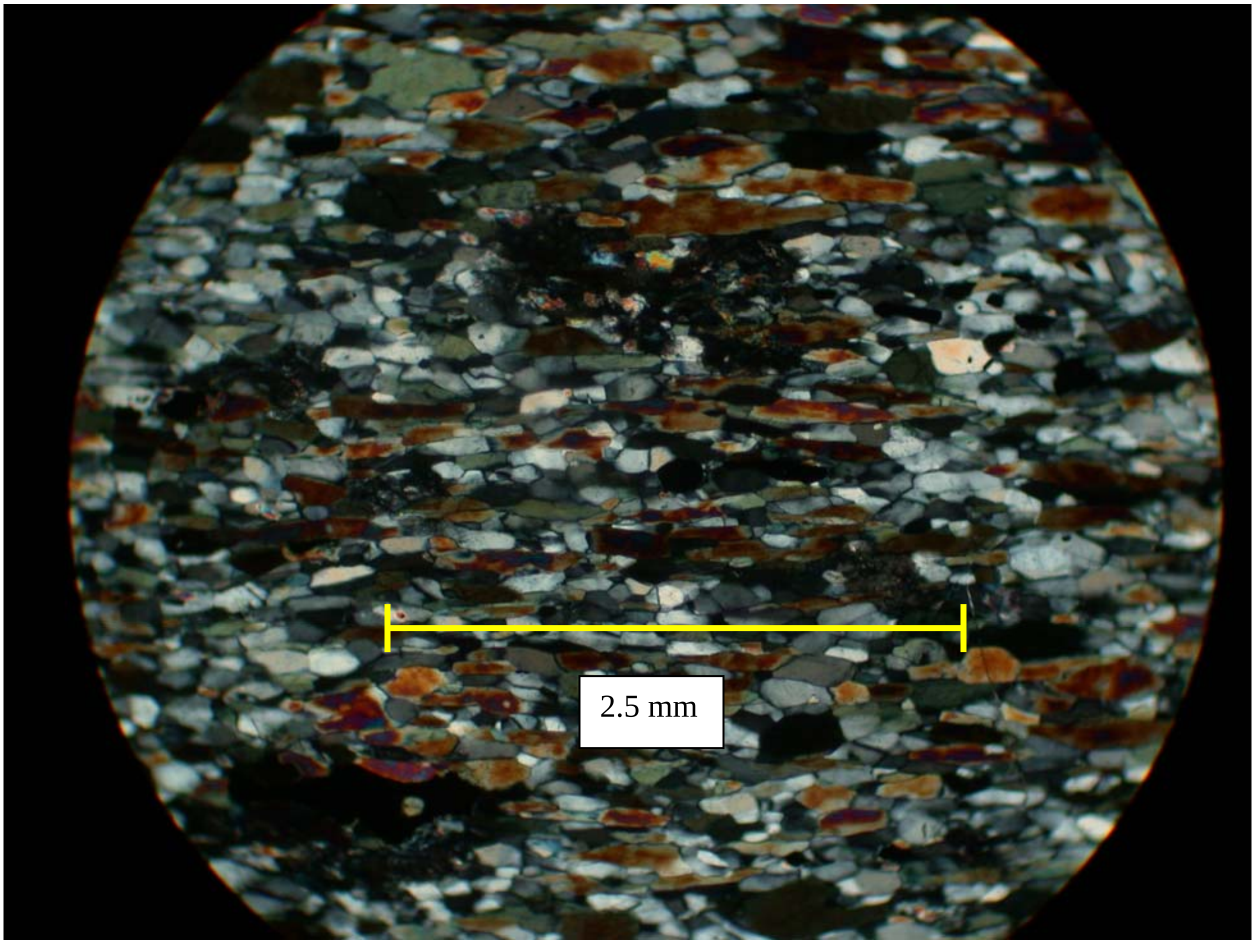

Figure 27. Photomicrograph of sample from Station #33 within the Cadwallader Group. This thin section was cut parallel to the dip direction and perpendicular to the foliation plane. Quartz and hornblende no longer exhibit euhedral characteristics but rather, appear elongate and stretched into a "cigar" shape. This sample would be considered an L-S Tectonite, displaying both prominent foliation and prominent lineation.

3.3. CHISM CREEK SCHIST SAMPLES

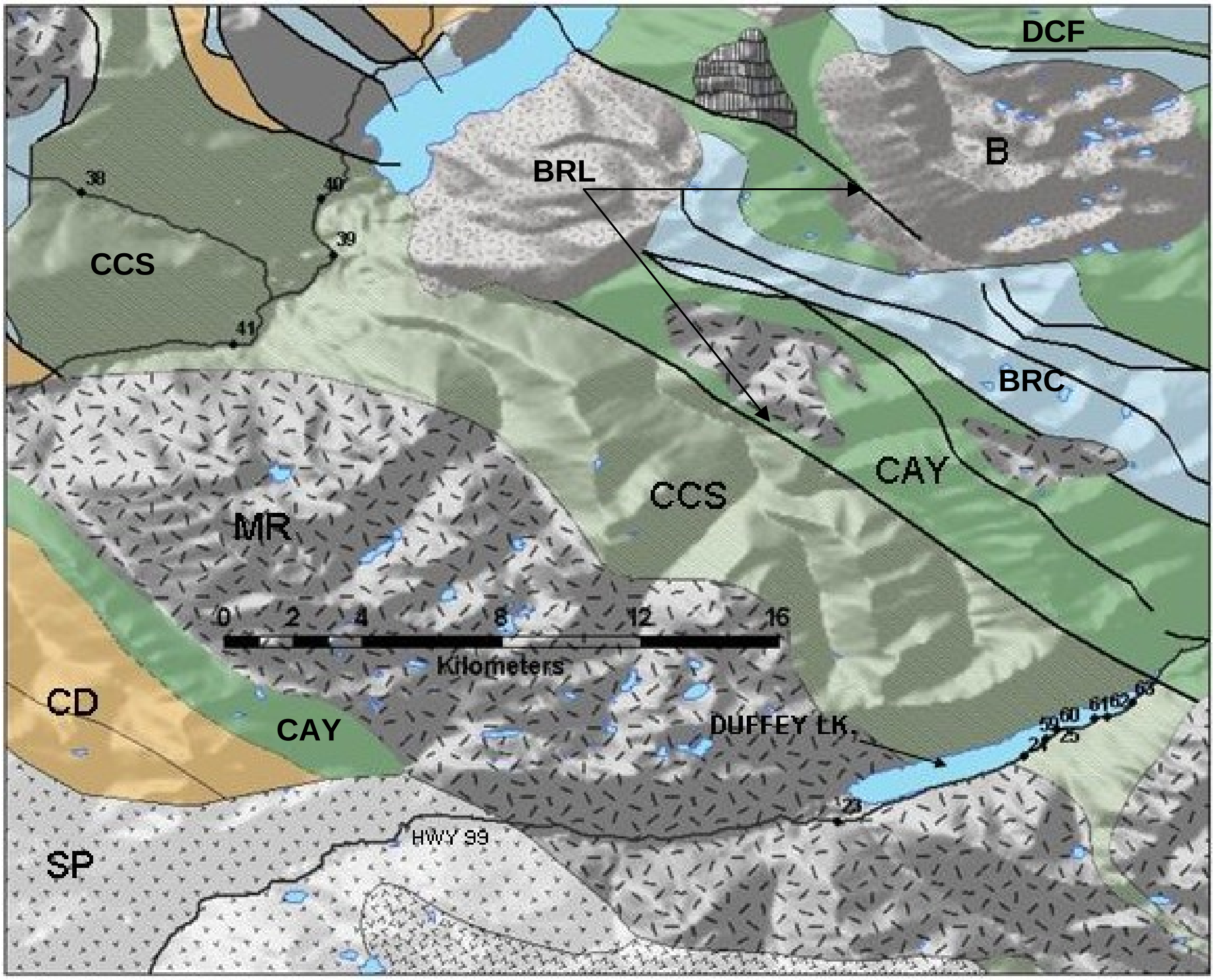

Figure 28. Detailed map showing the location of samples from the Chism Creek Schist. SP=Spetch Creek Pluton, CD=Cadwallader Group, MR=Mt. Rohr Pluton, CCS=Chism Creek Schist, CAY=Cayoosh Assemblage, B=Bendor Pluton, BRC=Bridge River Complex, BRL=Bralorne Fault System, DCF=Downton Creek Fault. Modified from Massey et al. (2005).

3.3.1. Lithologic Classification

On Highway 99 along the south bank of Duffey Lake, the Chism Creek Schist (CCS) is exposed along the road cut. Samples were collected at eight stations, 20 km northwest, on a dirt road leading to Anderson Lake, the CCS was sampled at four additional stations. The CCS outcrops as a northwest trending, steeply dipping belt 4 to 8 km wide (Figs. 15, 28, 29).

Figure 29. Outcrop photo from Station #25 within the Chism Creek Schist. Notice the near-vertical, thinly spaced foliation.

The Chism Creek Schist is 70-80% quartz with biotite as the foliation defining mineral. Near the contact with the Mount Rohr pluton at Station #24, the CCS is almost completely recrystallized. The quartz is euhedral and the grain size is consistently <1mm in diameter. The biotite is randomly oriented and euhedral garnet is concentrated in the layers (Fig. 84-App B). Even through the recrystallization, aggregates of micaceous minerals retain the property of define foliation, appearing as thin laminae (Fig. 30). At the western edge of the CCS exposures, the rock is quartz-biotite-garnet gneiss. This is the highest grade of contact metamorphism observed in samples of the CCS. Moving away from the zone of contact metamorphism (Station #25), clino-zoisite appears instead of garnet within the biotite (Figs. 31, 85-App B); at a greater distance calcite becomes more prevalent within the rock.

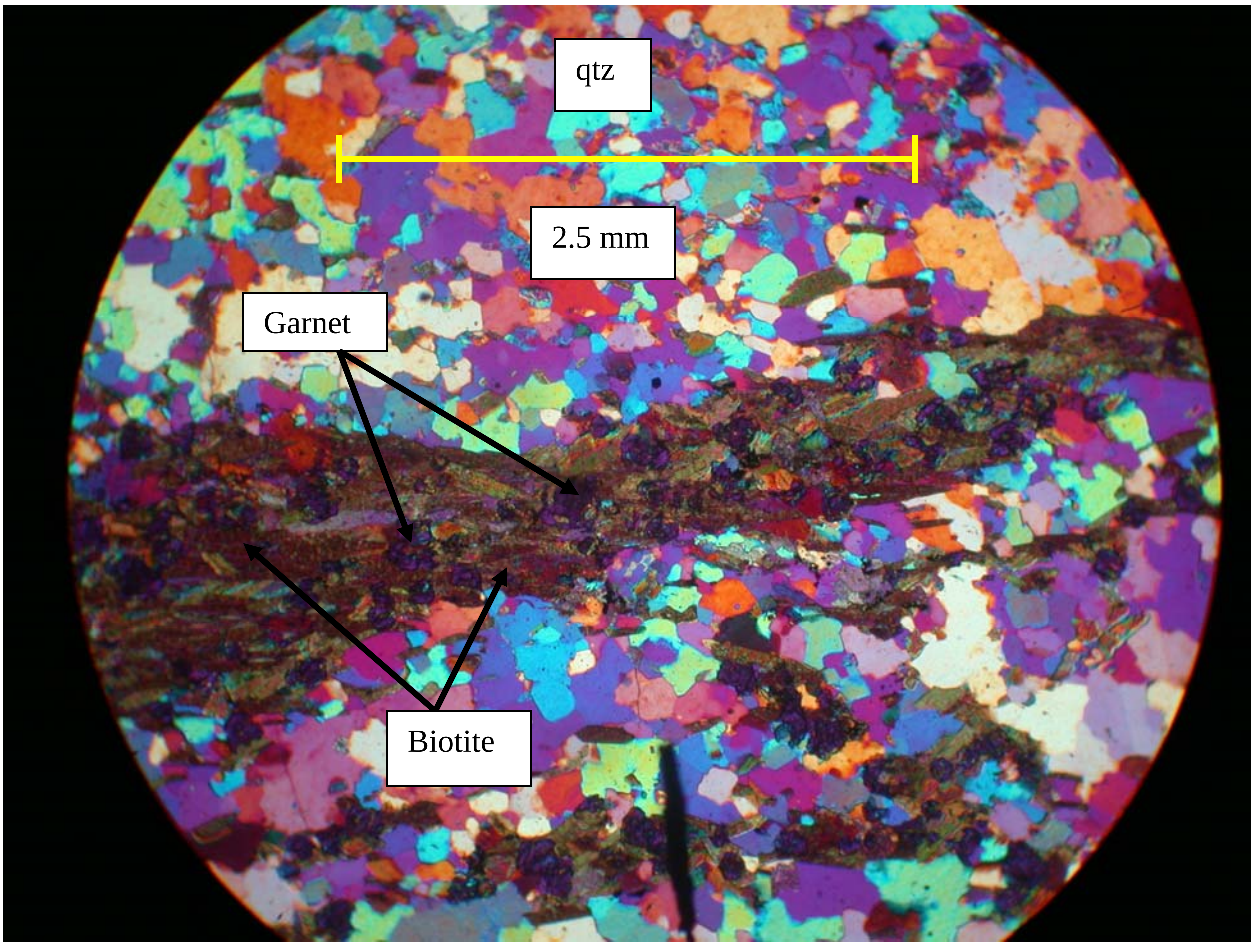

Figure 30. Photomicrograph of a sample from Station #24, cut parallel to the dip direction and perpendicular to the foliation plane. Quartz grains are recrystallized and biotite displays no preferred orientation. Garnet is concentrated within the biotite rich layers (gypsum plate inserted).

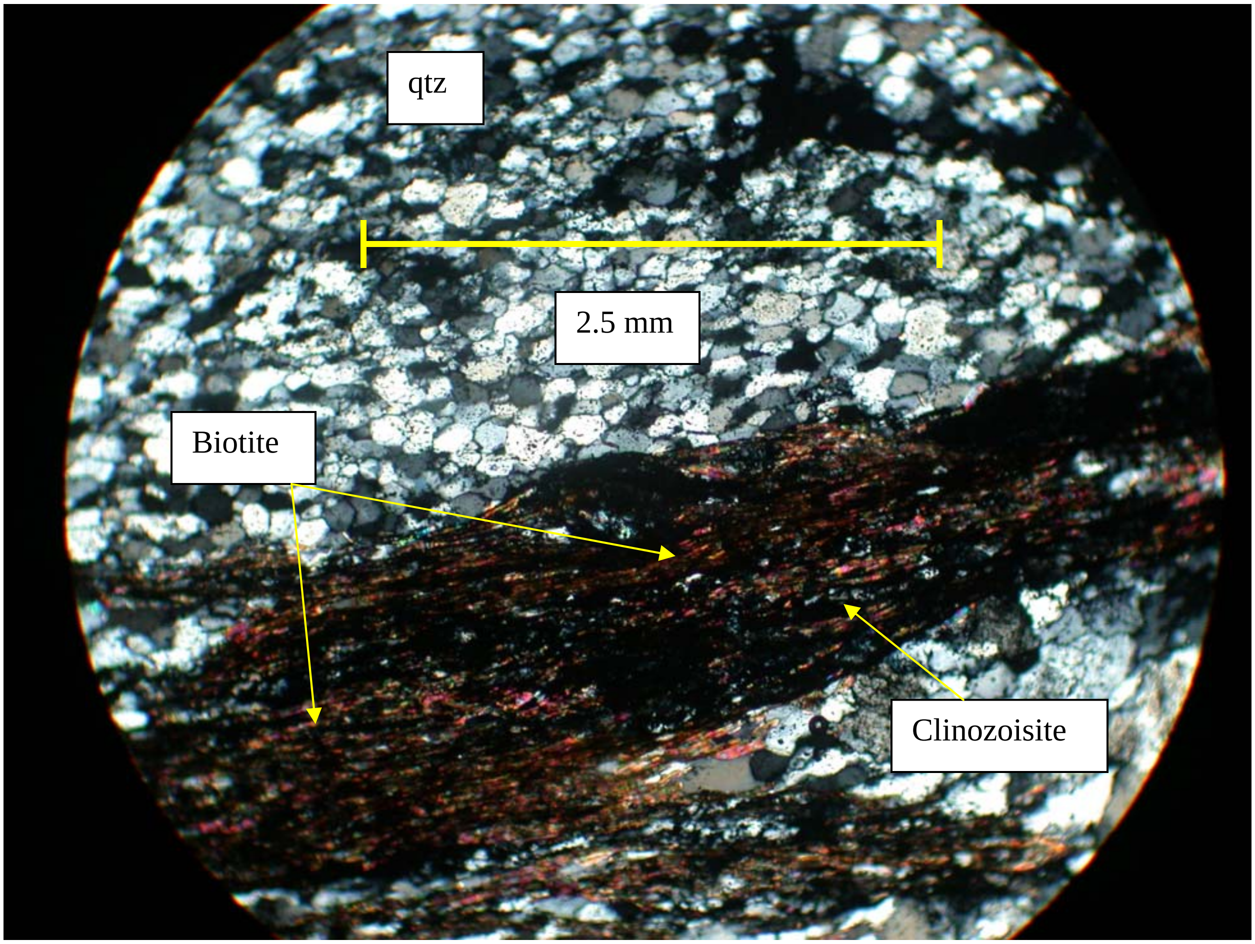

Figure 31. Photomicrograph of a sample from Station #25 within the Chism Creek Schist, cut parallel to dip and perpendicular to foliation. This sample is further away from the zone of contact metamorphism by the Mt. Rohr pluton and appears finer grained than Sample #24. Biotite is oriented along the foliation plane and clinozoisite has taken the place of garnet within biotite rich layers.

Hand samples of the CCS are commonly gray in appearance, suggesting a more intermediate composition than is revealed by thin section analysis. This is due to the concentration of opaque minerals along quartz grain boundaries. This pressure solution appears to become more evident toward the eastern edge of the CCS. In this area quartz is concentrated within thin veins rather than throughout the body of the rock. Combining the dominant presence of quartz throughout the body of the rock in the western section of the CCS and the confinement of quartz to veins in the eastern section, it can be hypothesized that pre-contact metamorphism was stronger in the eastern CCS than in the west.

Sample #39 is from the northern section of the Chism Creek Schist, near Anderson Lake. It has a distinctly different lithology than CCS rocks to the south, near Duffey Lake. It is a phyllitic rock whose parent was probably calcareous lithic sandstone. In hand sample, the foliation plane is covered with bumps, 1-2mm wide, ~1mm high and spaced ~3-4mm apart. In thin section it can be seen that these bumps are the result of 1-2mm lithic fragments of calcite, quartz, plagioclase feldspar and clino-zoisite (Fig. 32). The dominant foliation plane is defined by muscovite, which bends around these lithic fragments. The matrix is composed of very fine grained (<<0.1mm) elongate grains of quartz, plagioclase, and calcite.

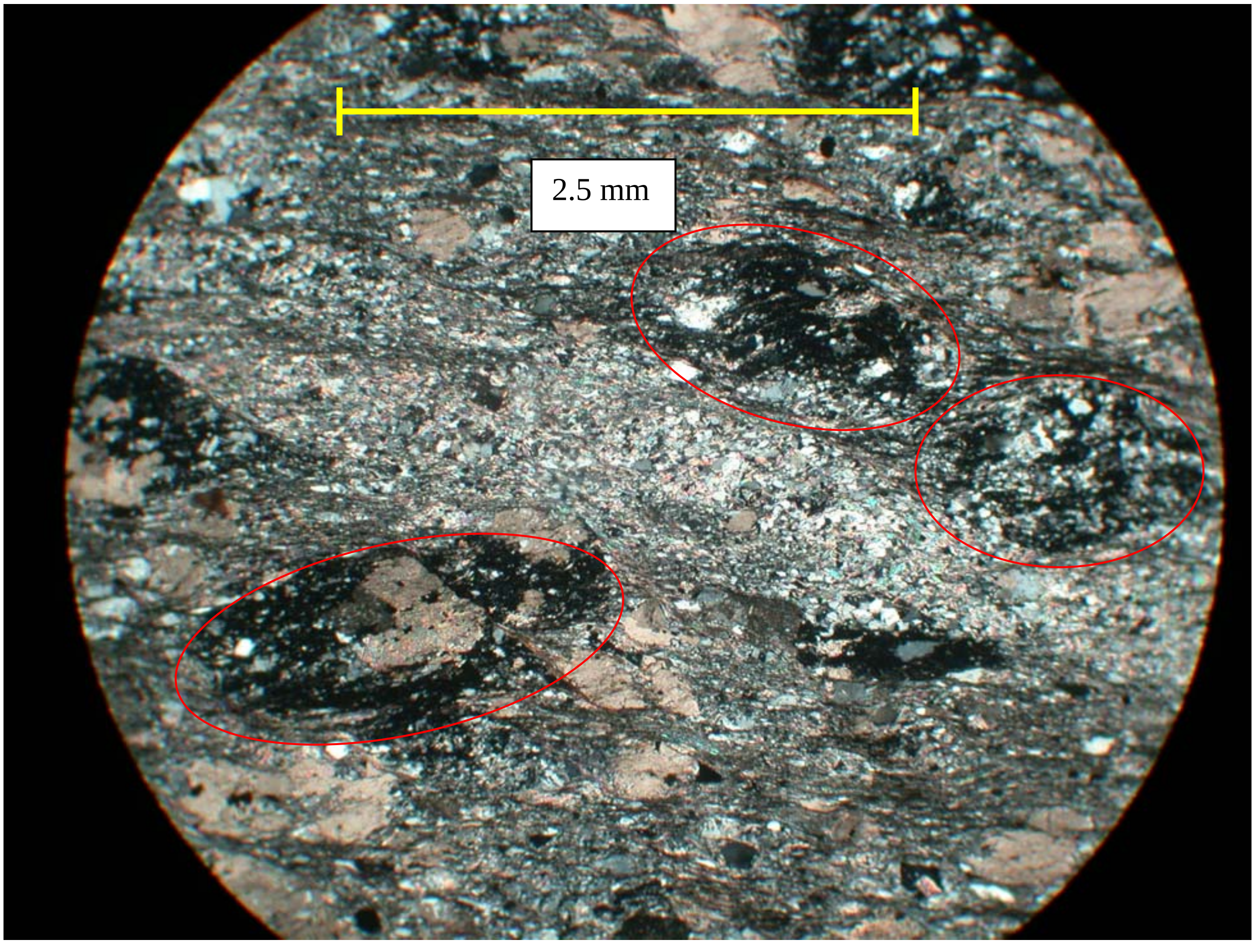

Figure 32. Photomicrograph of sample #39 showing the lithic fragments within a very fine grained matrix, encircled in red.

3.3.2. Field Measurements and Structural Analysis

The CCS is intruded by the Mount Rohr pluton to the west and abuts the Cayoosh Assemblage and members of the Bendor Plutonic suite to the east. The average strike and dip of the foliation within the unit is N45ºW, 85ºNE (Fig. 33). Granodiorite intrusions into the CCS caused contact metamorphism that decreases from west to east. A lens of CCS included in the Mount Rohr pluton (Station #23) is the first appearance of the unit in the Southern Coast Belt heading east on Highway 99. Within this lens, meso-scale asymmetric folds display near-vertical fold hinges indicative of right lateral strike-slip movement (Figs. 34, 35). Micro and meso-scale structures associated with a mineral lineation present near the middle of the main belt of CCS record oblique-left slip in thin section and in the outcrop (Station #61) (Fig. 86-App B). Symmetrically flattened quartz lenses and symmetric biotite tails indicate flattening is predominant.

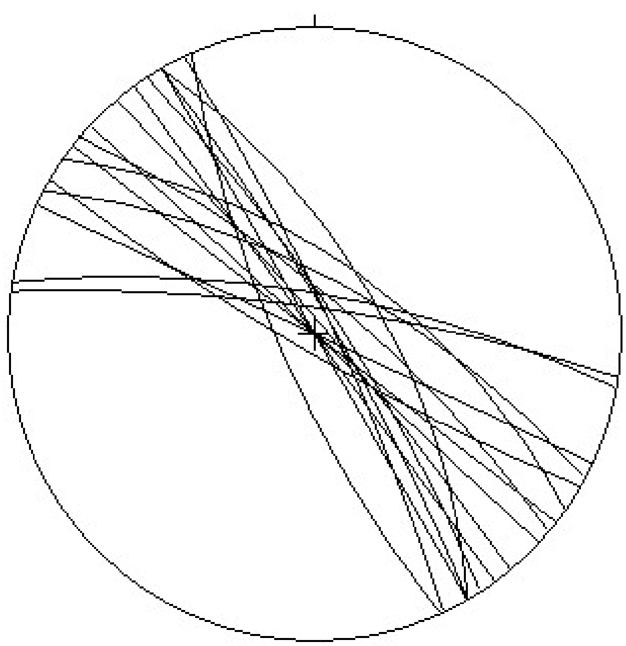

Figure 33. Equal area plot of 19 foliation measurements within the Chism Creek Schist.

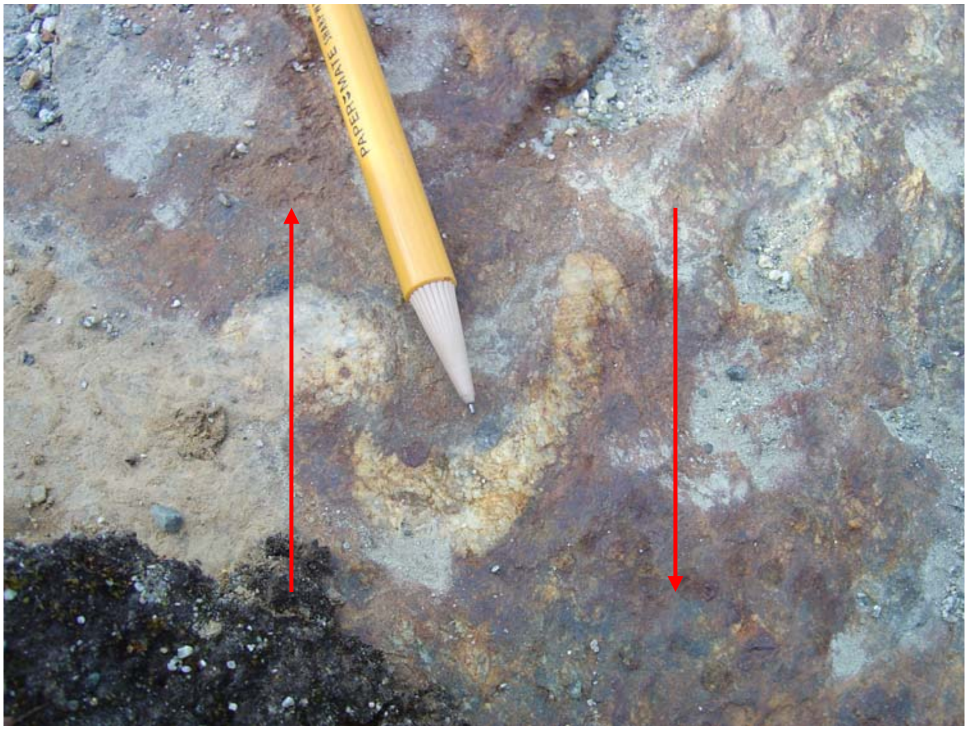

Figure 34. Asymmetric fold within the Chism Creek Schist at Station #23. Pencil is oriented perpendicular to the steep fold axis and the sense of movement is given by the arrows indicating a component of strike-slip.

Figure 35. Assymetric fold within the Chism Creek Schist at Station #23. Pencil is oriented parallel to the steep fold axis, but the sense of movement is indistinguishable.

Sample #39, which is unique in its lithology and mineralogy within the Chism Creek Schist, displays much of the same microstructural properties as the other samples from the CCS. Vertical foliation at this location strikes N65ºW (Fig. 83-App B). In thin section, parallel to dip and perpendicular to foliation, NE-side-up sense of movement is recorded (Fig. 36). Parallel to strike and perpendicular to foliation, both left (Fig. 37) and right lateral (Fig. 38) C-S structures are present, with right lateral seeming to overprint left lateral.

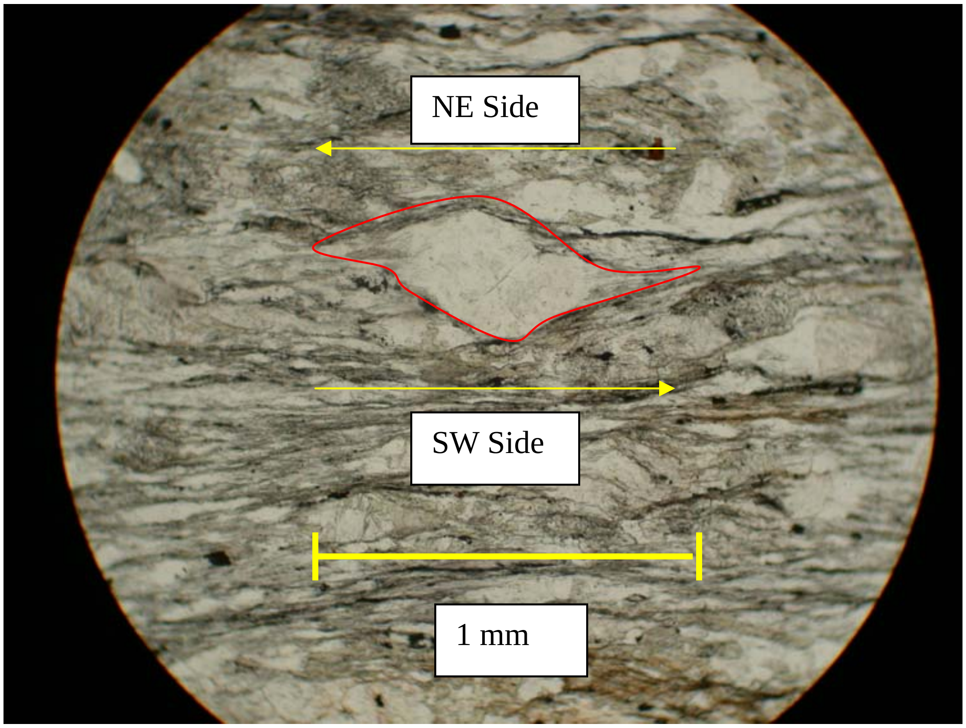

Figure 36. Photomicrograph of Sample #39, from the Chism Creek Schist, cut parallel to dip and perpendicular to foliation. The asymmetrically rotated grain in the center if the field of view shows the NE side up displacement present at this location within the CCS.

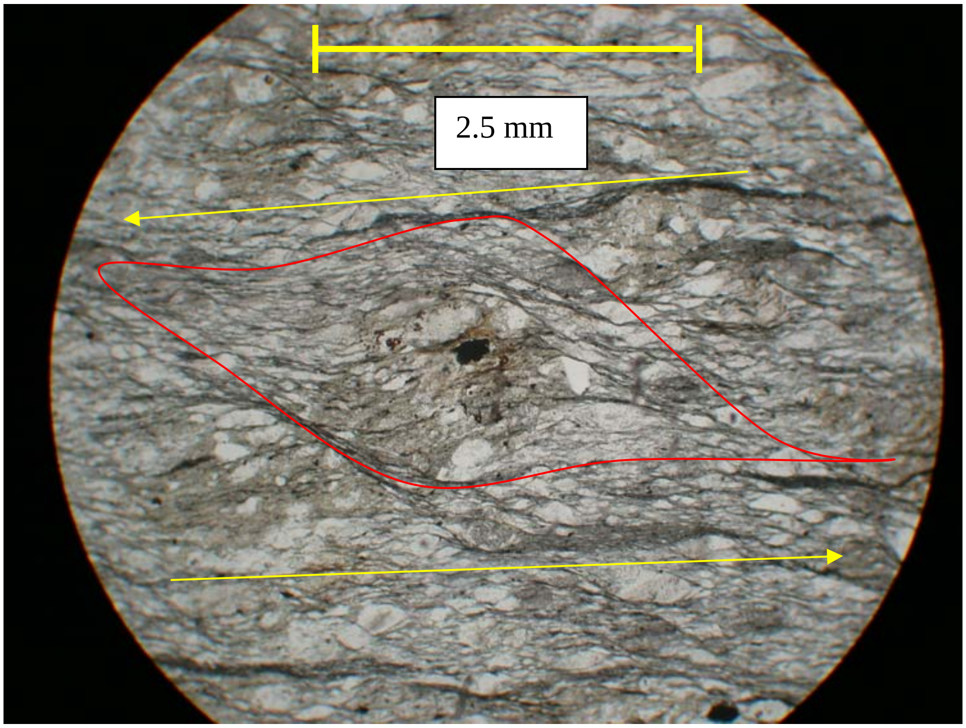

Figure 37. Photomicrograph of Sample #39, from the Chism Creek Schist, cut parallel to strike and perpendicular to foliation. The C-S structures record left lateral movement.

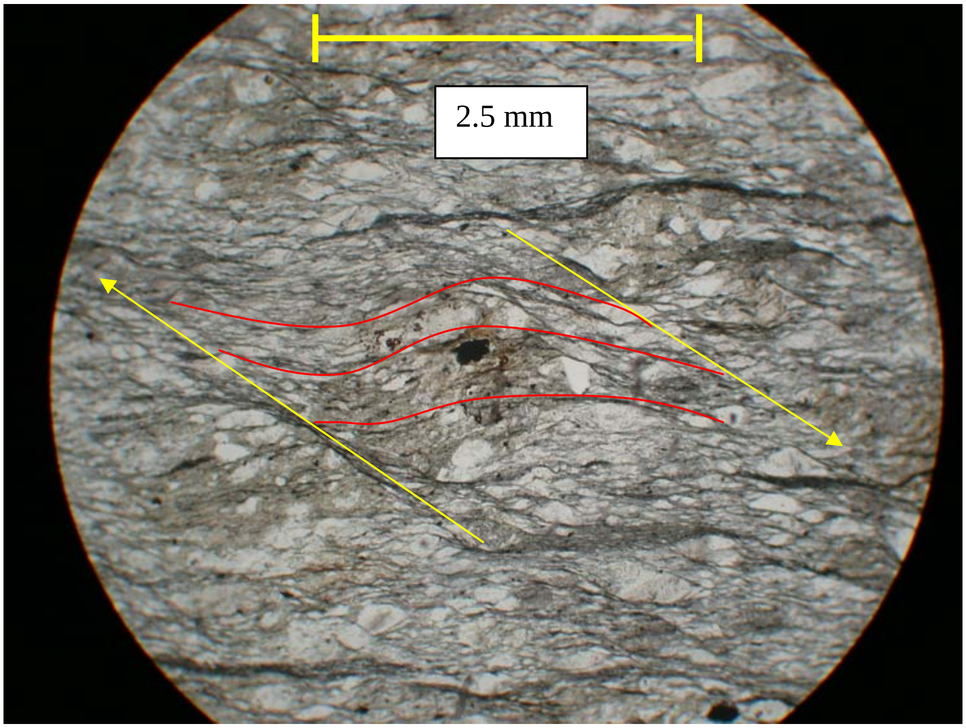

Figure 38. Photomicrograph of Sample #39, from the Chism Creek Schist, cut parallel to strike and perpendicular to foliation. The C-S structures record right lateral movement, which appears to disrupt the left lateral structures.

3.4. CAYOOSH ASSEMBLAGE SAMPLES

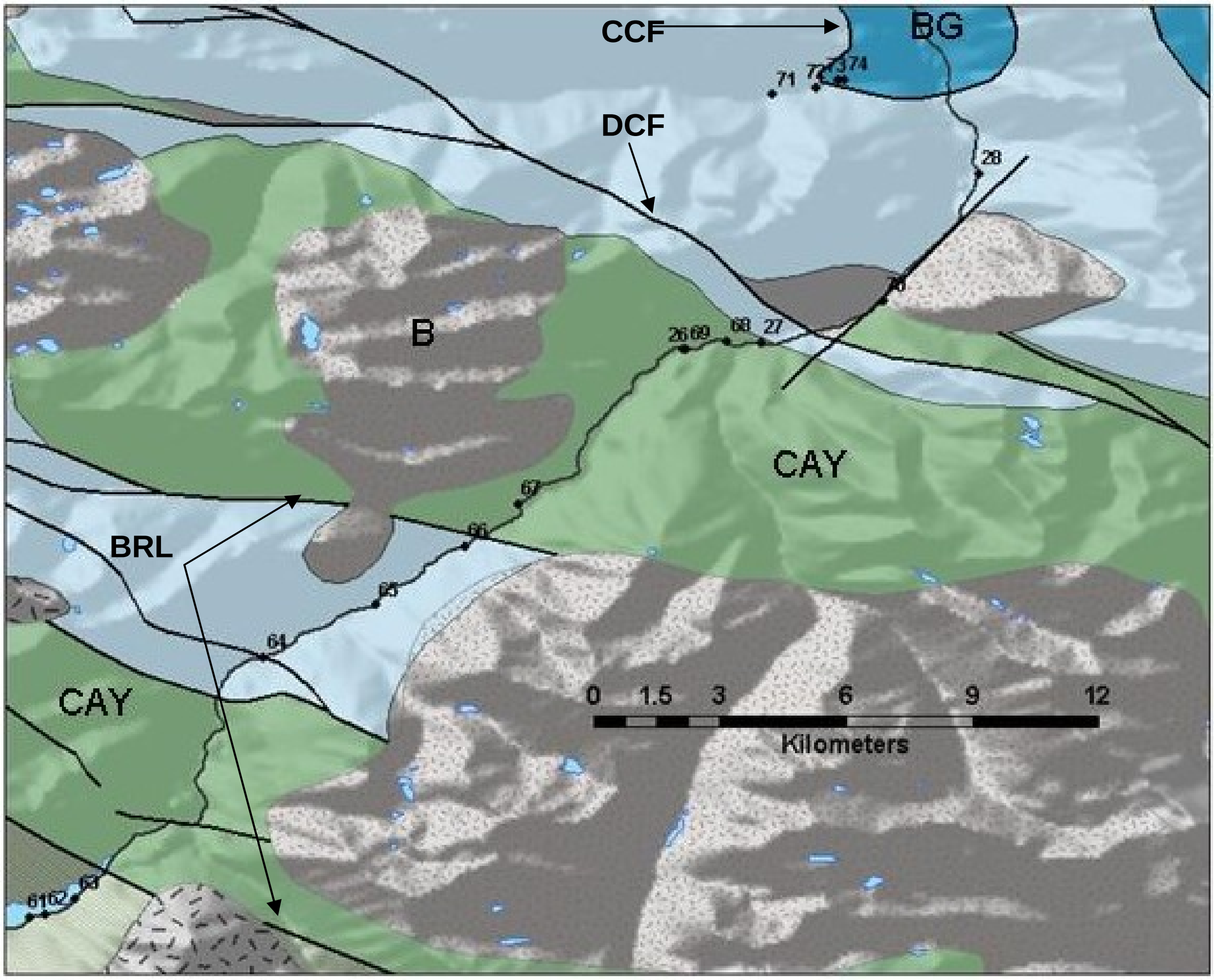

Figure 39. Detailed map showing the locations of samples from the Cayoosh Assemblage. CAY=Cayoosh Assemblage, BRC=Bridge River Complex, B=Bendr Pluton, BG=Brew Group, BRL=Bralorne Fault System, DCF=Downton Creek Fault, CCF=Cayoosh Creek Fault. Modified from Massey et al. (2005).

3.4.1. Lithologic Classification

The Cayoosh Assemblage is mapped within two major northwest trending belts crossed on Hwy 99. Journeay and Mahoney (1994) describe this assemblage as a sequence of mostly arc-derived turbiditic sandstone interbedded with quartzite, shale, conglomerate with plutonic clasts, and rare volcanics (Figs. 15, 39). The exposures are imbricated with the Bridge River Complex and Chism Creek Schist (Price and Monger, 2000). The Cayoosh Assemblage rocks are commonly 60-90% quartz, with minor calcite and biotite, which defines the foliation (Fig.

40). Overall, the grain size in the Cayoosh Assemblage is very fine (<0.1mm) and variably recrystallized. Some quartz crystals have sharply defined grain boundaries whereas others show serrated boundaries. Sample #27 is from the transition zone between Cayoosh Assemblage rocks and rocks of the Bridge River Complex, near the Downton Creek Fault. This sample shows concentration of opaque minerals that, along with biotite, define the foliation (Figs. 41, 42). At this sample location, there are also chert layers which pinch and swell, indicating extension typically seen in accretionary prisms (Fig. 43). Contact metamorphism from the Bendor Plutonic Suite has resulted in variable recrystallization in Cayoosh rocks. Quartz varies from euhedral to elongate in appearance. Micaceous minerals still show strong alignment along the foliation plane and do not appear to have been recrystallized.

Figure 40. Outcrop photo of Cayoosh Assemblage at Station #27 showing the steeply dipping, thinly laminated foliation.

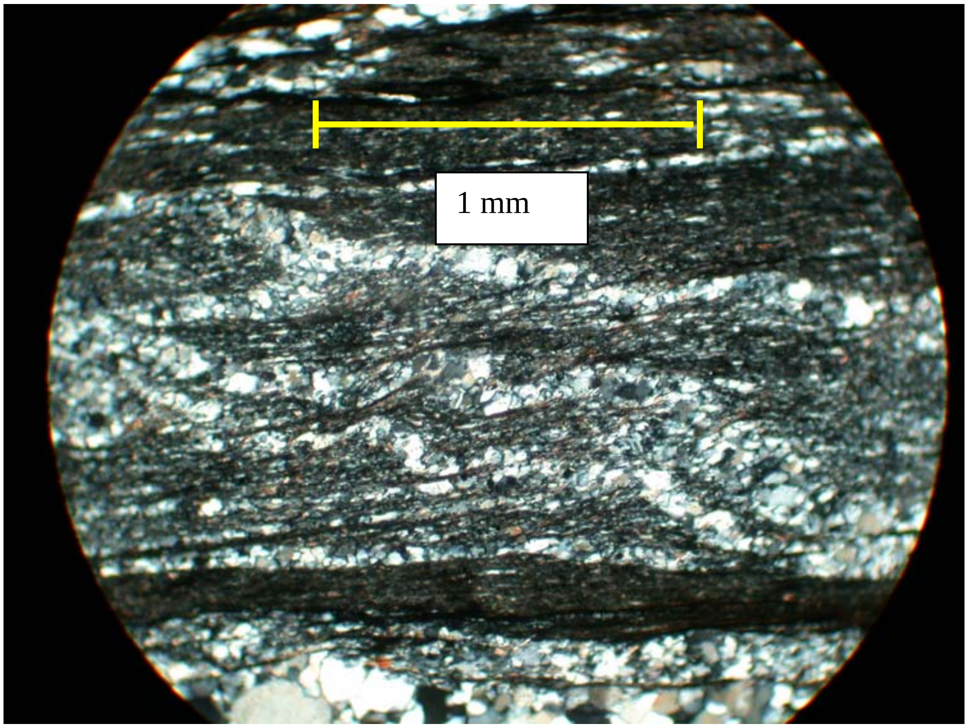

Figure 41. Photomicrograph of sample taken from the Cayoosh Assemblage (Station #27), showing the quartz grain size variation and thinly banded micaceous minerals.

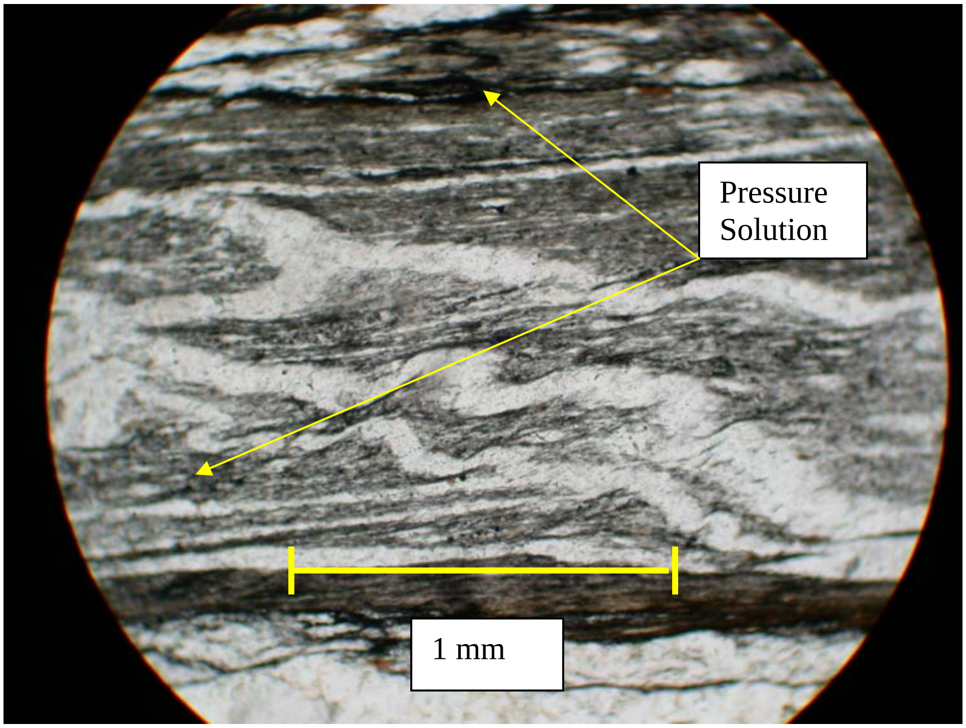

Figure 42. Same view as Fig. 31, but in plane polarized light. This view shows the opaque pressure solution within the fine-grained quartz matrix.

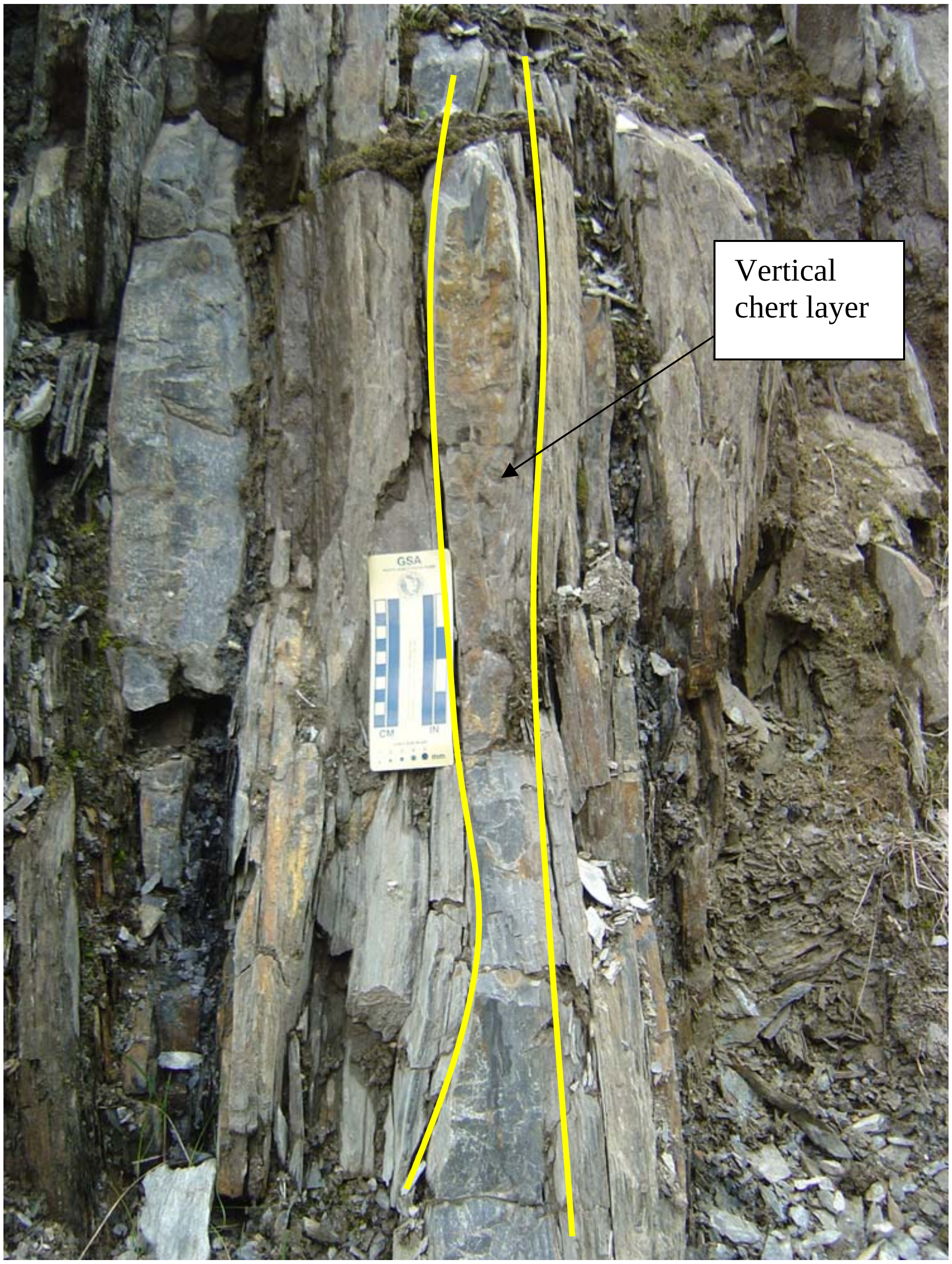

Figure 43. A vertical layer of chert in the Cayoosh Assemblage (Station #27). This type of pinching and swelling morphology is typical in accretionary prism settings.

3.4.2. Field Measurements and Structural Analysis

Journeay and Mahoney (1994) describe the Cayoosh as being largely metamorphosed in greenschist facies and penetratively deformed. Crossing the more northeasterly belt, which is ~6.5 km wide, five samples were collected which display an average foliation of N2ºW, 82ºNE (Figs. 39, 44, 87-App B, 88-App B).

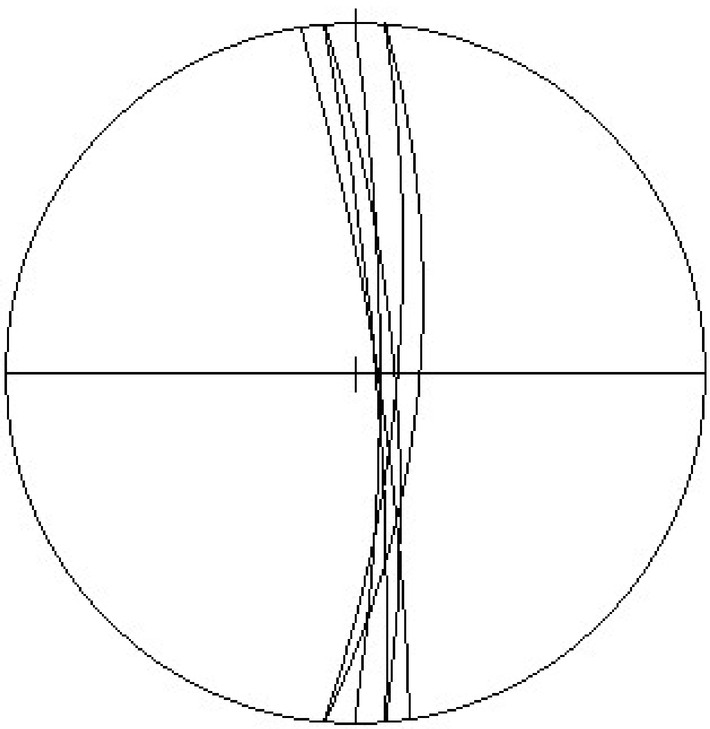

Figure 44. Equal area plot of 7 foliation measurements within the Cayoosh Assemblage.

Adjacent to a segment of the Bralorne/Twin Lakes fault system, which strikes W-NW at this location, Sample #67 has a foliation plane that strikes E-W and dips vertically. Overall, micro-structural analysis of thin sections cut perpendicular to the foliation plane and parallel to strike and dip directions reveals symmetric tails, flattened grains and grain aggregates that show consistent shear sense. Pure shear is dominant (Fig. 45). Isolated left and right lateral microstructures are also seen, often in close proximity to each other (Figs. 46, 47, 48, 49).

Mesoscopic folds and faults at Station #27 do give a sense of movement. Two steeply dipping, northeast striking faults with sub-horizontal slicken-lines were mapped, indicating a component of oblique strike-slip movement on the Downton Creek Fault. The orientation of these faults and slicks is: 1) N37ºE, 85ºNW; 18º, N40ºE 2) N46ºE, 85ºNW; 30º, N35ºE. Assymetric folds with steep fold hinges at Station #27 give a right lateral sense of shear along the main foliation within the Cayoosh (Fig. 50).

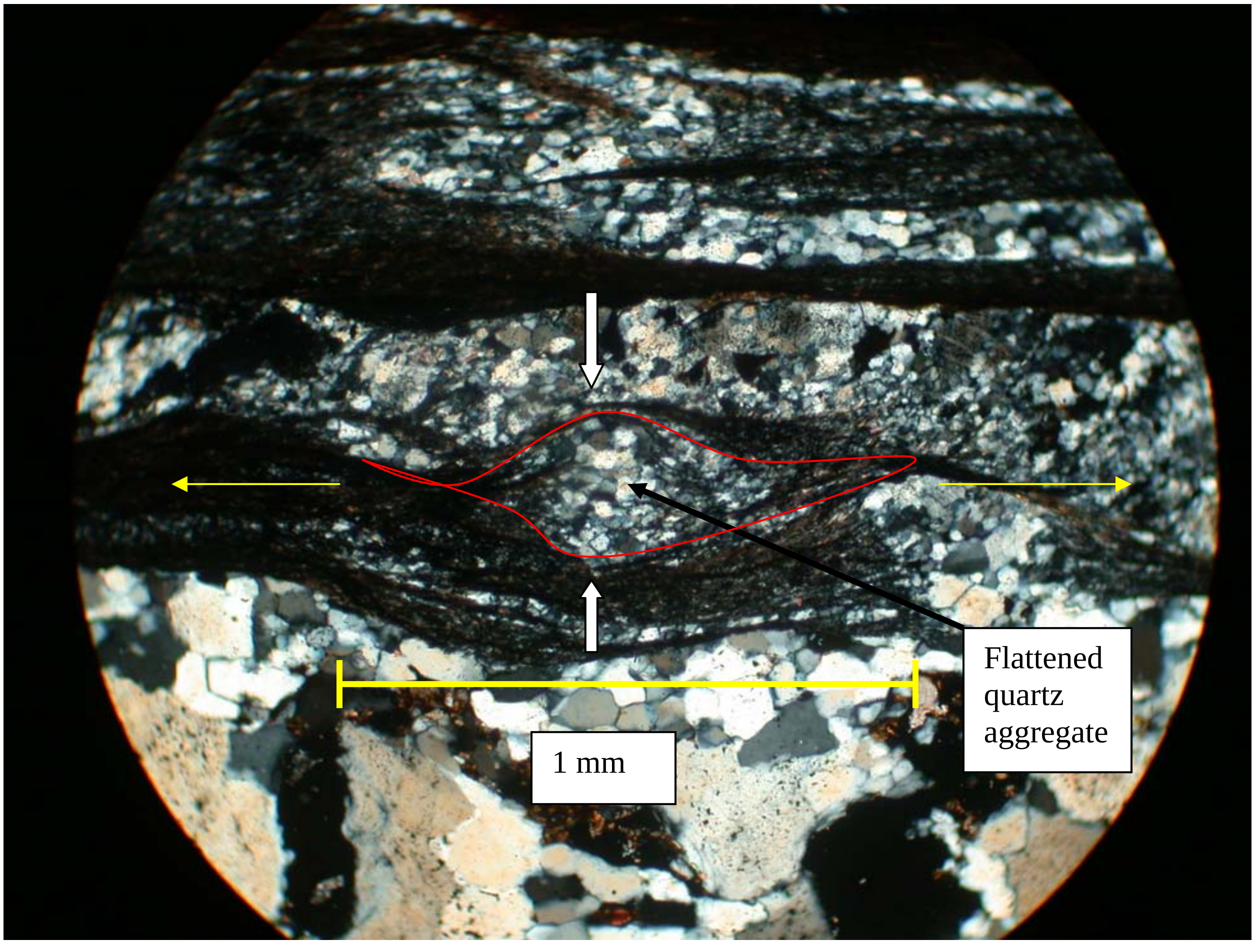

Figure 45. Photomicrograph of sample from Station #27 within the Cayoosh Assemblage. This view shows a flattened aggregate of very fine quartz grains adjacent to masses of much larger quartz grains. The white arrows indicate the flattening direction and the yellow arrows indicate the extension direction. Thin section cut parallel to dip and perpendicular to the plane of foliation.

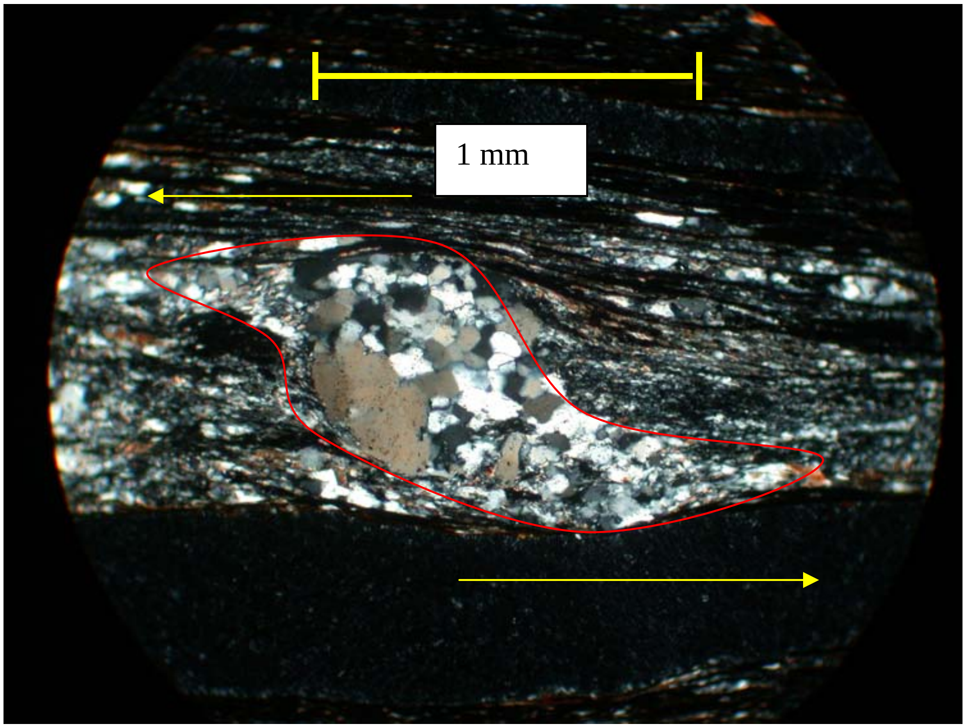

Figure 46. Photomicrograph of asymmetrically rotated recrystallized quartz grain aggregate within the Cayoosh Assemblage (Station #27). Yellow arrows show the inferred direction of movement. Section cut parallel to strike and perpendicular to foliation, indicating left-lateral strike slip.

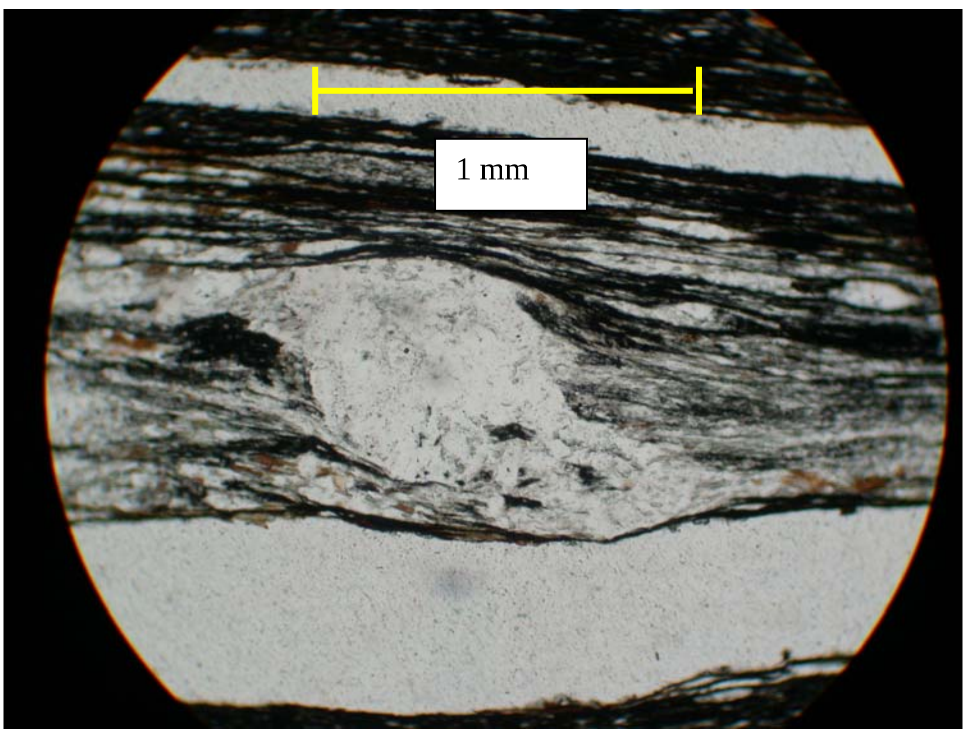

Figure 47. Same view as Fig. 37, but in plane polarized light. This view accentuates the flow of the foliation around the more resistant, large grained quartz aggregate.

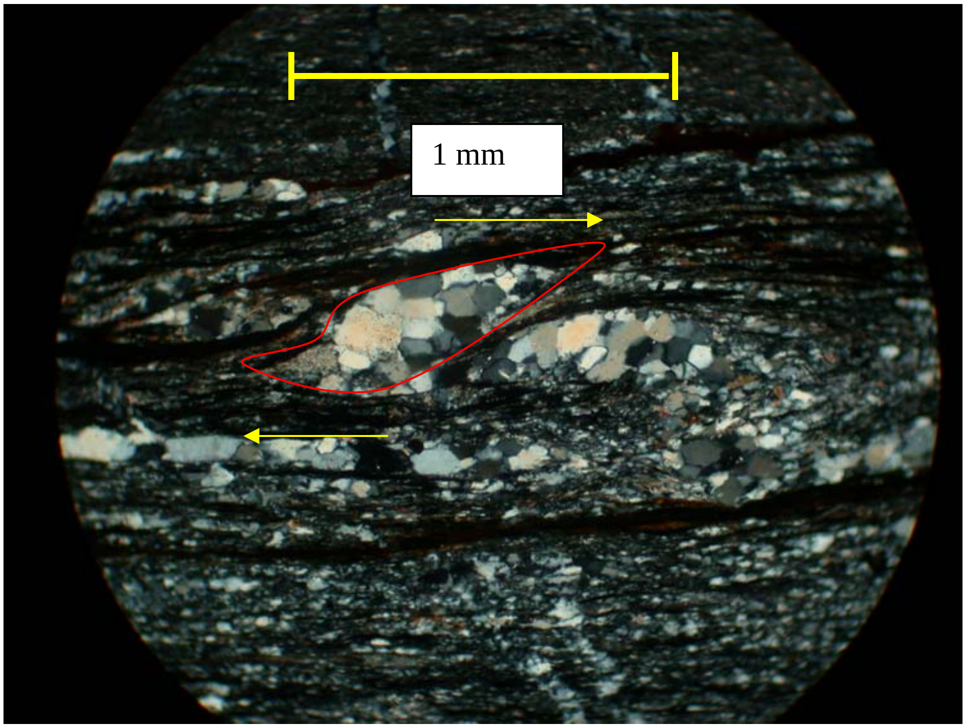

Figure 48. Photomicrograph of asymmetrically rotated quartz grain aggregate from Station #27 within the Cayoosh Assemblage. Yellow arrows show the inferred direction of movement. Section cut parallel to strike and perpendicular to foliation, indicating right-lateral strike-slip. Picture taken under cross-polarized light.

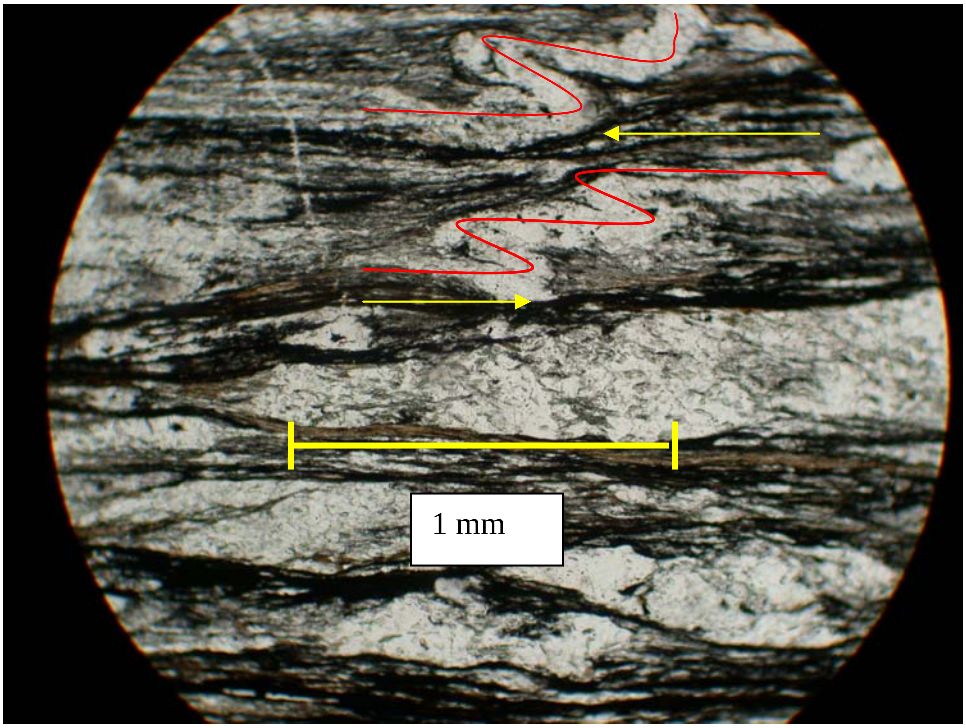

Figure 49. Photomicrograph of asymmetric micro-folds within the Cayoosh Assemblage (Station #27). The fold is traced in red and the yellow arrows indicate the inferred direction of movement. Section cut parallel to strike and perpendicular to foliation, indicating left-lateral strike-slip.

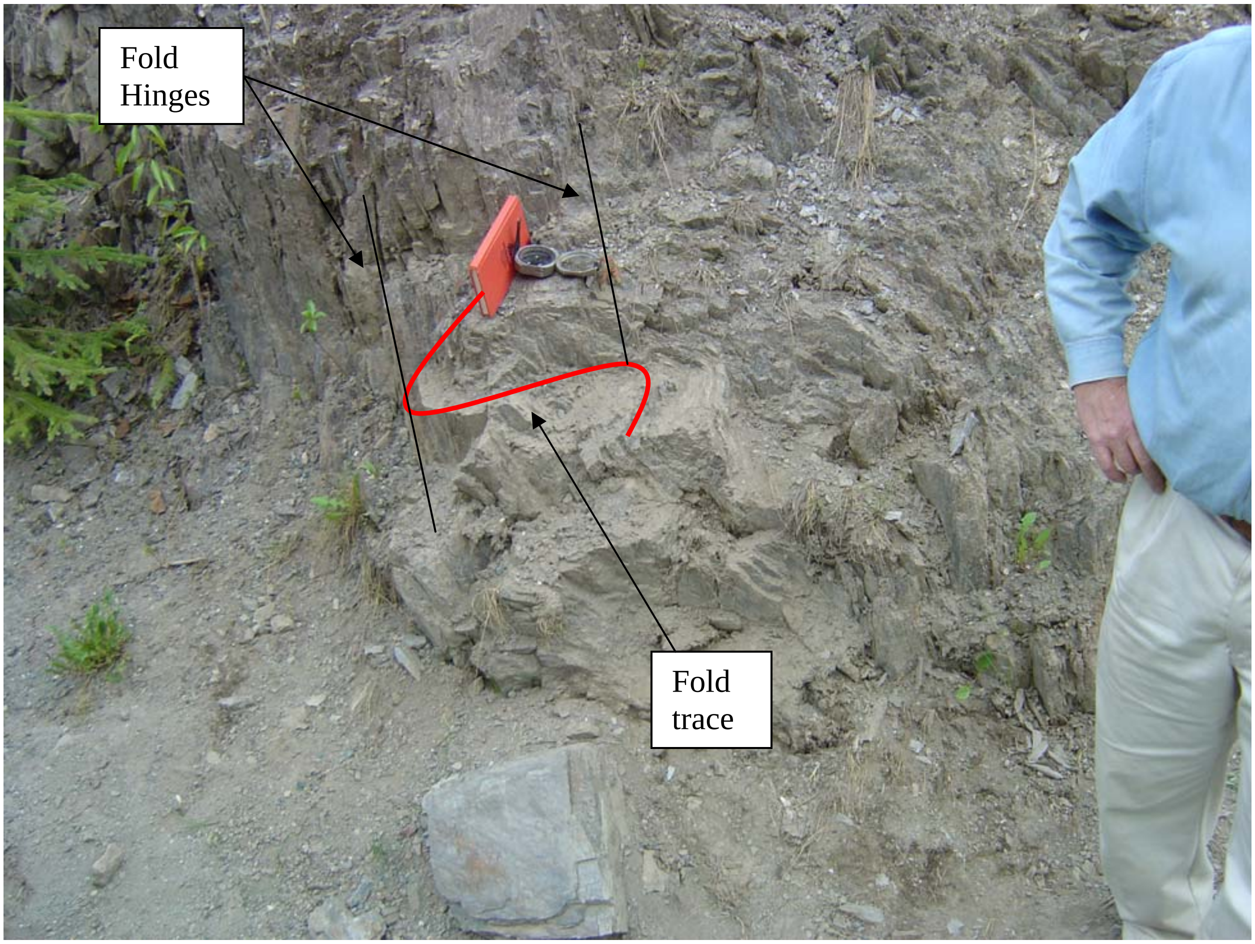

Figure 50. Meso-scale asymmetric fold at Station #27 within the Cayoosh Assemblage. Fold is traced in red and steep fold hinges are traced in black. Fold limbs are missing, so the sense of shear cannot be determined.

3.5. BRIDGE RIVER COMPLEX SAMPLES

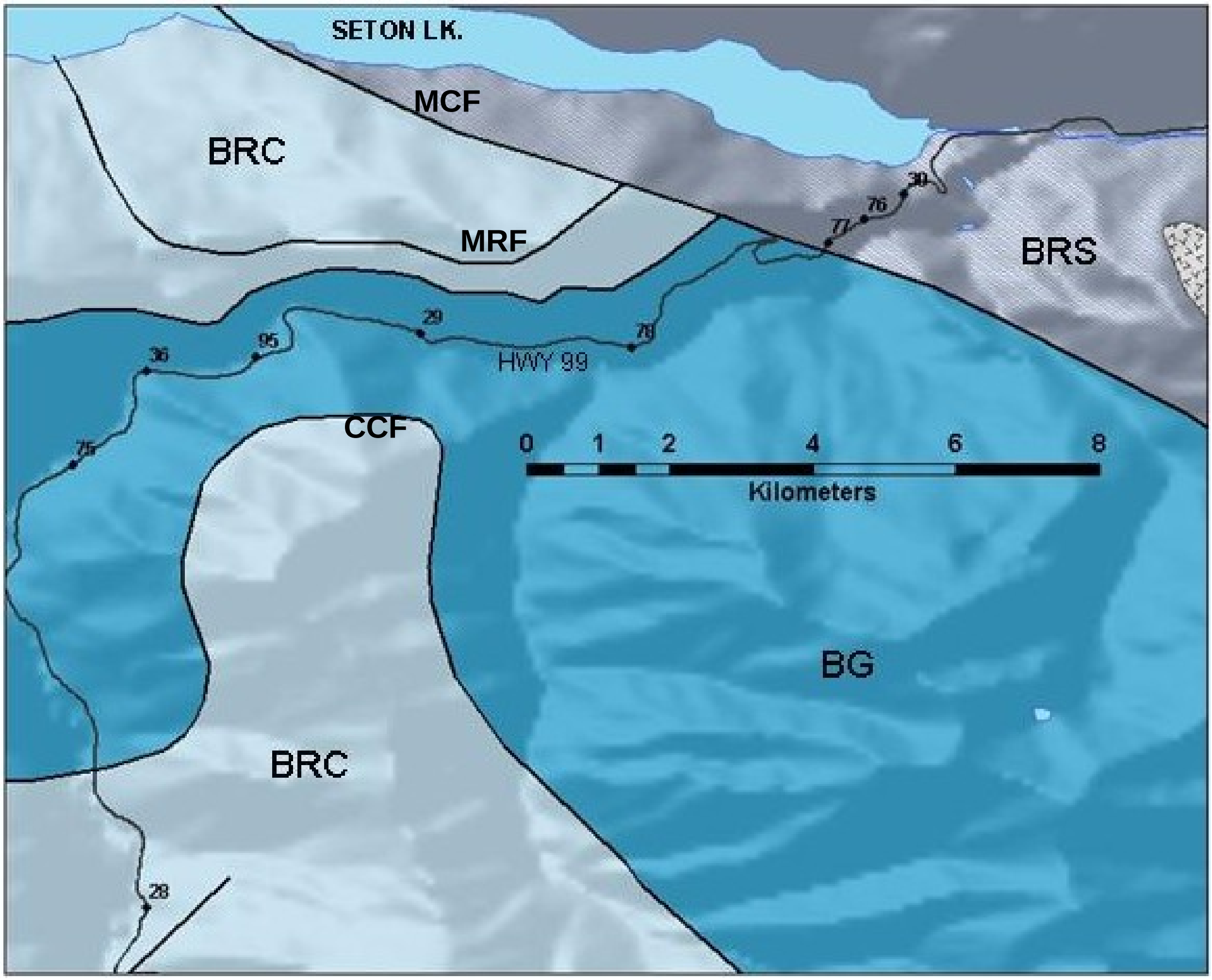

Figure 51. Detailed map showing the locations of samples from the Bridge River Schist and Bridge River Complex. BRC=Bridge River Complex, BG=Brew Group, BRS=Bridge River Schist, MCF=Marshall Creek Fault, MRF=Mission Ridge Fault, CCF=Cayoosh Creek Fault. Modified from Massey et al. (2005).

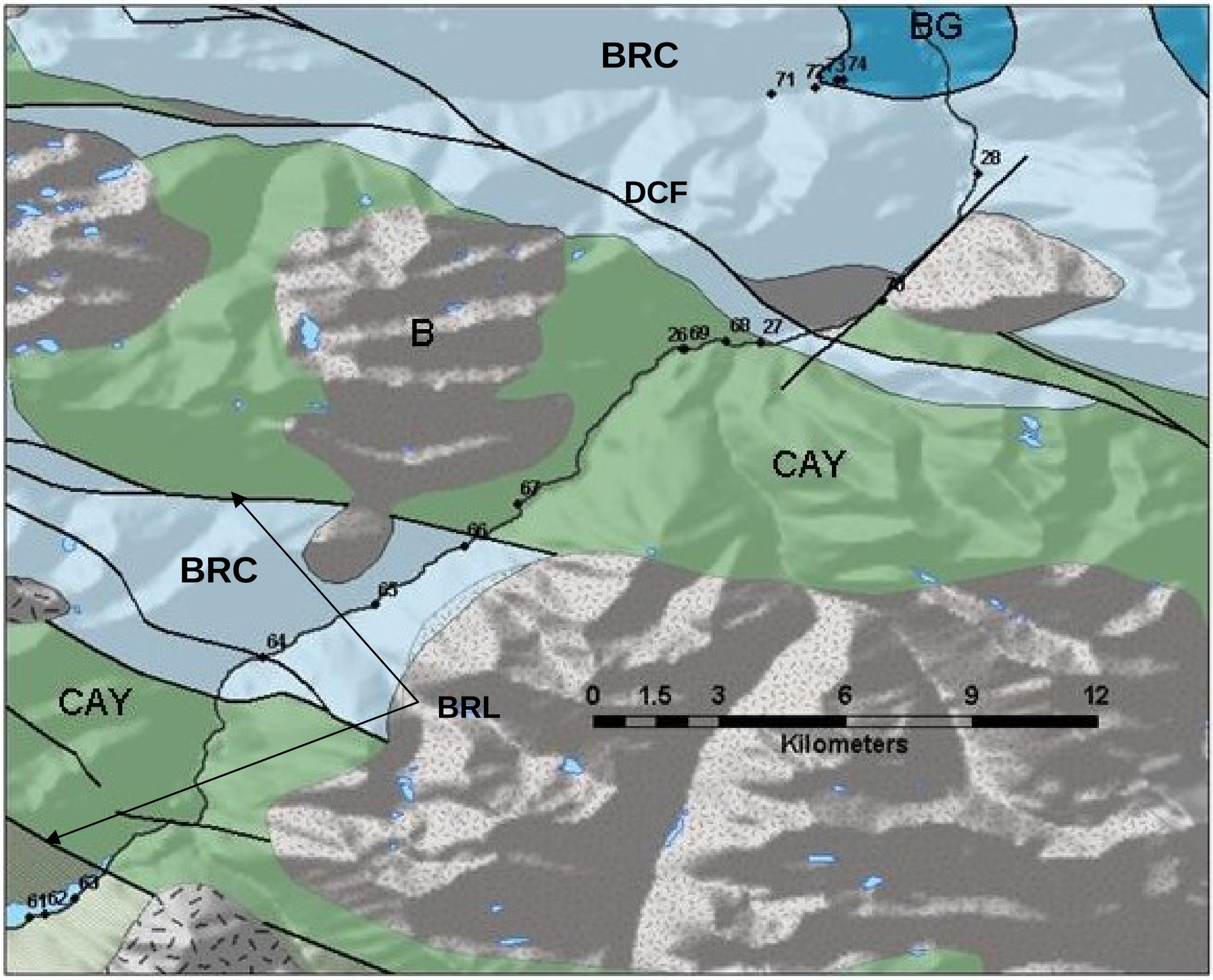

Figure 52. Detailed map showing the locations of samples from the Bridge River Complex. CAY=Cayoosh Assemblage, BRC=Bridge River Complex, B=Bendor Pluton, BG=Brew Group, DCF=Downton Creek Fault, BRL=Bralorne Fault System. Modified from Massey et al. (2005).

3.5.1. Lithologic Classification

In the northeastern half of the traverse across the Coast Mountains, the Bridge River Complex (BRC) is crossed multiple times over a ~45 km stretch of Highway 99, ending in the town of Lillooet. Lillooet is situated within the BRC and rocks directly to the southwest are located within a sub-unit called the Bridge River Schist as described by Potter (1986) (Figs. 15, 51, 52). The Bridge River is part of an accretionary complex (Potter, 1986; Coleman and Parrish, 1991), and is highly disrupted and variably metamorphosed. The BRC includes meta-chert, meta-sandstone, and calcareous siltstone and shale (Potter, 1986). The most southwesterly exposure of BRC is characterized by green, chlorite-bearing rocks with splintery fracture. Within this first segment of the BRC the lithology is graphitic quartz-mica-chlorite phyllite. The lithology is graphitic quartz-mica-chlorite phyllite. The three samples from this segment, #64, #65 and #66, are very fine grained and quartz is concentrated in layers and within veins and fractures.

Hwy 99 enters the Cayoosh Assemblage for a second time heading northeast and then re-enters the BRC (Fig. 52). Four samples were collected, three of which are rocks of the BRC. One is mapped as being a member of the Brew Group. These three samples include meta-chert and quartz-biotite-chlorite phyllite. The two phyllitic samples are probably derived from a sandstone parent.

Hwy 99 crosses through the Brew Group, which is in contact with the Bridge River Schist along the Marshall Creek Fault (Journeay et al., 1992). At this contact highly disrupted greenschist mylonite crops out adjacent to relatively undeformed chlorite-rich feldspar porphyry. The greenschist, Sample #77, was thin sectioned parallel to strike/perpendicular to foliation. Mineralogy consists of chlorite, biotite, calcite and quartz. The whole rock is extremely fine-grained. Sample #76 is a fine grained meta-chert with minor calcite. This sample is within the Bridge River Schist.

Further east, at Station #30 six samples were collected. Two of these samples appear to be from the Bridge River Schist. Sample #30A was thin sectioned and is a fine-grained quartz-mica tectonite, probably derived from chert. Sample #30F is also quartzose but displays 1mm thin dark bands of micaceous minerals in between quartz layers. This is probably representative of a metamorphosed turbidite sequence. The fine grained clay turbidite minerals have been converted to biotite and muscovite. The remaining samples are probably highly strained Eocene intrusions, based on the presence of Eocene intrusives to the northwest and southeast of the sample location (Schiarizza et al., 1997). These samples exhibit L-Tectonite characteristics and are quartz-feldspar porphyry.

3.5.2. Field Measurements and Structural Analysis

The average strike and dip of foliation within the Bridge River Complex (BRC) is N33ºW, 84ºSW (Fig. 53). There are two distinct sets of faults seen within the complex. One set is oriented roughly north-south and the other is oriented roughly east-west (Fig. 54).

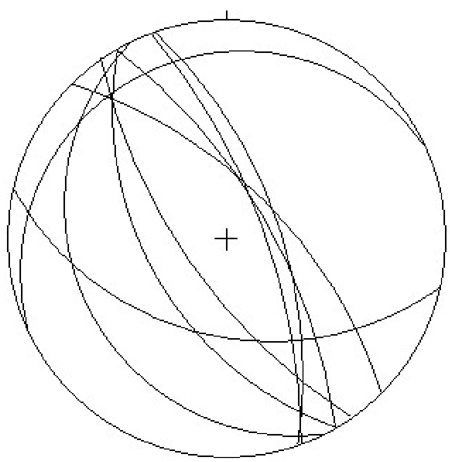

Figure 53. Equal area plot of 9 foliation measurements within the Bridge River Complex

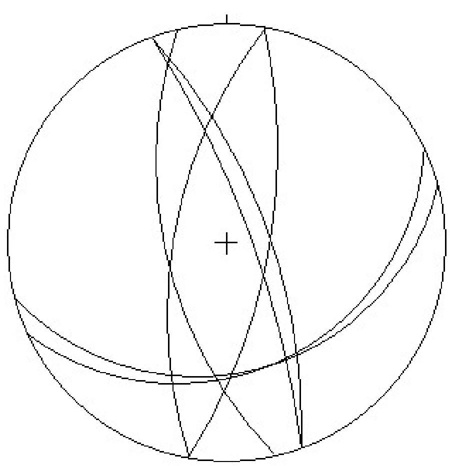

Figure 54. Equal area plot of 7 fault plane measurements within the Bridge River Complex. Notice the grouping of a set of ~N-S trending planes and a set of ~E-W trending planes.

BRC rocks at Station #28, are highly faulted. Two thrust faults show top-to the north displacement along discrete ductile shear zones (Fig. 55, 57). Figure #56 shows a small thrust fault with an orientation of N65ºE, 40ºSE. This fault cuts across a left oblique fault (labeled "1" in Fig. 55) with an orientation of N10ºE, 70ºNW. Left oblique-slip movement along this fault is indicated by slickenside surfaces along the face (Fig. 56). Foliation within the BRC at this location is N20ºW, 76ºNE and is cut by both faults.

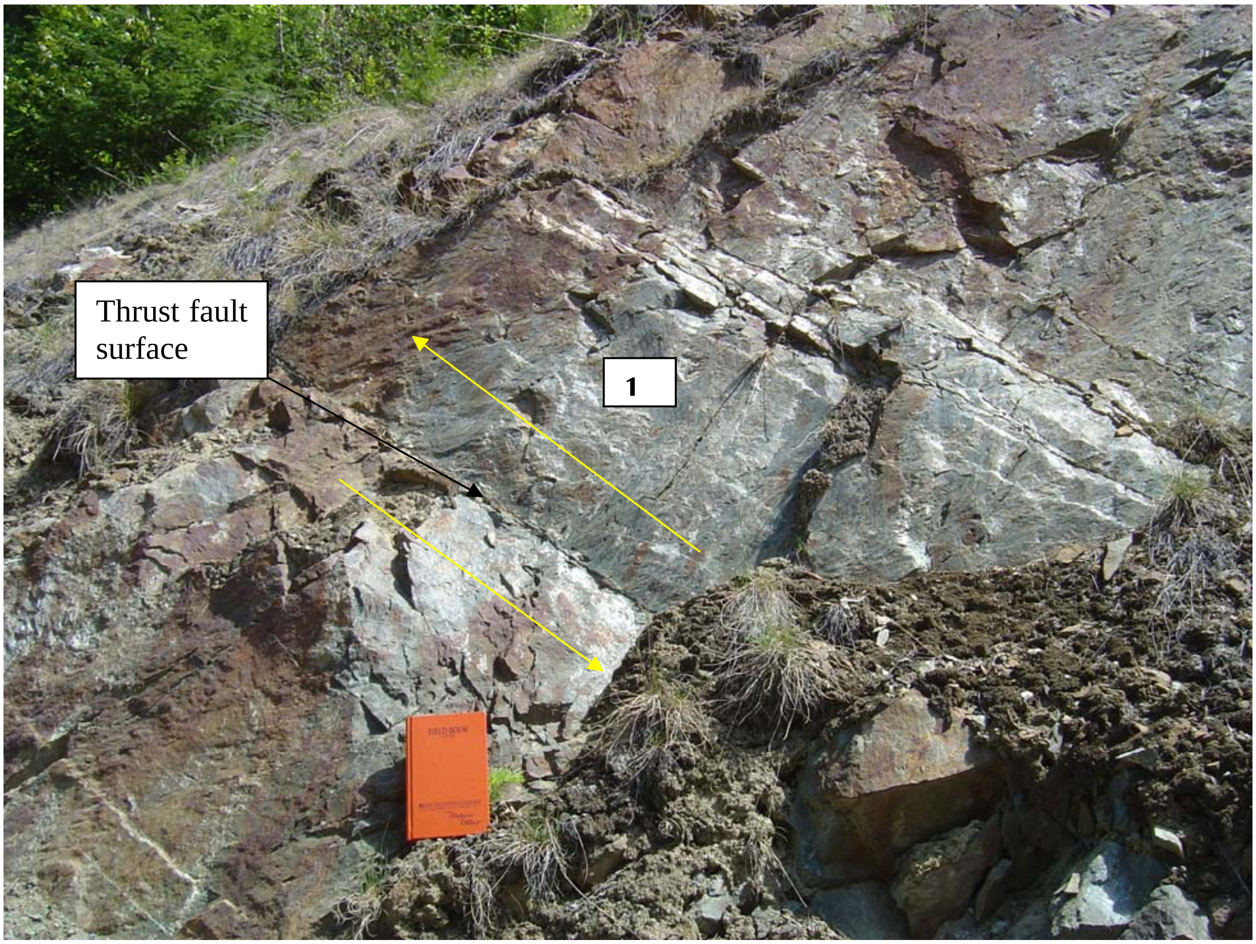

Figure 55. A top to the north thrust fault within the Bridge River Complex, at Station #28. Surface labeled "1" is an oblique left slip fault which is cut by the thrust.

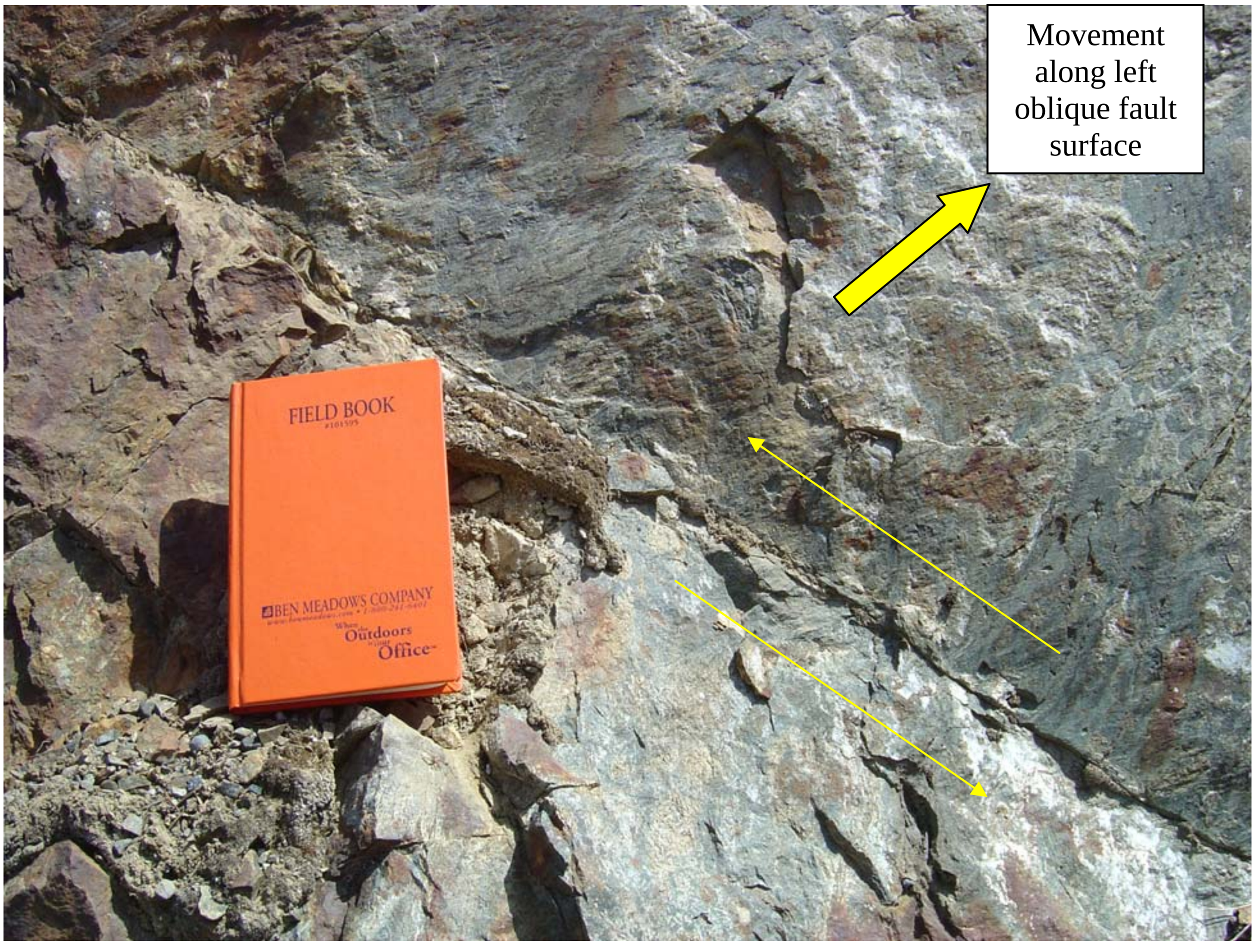

Figure 56. An oblique left slip fault at Station #28. Movement along the fault plane is given by the heavy arrow. Thin arrows indicate movement on the thrust fault depicted in Fig. 55.

Figure #57 shows another thrust fault that cuts across the general plane of foliation within the BRC. The orientation of this fault is N75ºE, 40ºSE. The plane of foliation that is cross-cut measures N15ºW, 67ºNE. Figure #58 depicts two small-scale left lateral faults. The fault below the coin off-sets two thin quartz veins and the surface measures N10ºE, 74ºSE. The other measures N20ºW, 74ºNE and cross-cuts the first. Also at Station #28, possible relict bedding within chert of the BRC is seen which measures N65ºE, 17ºNW (Figs. 59 , 60).

Figure 57. A second top to the north thrust fault mapped within the Bridge River Complex (in yellow) at Station #28. Notice the visibly disrupted foliation planes curving into the fault plane (in red). Total offset=<1m.

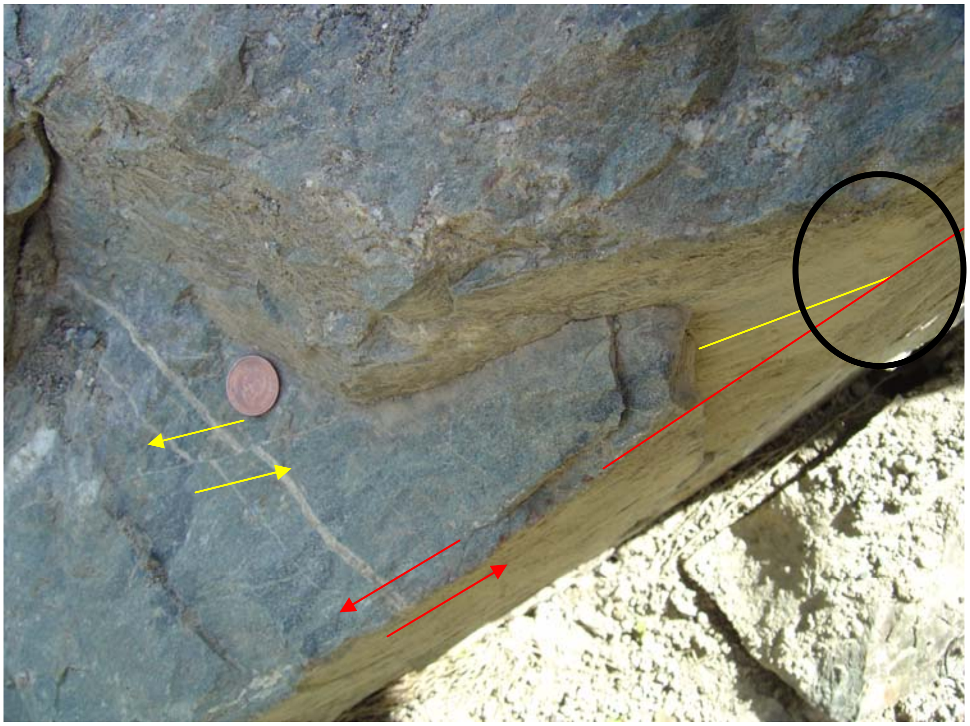

Figure 58. Very small scale left lateral faults at Station #28. The fault defined by the yellow arrows is truncated by the fault defined in red. Point of truncation is encircled.

Figure 59. Possible relict chert bedding of the Bridge River Complex at Station #28.

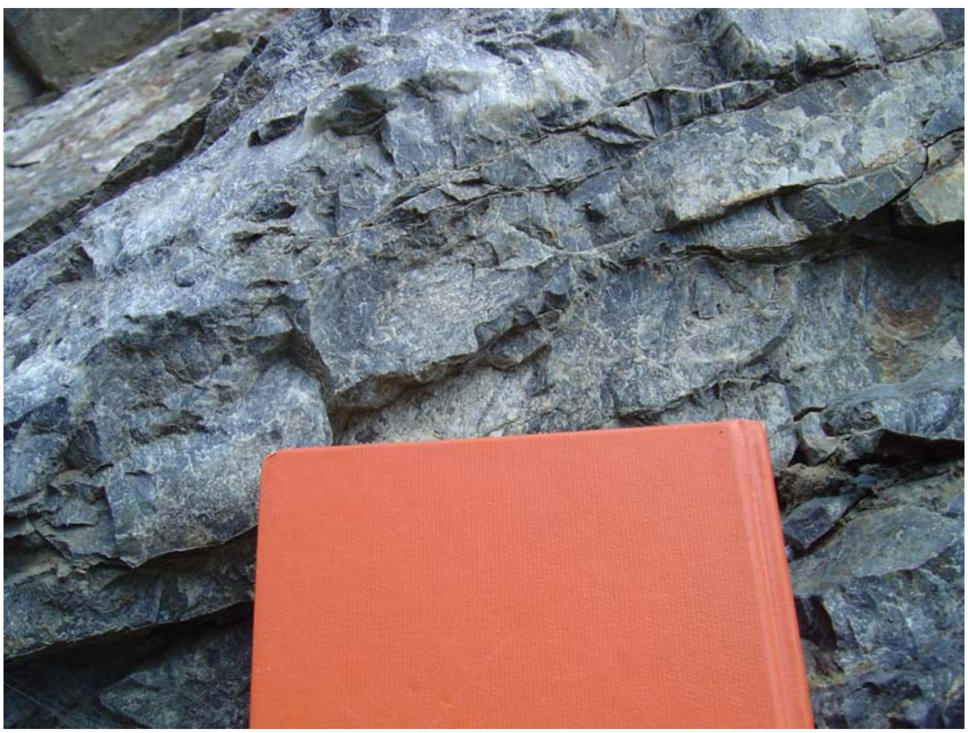

Figure 60. Closer view of outcrop in figure #59.

Samples of the BRC in the northeastern corner of the study area are within a sub-group of the BRC called the Bridge River Schist (BRS) (Friedman and Armstrong, 1995). Samples from the BRS are highly deformed and intruded by Eocene plutons (Fig. 61). At Station #77, greenschist of the BRS has a foliation of N30ºW, 65ºSW. Analyzed in thin section, shear bands give a right lateral sense of motion (Fig. 62).

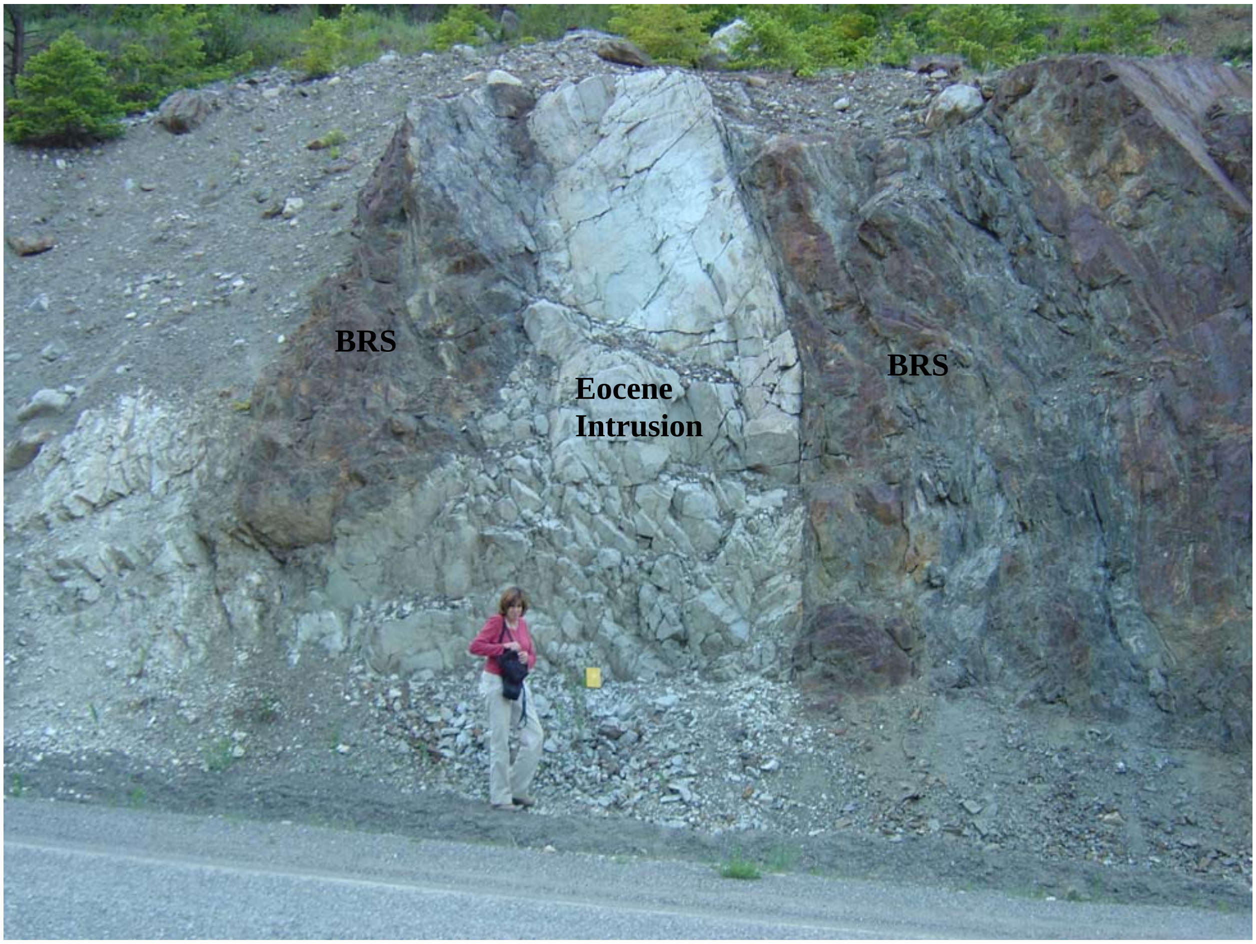

Figure 61. Contact relationship between the Bridge River Schist and an Eocene intrusion at Station #30

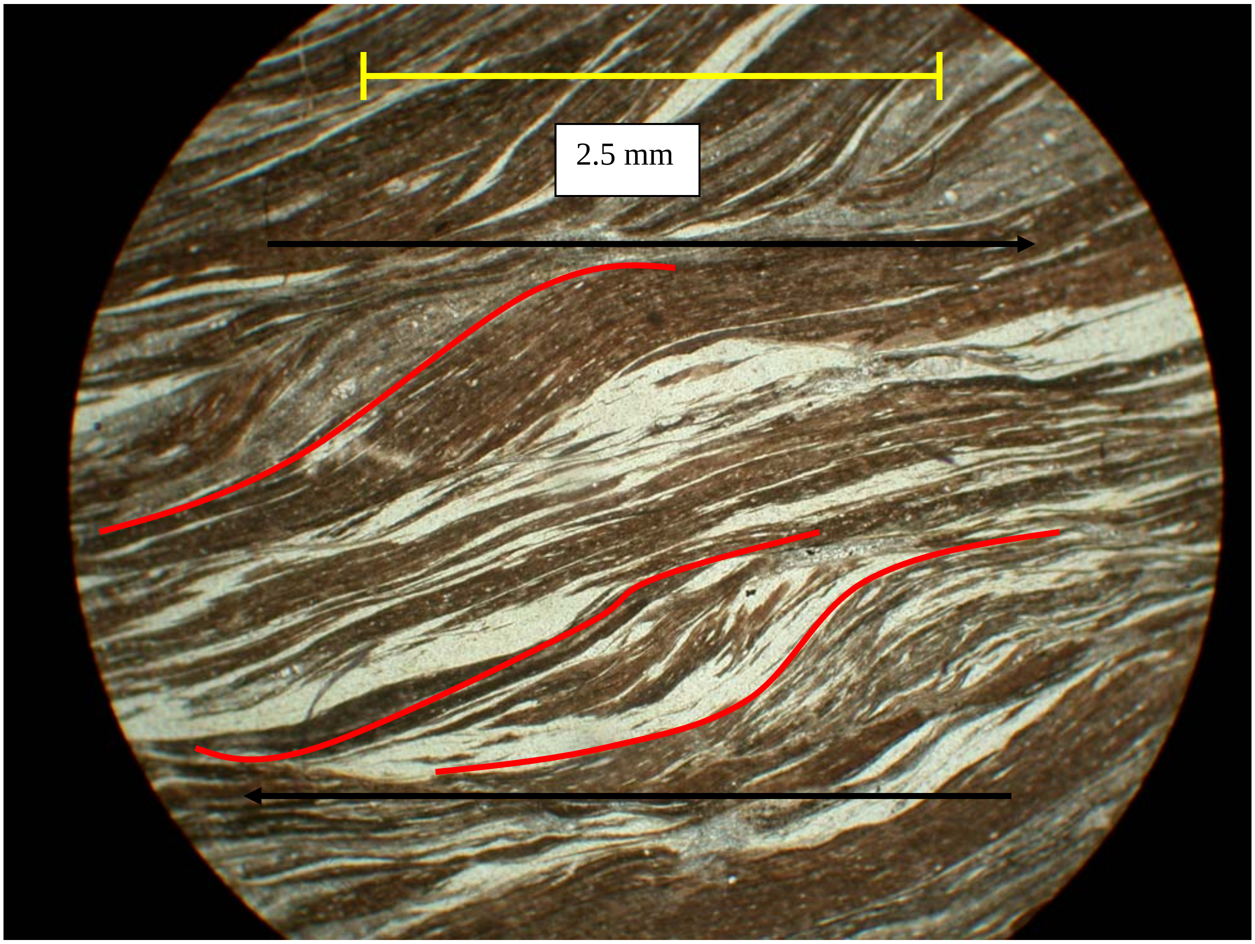

Figure 62. Photomicrograph of Sample #77. This strongly foliated greenschist is fine grained and not recrystallized and shear bands indicate right lateral movement. Thin section was cut parallel to strike and perpendicular to foliation.

Sample #76 is a meta-chert which shows elements of left-lateral movement preserved in C-S structures (Fig. 63). The rock is composed of medium grained quartz and calcite (<1mm) within a very fine grained (<<0.1mm) matrix of mica, calcite and quartz. Muscovite defines the foliation plane, which measures N65ºW, 53ºSW. It is within this matrix that left lateral movement is preserved.

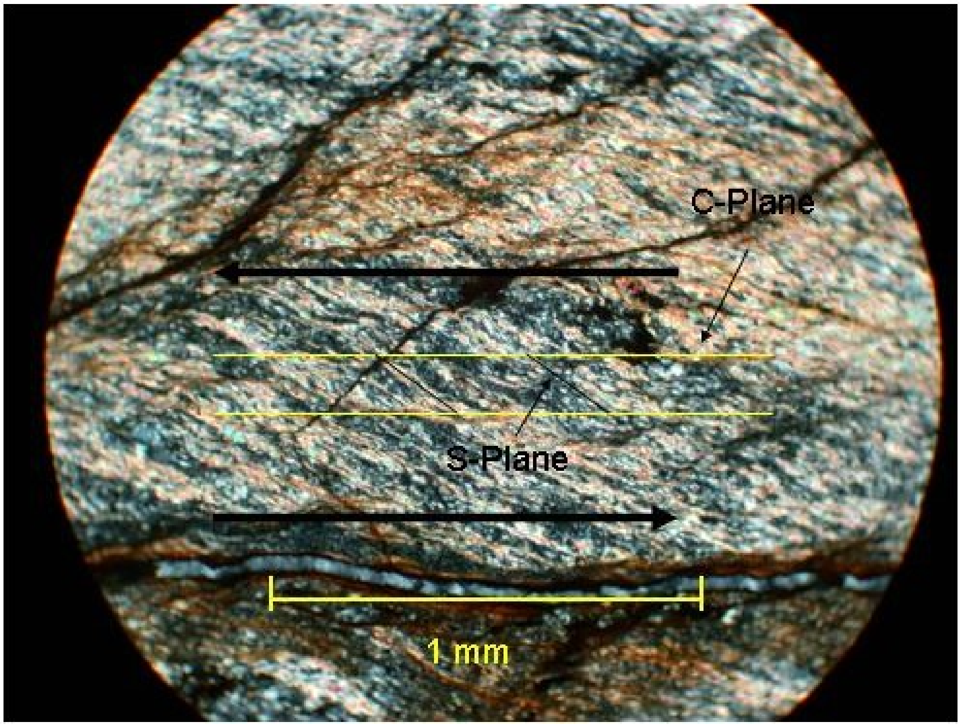

Figure 63. Photomicrograph of Sample #76, cut parallel to strike and perpendicular to foliation. Photo displays the left lateral C-S structures present at this location.

At Station #30, dynamically recrystallized Eocene granitic rocks which contain abundant plagioclase feldspar and quartz are deformed and preserve L-tectonite fabrics (Figs. 64, 65, 66, 90-App B). Sub-horizontal mineral lineations that plunge 4-6º and trend along strike record ductile lateral shear. Thinly banded gneiss which is a member of the Bridge River Schist based on its quartz rich mineralogy is not an L-tectonite. There is a well defined plane of foliation in rocks of the Bridge River Schist, characteristic of an S-tectonite fabric. Sub-horizontal mineral lineations and grain elongation along strike suggest lateral shear in the same deformation regime as the Eocene granitic rocks (Figs. 67, 68, 69). The presence of both strong lineation and strong foliation would classify this gneiss as an L-S tectonite.

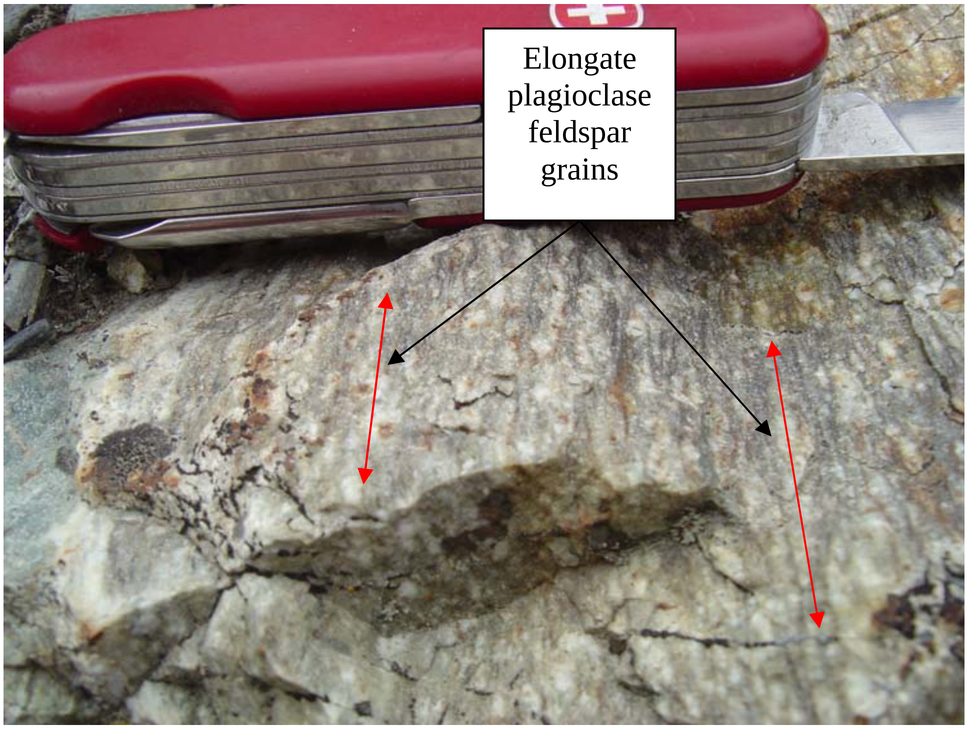

Figure 64. A feldspar porphyry displaying conspicuous rods of plagioclase. The L-tectonite is well developed at Station #30 within Eocene intrusions into the Bridge River Schist.

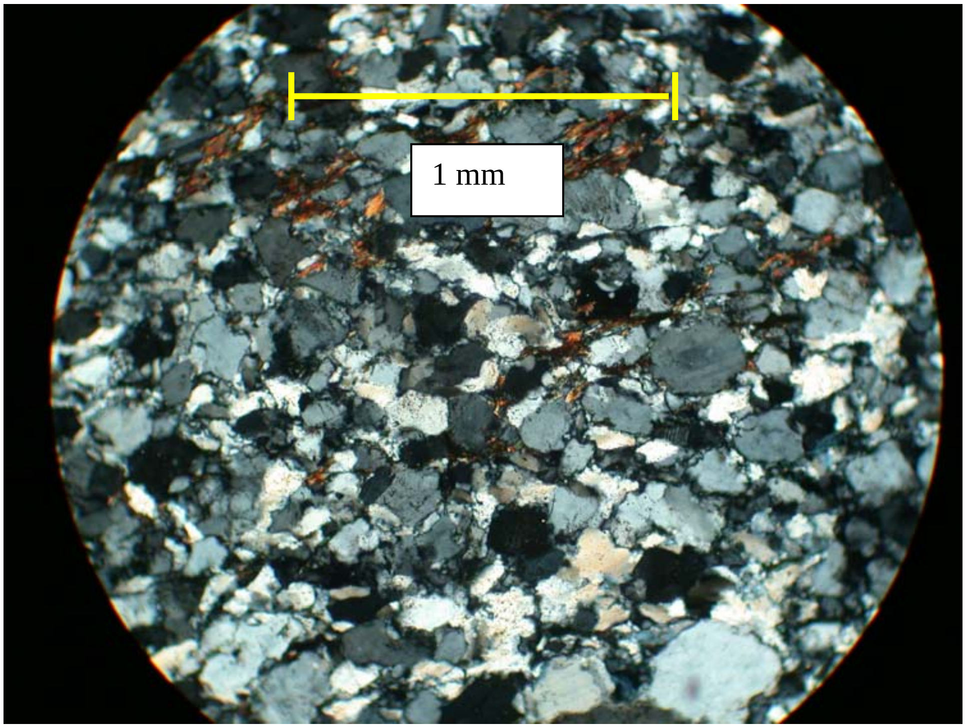

Figure 65. Photomicrograph of porphyry in Figure #64, cut parallel to dip and perpendicular to foliation. Notice the roughly equi-dimensional grain shapes. This is the result of viewing parallel to the mineral lineation.

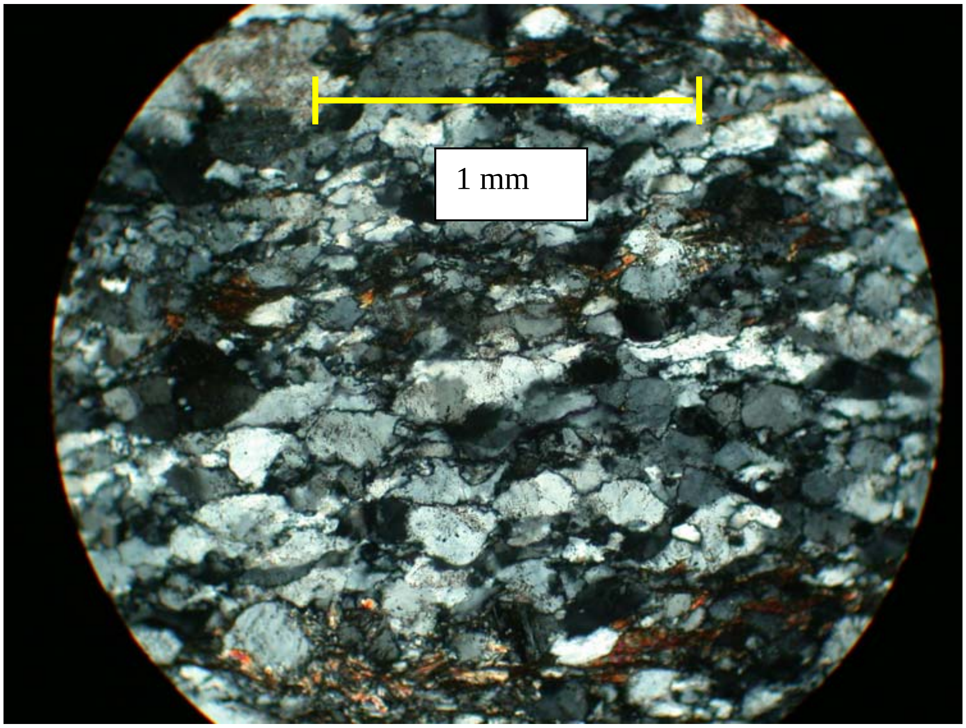

Figure 66. Photomicrograph of rock in Figure #64, cut parallel to strike and lineation and perpendicular to foliation. Notice the elongate grain shapes. This is the result of viewing perpendicular to the mineral lineation.

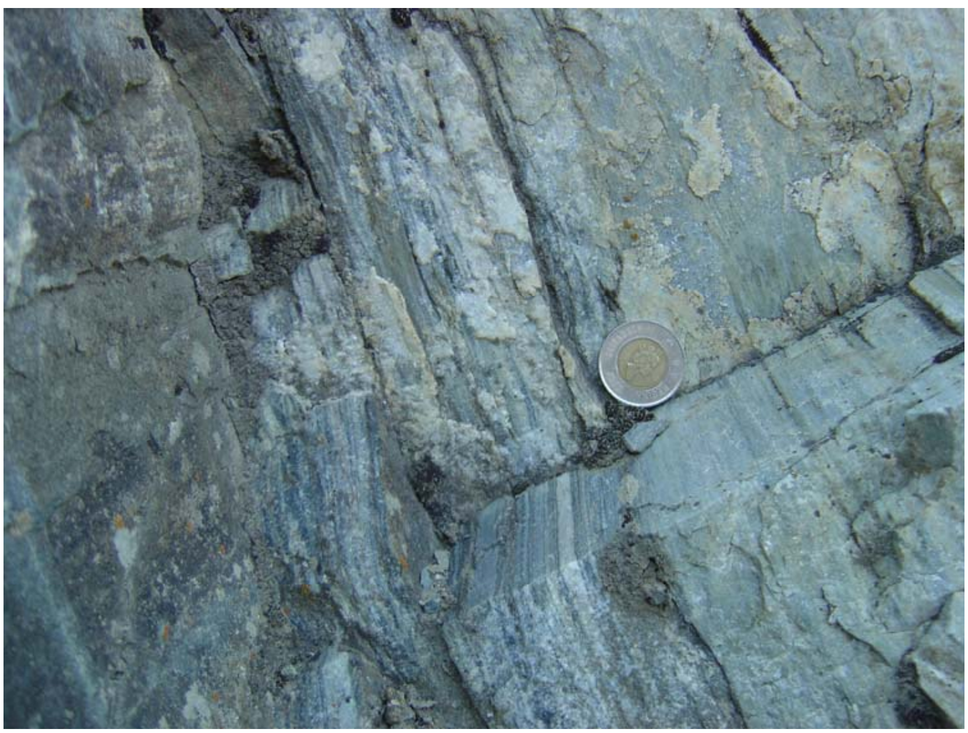

Figure 67.Thinly banded mylonite of the Bridge River Schist derived from meta-sediments of the Bridge River Complex at Station #30.

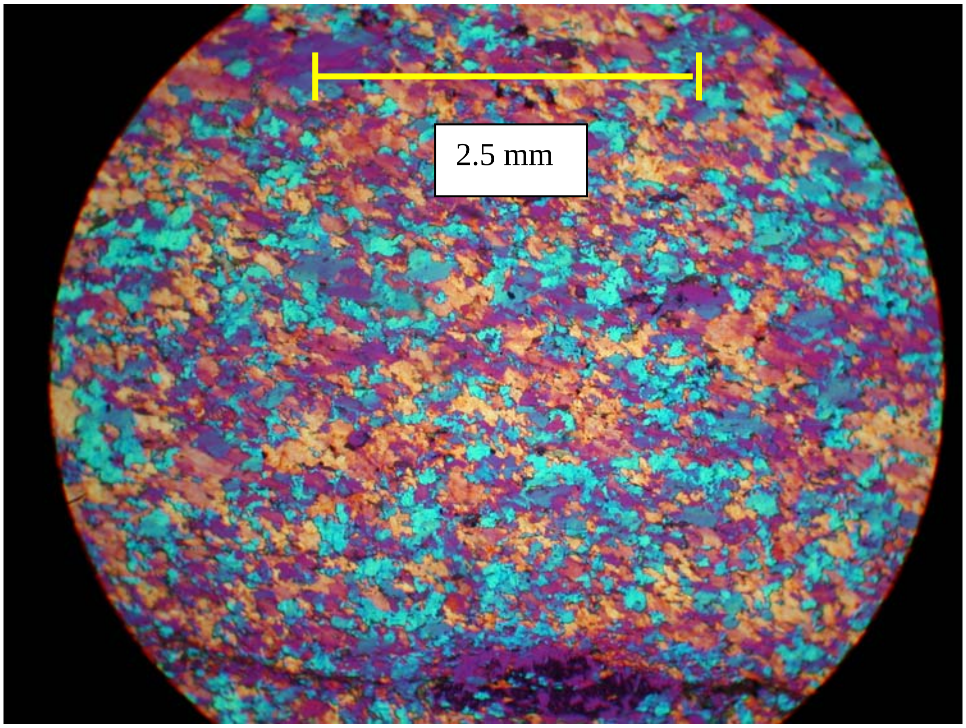

Figure 68. Photomicrograph of rock in Figure #67. Section cut parallel to dip and perpendicular to foliation. Notice the fused quartz grain boundaries as a result of dynamic recrystallization within this rock.

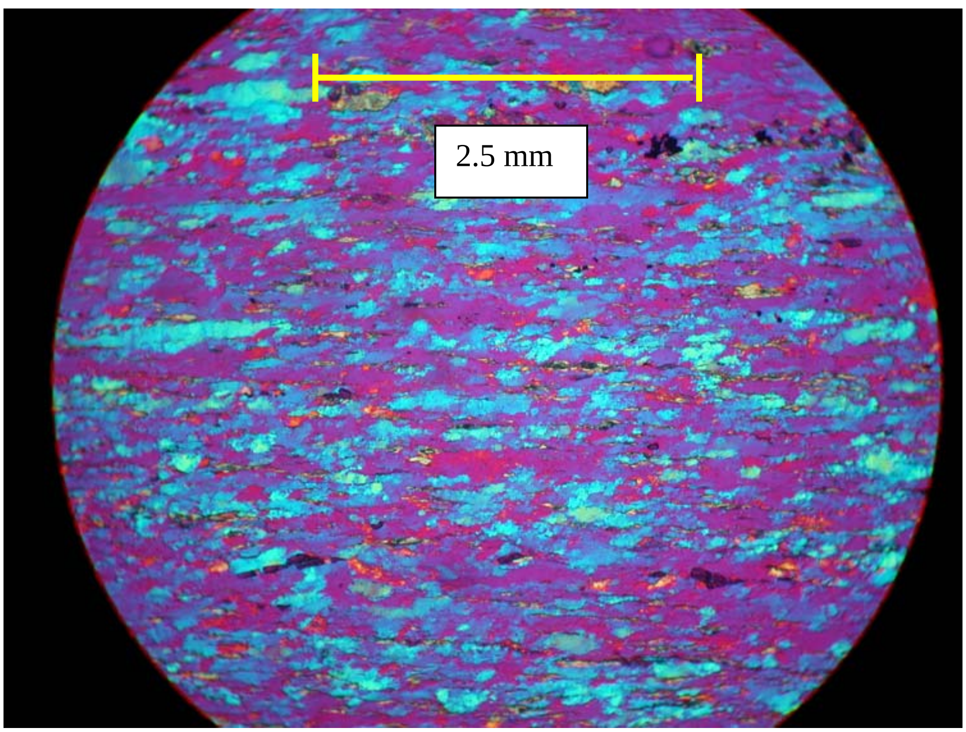

Figure 69. Photomicrograph of rock in Figure #67. Section cut parallel to strike and perpendicular to foliation. Notice the elongate appearance of the quartz grains compared to their appearance in Figure #68.

3.6. BREW GROUP SAMPLES

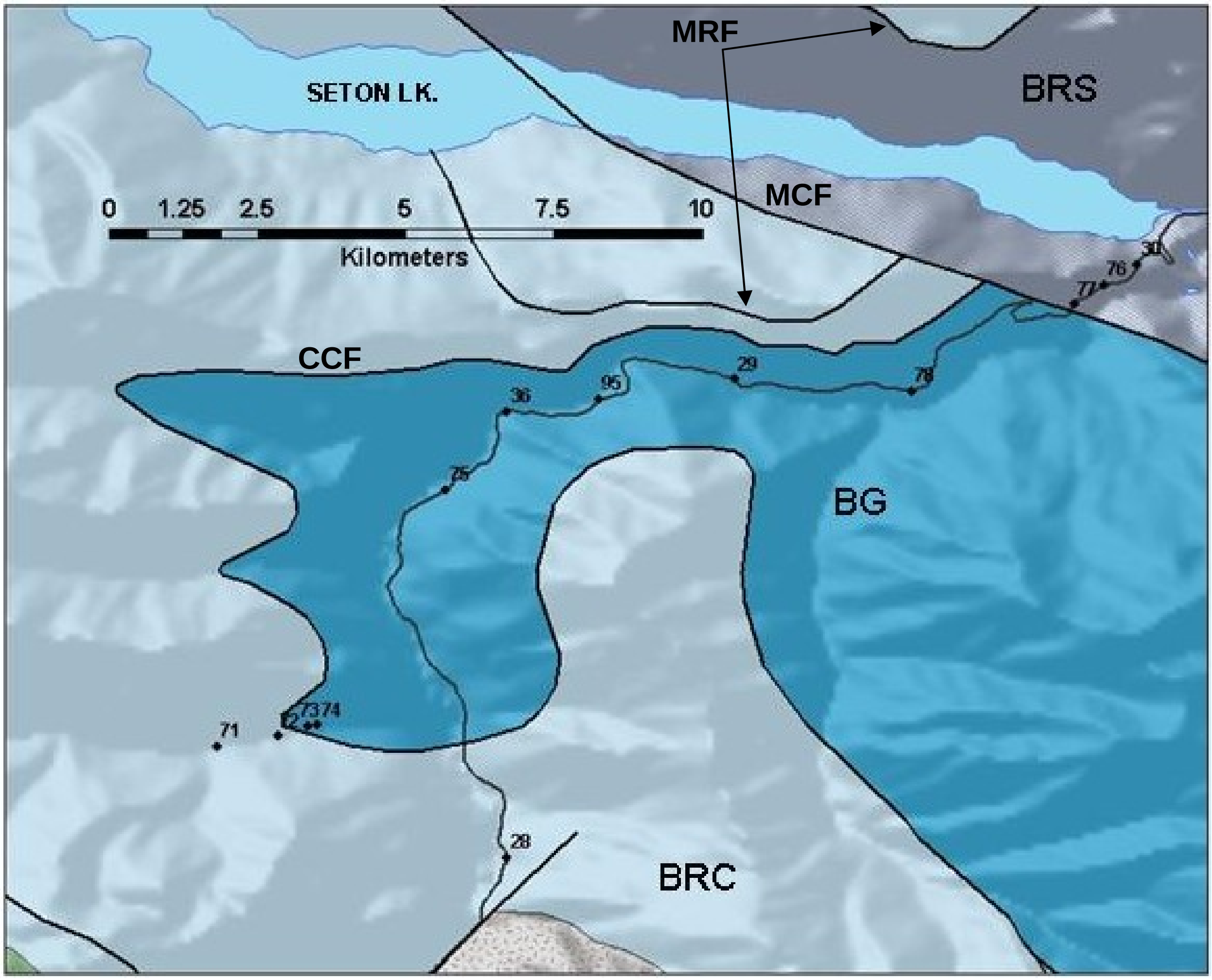

Figure 70. Detailed map showing the locations of Stations within the Brew Group. BRC=Bridge River Complex, BG=Brew Group, BRS=Bridge River Schist, MCF=Marshall Creek Fault, MRF=Mission Ridge Fault, CCF=Cayoosh Creek Fault. Modified from Massey et al. (2005).

3.6.1. Lithologic Classification

The Brew Group is best exposed along Highway 99 at Station #29 within a gorge ~6 km southwest of the town of Lillooet (Figs. 15, 70, 71). Generally, exposures reveal shallowly dipping calcareous meta-sandstone as described by Duffel and McTaggart (1952). Five hand samples were collected from areas mapped as Brew Group southwest of Lillooet. Sample #74 is near the contact between the Brew Group and the Bridge River Complex along the Cayoosh

Creek Fault. The mineralogy within this highly strained section of the Brew is ~50% calcite, ~25% quartz and ~25% micaceous minerals. The quartz is very fine grained; microcrystalline (<<0.1mm) with the exception of vein filling quartz. Very fine grained biotite and mica define the foliation within the rock. Calcite is the most abundant mineral and composes coarse grained aggregates of interlocking crystals (~1mm) that are parallel to the plane of foliation (Figs. 72, 73)

Figure 71. Outcrop photo of the Brew Group at Station #29. View is looking up a near vertical cliff face.

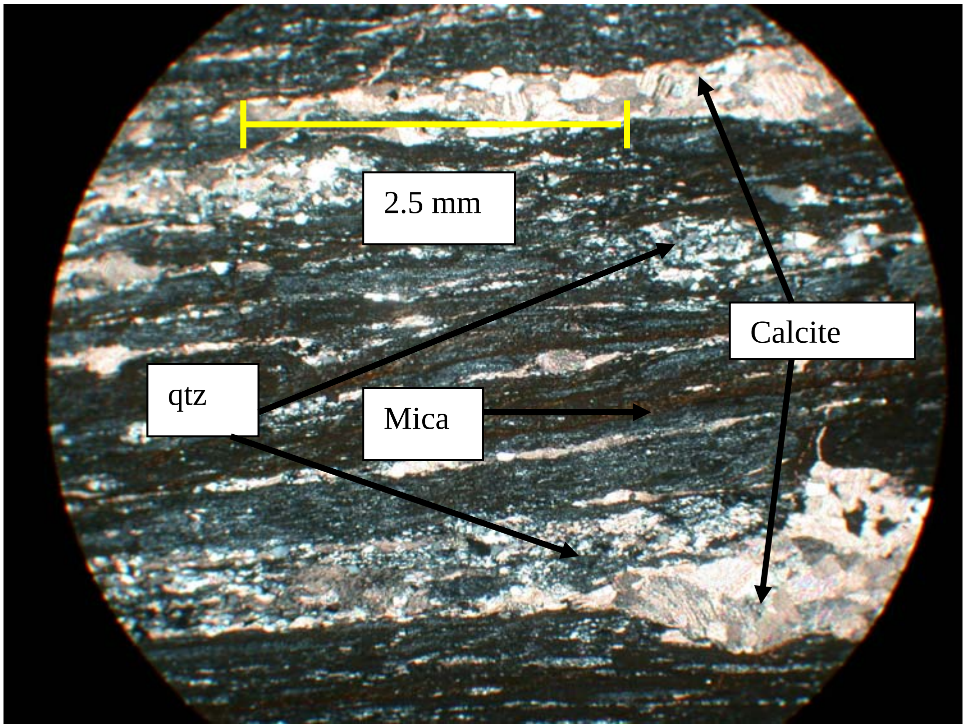

Figure 72. Photomicrograph of Sample #74 within the Brew Group showing abundant coarse grained calcite, fine grain quartz and fine grained, aligned mica. This section cut parallel to the dip direction and perpendicular to the foliation plane

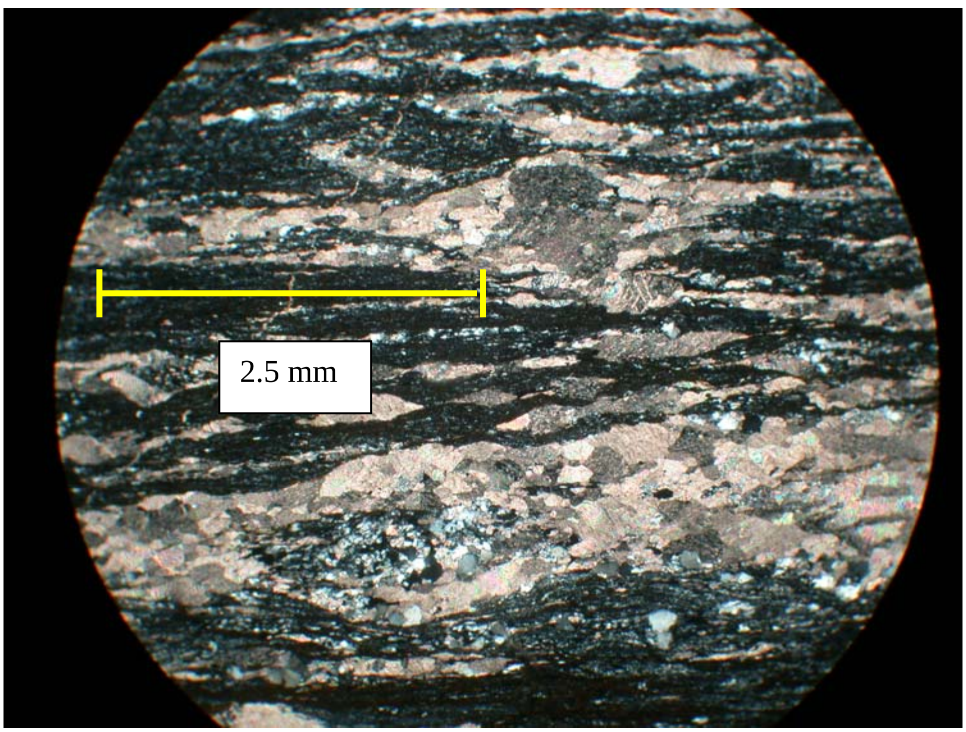

Figure 73. Sample #74, cut parallel to strike direction and perpendicular to the foliation plane.

At two locations within the Brew Group, along Hwy 99, unmapped, unfoliated igneous intrusions are encountered. At the southwestern contact with the Bridge River (N50º 35’ 27.9”, W122º 6’ 57.2”), a fine to medium grained plagioclase feldspar porphyry intrudes into the foliated rocks of the Brew Group. At Station #75 (N50º 37’ 36.6”, W122º 5’ 47.5”), fine grained (micro-crystalline to 1mm) and coarse grained (1-3mm) feldspar porphyry intrude the Brew Group. These intrusions are probably of Eocene or younger age based on the presence of Eocene plutons to the northwest in the Bridge River Complex. These intrusions outcrop in a northwest trending belt which would include the Brew group.

3.6.2. Field Measurements and Structural Analysis

Foliation within the Brew at Station #29 is sub-horizontal and cut by shear bands that record a normal sense of displacement (Fig. 74). Foliation is best developed along the contact between the Brew and overlying Bridge River Complex. The deformation is attributed to shallow-dipping detachment between these two units probably during exhumation of the Brew along the Cayoosh Creek Fault in Eocene time. The structural relationship is shown near the southwestern fault contact with the Bridge River, at Station #74 (Fig. 89-App B), where foliation within the Brew Group is roughly the same orientation as the fault plane, N30ºW, 22ºSW. Away from the contact with the Bridge River Complex, at Station #29, normal faults within the Brew Group record extension. Extensional shear-bands within the Brew commonly strike S70ºW, 48ºNW, showing NW-SE extension (Fig. 75). The hinges of roughly orthogonal isoclinal folds have an average trend of 7º, N47ºW (Figs. 76, 77, 78).

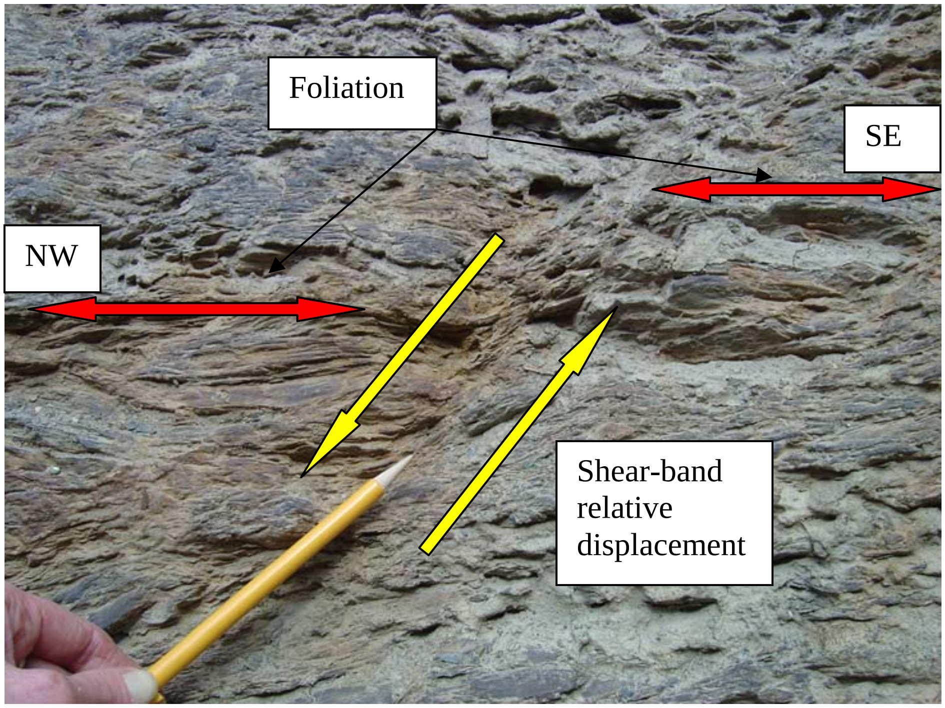

Figure 74. Photo from Station #29, showing extensional shear bands in a NW-SE extensional regime. The pencil is parallel to the plane of the shear band.

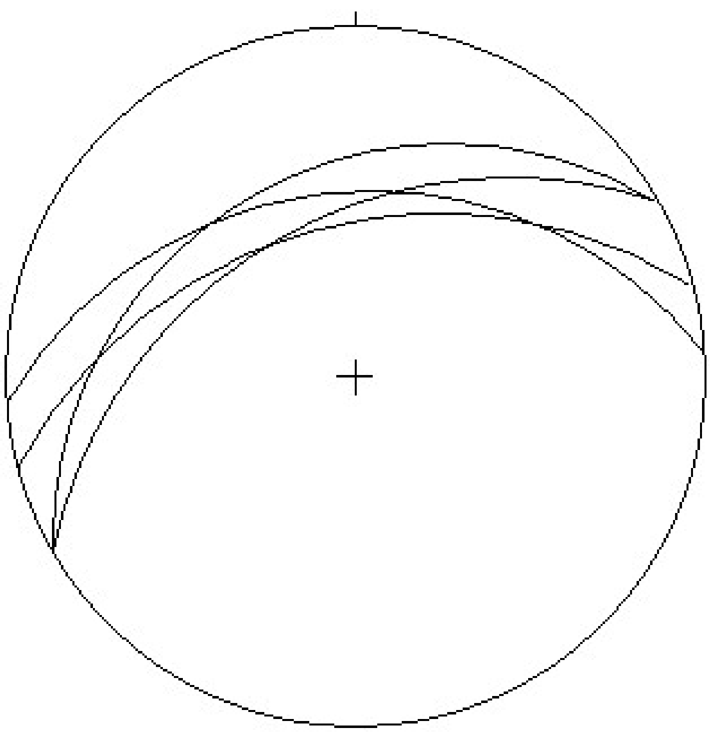

Figure 75. Equal area plot of shear band planes within the Brew Group at Station #29.

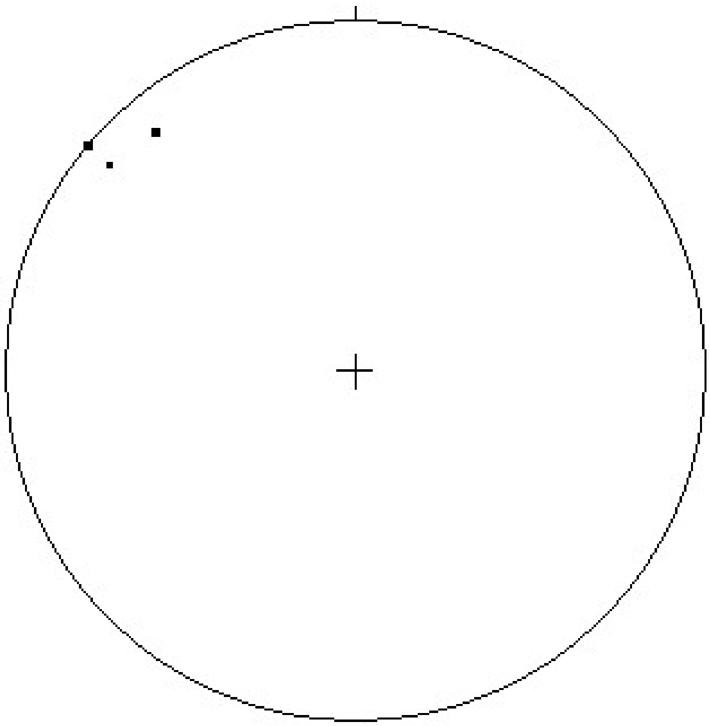

Figure 76. Equal area plot of sub-horizontal.isoclinal fold axes within the Brew Group at Station #29.

Figure 77. Isoclinal fold within the Brew Group at Station #29. View looking down the fold axis.

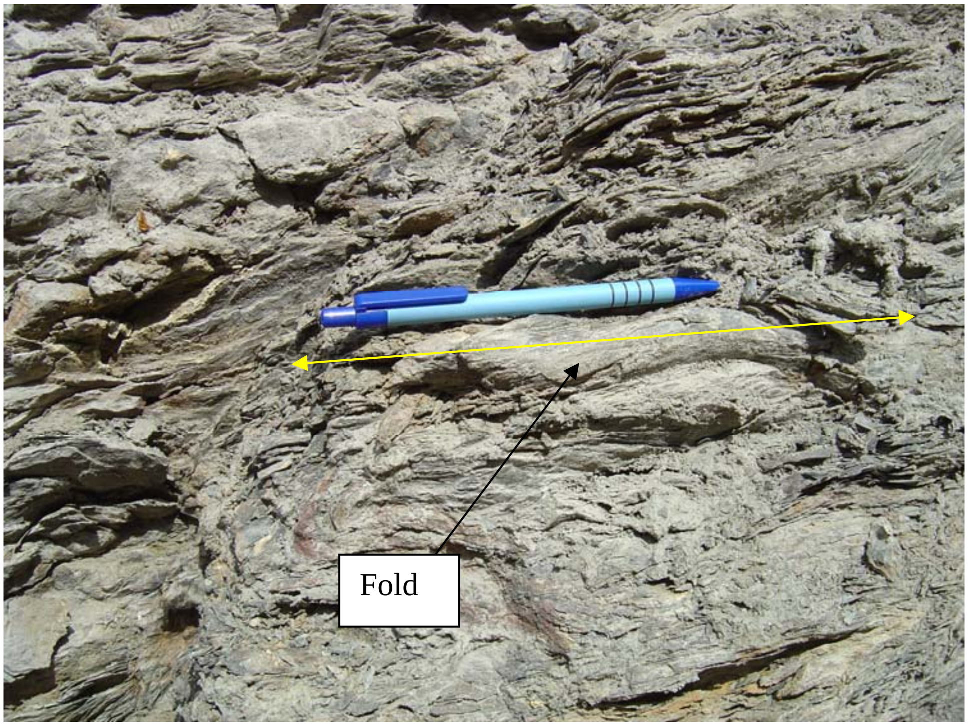

Figure 78. Isoclinal fold at Station #29. View perpendicular to the fold axis, in yellow.

Further northeast along Hwy. 99, a greenschist member (Price and Monger, 2000) within the Brew group crops out at Station #95 (Fig. 79). It is a quartz-biotite-chlorite meta-sedimentary rock which was probably derived from sandstone. This sample shows mineralogy and deformation which could easily be confused with that of the Bridge River Complex. The strike and dip at this location measures N75ºE, 40ºSE, which is distinct from foliation within the Bridge River.

Figure 79. Photo of outcrop from Station #95 within the Brew Group. The rocks display color and foliation very similar to that seen in the Bridge River Complex.

4. DISCUSSION

4.1. SUMMARY OF RESULTS

The rocks along this 110 km transect commonly record foliation that dips 30ºNE to vertical and strikes northwest. Down-dip lineation is common in these rocks. Although they are commonly recrystallized, locally developed microstructures preserve shear sense indicators in dip-parallel and strike-parallel thin sections cut perpendicular to the foliation plane. Differences among ductile structures within this field area indicate at least five styles of deformation. From west to east along the transect the following different fabrics are recognized: 1) Near Whistler, outcrops of strongly foliated, very fine grained volcanic rocks and meta-sediments of the Gambier Group have closely spaced and mylonitic foliation and show strong mineral lineation parallel to the dip direction. In thin section, overall the foliation is much more defined parallel to the dip direction than parallel to strike. Meso-scale kink folds and asymmetric tails in thin section are interpreted to be extensional in nature; symmetric tails in thin section also suggest flattening. Late Jurassic intrusive rocks adjacent to this belt of meta-volcanics on the west and east are also ductily deformed. 2) On Highway 99, west of Pemberton, Late Jurassic and Early Cretaceous plutons show northeast striking foliation. This is thought to be the result of northeast striking Oligocene-Miocene (~25-14 Ma) faults (Price and Monger, 2000). This system of faults cuts across all northwest striking faults and stratigraphic units. 3) Within the Chism Creek Schist, contact metamorphism from the 85-86 Ma Mount Rohr Pluton has completely annealed the rocks. Mineral lineations and meso-scale asymmetric folds have been preserved, however, that give a sense of oblique left-slip and pure shear in close proximity to the Bralorne fault system. This deformation does not affect the intrusive rock in contact, and therefore is pre-85 Ma. Both right and left lateral movement, along with flattening is observed within rocks of the Cayoosh Assemblage as well. Within the scope of this field study, an upper age limit cannot be determined. 4) The Brew Group of Duffell and McTaggart (1952) shows distinctly different deformation characteristics than surrounding rock units. Sub-horizontal penetrative foliation and shear bands record NW-SE extension probably related to structural exhumation of the Brew Group along the gently dipping Eocene Cayoosh Creek Fault in the footwall beneath the Bridge River Complex. 5) At Lillooet, the NE limit of this field study, steeply dipping mylonite along the dextral, Eocene Marshall Creek Fault consists of L-tectonites with distinct sub-horizontal mineral lineation. This penetrative deformation affects rocks of the Bridge River Complex in which left and right lateral shear sense indicators are found in thin section. Also affected are Eocene intrusive rocks in which only right-lateral movement is observed rocks.

4.2. CONCLUSIONS

Price and Monger (2000) report an age limit on the deformation at Whistler to be between 91 and 94 Ma. About 12 km southeast of Whistler, the Castle Towers Pluton, U-Pb dated at 91 Ma, cuts across the shear zone, and ~60 km southeast, granitic rocks dated at 94 Ma are cut by the shear zone. This is in agreement with the estimate by Journeay and Friedman (1993) of 91-97 Ma for large scale crustal shortening on the Coast Belt Thrust System. Structures which would indicate an older deformational regime within this shear zone are not seen within samples from the Whistler shear zone. The rocks are very fine grained and highly altered.

Northeast striking foliation seen within Late Jurassic and Early Cretaceous rocks, at Station #89 in between Whistler and Pemberton is the result of a late-stage (25-14 Ma), northeast trending fault system which cuts across elements of the Coast Belt and CBTS (Price and Monger, 2000).

Ductile deformation within the southwest belt of Cadwallader Group rocks within this field area is in close proximity to the Central Coast Belt Detachment (CCBD) which was active at 97-91 Ma (Journeay and Friedman, 1993). The 103 Ma Spetch Creek Pluton, which bifurcates the two belts of Cadwallader Group rocks does not show any signs of deformation within this field area. Therefore, the deformation within the southwest belt is possibly the result of strain along the CCBD. A discrete ductile shear zone in the northeast belt of Cadwallader has not been recognized previously and is probably not attributed to the CCBD. It is in closer proximity to the Bralorne-Twin Lakes fault system, active at 91-86 Ma (Leitch, 1989), which is a system of thrust and left-oblique faults. Deformation seen at Station #33 shows extensive down-dip stretching and overall, a regime of dip-slip movement, which is in agreement with deformation along the Bralorne-Twin Lakes fault system.

Rocks of the Chism Creek Schist, Cayoosh Assemblage and Bridge River Complex are deformed as a result of thrusting, right lateral and left-oblique slip along the Bralorne-Twin Lakes fault system and Downton Creek Fault. The Mount Rohr pluton is responsible for extensive contact metamorphism and recrystallization within the Chism Creek Schist.which has destroyed microstructures near the contact. The Chism Creek Schist was deformed between 91 and 86 Ma, given by age constraints on the Bralorne fault system. Price and Monger (2000) document that the Scuzzy Pluton (85 Ma) cross-cuts the fault and Leitch (1989) detailed the presence of meso-thermal gold veins which have been associated with movement along the fault and dated at 91-86 Ma. Roddick (1987) constrains movement along the reportedly right lateral Downton Creek Fault (DCF) at ~77 Ma. This study supports the presence of left lateral deformation along the DCF, possibly in an older, left-oblique extensional deformation regime.

The sub-horizontal foliation and extensional shear bands of the Brew Group are the result of its exhumation in the footwall under the BRC, along the Cayoosh Creek Fault (Coleman and Parrish, 1991). The Cayoosh Creek Fault is a shallowly nourtheast dipping thrust active in the Eocene.

Within the Bridge River Schist (BRS), several styles of deformation are observed. At Station #76, left later C-S structures are preserved, which would indicate an episode of left lateral movement along the Marshall Creek Fault (MCF). The MCF has previously been reported as an Eocene dextral strike-slip and thrust fault (Journeay et al., 1992; Coleman, 1990). The left lateral movement could possibly be an older episode of strike-slip along the Marshall Creek Fault, which was then reactivated in Eocene times. Right lateral movement along the MCF is recorded at Station #77, in shear bands within a highly strained greenschist. Station #30 is the locus for dynamic strike slip movement which has completely annealed rocks of both the BRS and Eocene intrusions. All microstructures have been overprinted by this deformation, but L-Tectonites and sub-horizontal mineral lineations within Eocene granitic rocks are interpreted to be the result of right lateral movement along the Marshall Creek Fault (Journeay et al., 1992; Coleman, 1990).

The discovery of relict left-lateral microstructures on the Downton Creek Fault and Marshall Creek Fault within the Cayoosh Assemblage and Bridge River Schist indicate the possibility of old lateral displacement in the Southern Coast Belt. In all instances, the left lateral micro-structures preserved are recrystallized or appear to disrupt flattening and right lateral structures. The presence of these sinistral displacement indicators *supports* the tectonic theories of Gehrels and Saleeby (1985), McClelland et al. (1992), and Monger et al. (1994) which seek to use lateral displacement to duplicate magmatic belts of the same age in the Coast Belt.

APPENDIX A

Sample Specific Descriptions and Locations

This Appendix contains sample specific locations and descriptions of each sample.

Table 1. Field stop locations

	LAT (ºN)				LONG (ºW)			DESCRIPTION
Station #	Deg	Min	Sec		Deg	Min	Sec	
23	50	23	8.1		122	21	21.9	Hand Sample: Block of Chism Creek Schist within Mt. Rohr pluton. Foliated: N25ºW, 85ºNE. Asymmetric folds with steep fold hinges: 88º, S25ºE fold axis.
24	50	24	9.6		122	18	27.9	Thin Section: Chism Creek Schist Foliated: N62ºW, 75ºNE 80% quartz, 15% biotite, 1-5% garnet Recrystallized by contact metamorphism from Mt. Rohr pluton. Hexagonal quartz <1mm grain size. Biotite shows no preferred orientation; garnet concentrated within biotite layers.
25	50	24	33.3		122	17	58.2	Thin Section: Chism Creek Schist Foliation: N40ºW, 87ºNE Lineation: 32º, N36ºW 70% quartz, 20% biotite, 10% opaques, chlorite, garnet, clino-zoisite. Recrystallized by contact metamorphism. No shear sense indicators.

26	50	32	0.2		122	9	1	Thin Section: Cayoosh Assemblage Foliated: N9ºW, 85ºNE Downdip lineation present Almost 100% quartz, minor calcite and opaque minerals within zones of pressure solution. Quartz recrystallized, <<.1mm grains size, no shear sense indicators. Quartz slightly elongate in dip parallel thin section
27	50	32	5.4		122	8	1.9	Thin Section: Cayoosh Assemblage Foliated: N5ºW, 81ºNE Mylonitic foliation 70% quartz, 20% opaque pressure solution, 10% calcite and mica. Fine grained quartz (<1mm) Recrystallized Flattened grain aggregates with symmetric tails give a sense of pure shear and flattening. Isolated left lateral indicators, not consistent
28	50	34	15.8		122	5	14	No Sample: Bridge River Complex Foliated: N20ºW, 76ºNE
29	50	38	36.4		122	3	10.1	No Sample: Brew Group Sub-Horizontal foliation
30	50	39	39.2		121	59	30.4	Thin Section: Bridge River Schist Sample described in Sections 3.5.1, 3.5.2.
31	50	22	10.3		122	44	44.2	Hand Sample: Cadwallader Group On Forest Service Rd, off Hwy 99. Dark greenstone, massive, unfoliated. Striations and chatter marks suggest minor right lateral displacement.
32	50	22	9.6		122	43	37.2	Hand Sample: Cadwallader Group Sample described in Section 3.2.2.
33	50	27	35.1		122	40	21.9	Thin Section: Cadwallader Group Sample described in Sections 3.2.1, 3.2.2.
34	50	28	38.6		122	38	6.9	Hand Sample: Cadwallader Group Massive chert, showing relict tilted bedding planes.

36	50	38	19.1		122	5	14.2	Field Stop: Possible contact between Brew Group and Bridge River Complex.
37	50	34	16.4		122	36	52	Field Stop: Bridge River Complex Chatter marks indicate right lateral movement:: Slick lines: 23º, N55ºW. Foliation: N35ºW, 74ºSW Foliated greenish-grey rock
38	50	32	54.1		122	33	7	Hand Sample: Chism Creek Schist Non-penetrative foliation in massive rock with sandy texture
39	50	31	56.7		122	29	13	Thin Section: Chism Creek Schist Sample described in Section 3.3.2.
40	50	32	48.1		122	29	23.8	Hand Sample: Chism Creek Schist Along railroad tracks outside D'arcy. Foliation: N52ºW, vertical Slaty texture
41	50	30	32.9		122	30	45.6	Hand Sample: Chism Creek Schist Foliation: N82ºW, 83ºNE Fault Face: E-W, 80ºN, thrust fault Mylonite
42	50	20	29.1		122	43	45.7	Hand Sample: Gambier?? Near Gambier-Cadwallader Contact. Feldspar porphyry, unfoliated
43	50	21	57.3		122	43	24.5	Hand Sample: Cadwallader Group Road through Owl Ridge Estates Fine grained, foliated, greenish rock. Description in Section 3.2.2.
44	50	27	55.1		122	39	45.6	Hand Sample: Granodiorite of the Spetch Creek Pluton, unfoliated.
45	50	19	29.4		122	48	30.1	Hand Sample: Pemberton Meadows Road. Granodiorite of the Pemberton Diorite Complex.
46	50	10	8.9		122	54	22.5	Hand Sample: Whistler Heli-port off Hwy 99. Non-penetrative foliation Possibly the eastern edge of the Whistler Shear Zone.
47	50	9	58		122	55	21.5	Hand Sample: First appearance of penetratively foliated, white mylonite of the Whistler Shear Zone. Foliation: N40ºW, 70ºNE

48	50	9	26.6		122	55	40.6	Hand Sample: Unfoliated granodiorite of uncertain age near Whistler.
49	50	6	37.8		122	57	53.5	Hand Sample: Whistler Shear Zone Foliation: N50ºW, 82ºSW
50	50	6	35.8		122	58	14.4	Thin Section: Whistler Shear Zone Foliation: N63ºW, 86ºSW Foliation: N65ºW, 82ºNE
51	50	6	42.2		122	58	16.3	Hand Sample: Road through Blueberry Hill Estates. Whistler Shear Zone Foliated: N32ºW, 64ºNE Kink folds present which are described in Section 3.1.2 and Fig. 21.
52	50	6	13.1		122	58	49.6	Hand Sample: Whistler Pendant Foliation: N59ºW, 85ºNE
53	50	6	14.2		122	59	0.8	Thin Section: Whistler Shear Zone Described in Section 3.1.2 and Fig. 20.
54	50	5	24.3		123	0	1.3	Hand Sample: Whistler Pendant Foliation: N60ºW, vertical
55	50	5	26.6		123	0	14.7	Hand Sample: Whistler Pendant Foliation: N40ºW, 70ºNE
56	50	5	26		123	0	23.8	Hand Sample: Whistler Pendant Foliation: N65ºW, 89ºNE
57	50	5	20.2		123	1	2.1	Hand Sample: Foliated Late Jurassic pluton west of Whistler Pendant Foliation: N50ºW, 69ºNE Description in Section 3.1.1.
58	50	5	14.5		123	2	0.6	Hand Sample: Foliated Late Jurassic pluton west of Whistler Pendant Foliation: N18ºW, 85ºNE Description in Section 3.1.1.
59	50	24	24.5		122	18	8.7	Hand Sample: Chism Creek Schist Foliation: N50ºW, 80ºNE Dark grey, quartz-rich
60	50	24	33.3		122	17	58.4	Hand Sample: Chism Creek Schist Foliation: N30ºW, vertical Dark grey, quartz rich Cross-cut by dikes (probably Mt. Rohr Pluton)

61	50	24	43.7		122	17	23.4	Thin Section: Chism Creek Schist Foliation: N30ºW, 72ºNE Assymetric folds present with steep fold axes: indicate oblique left slip. See Section 3.3.2.
62	50	24	46.1		122	17	11.8	Hand Sample: Chism Creek Schist Foliation: N30ºW, vertical Dark grey, quartz-rich
63	50	24	58		122	16	48.3	Hand Sample: Chism Creek Schist Foliation: N47ºW, vertical Dark grey, quartz-rich
64	50	28	3.4		122	14	23.9	Hand Sample: Bridge River Complex Foliation: N30ºW, 74ºNE Description in Section 3.5.1.
65	50	28	43.9		122	12	57.8	Hand Sample: Bridge River Complex Foliation: N19ºW, 70ºNE Description in Section 3.5.1.
66	50	29	29.2		122	11	48.9	Hand Sample: Bridge River Complex Foliation: N45ºW, 70ºNE Mylonite, mafic-rich, weathers to green color (chlorite) Description in Section 3.5.1.
67	50	30	2		122	11	8.2	Hand Sample: Cayoosh Assemblage Foliation: E-W, Vertical Dark, mafic rich mylonite
68	50	32	6.5		122	8	27.6	Hand Sample: Cayoosh Assemblage Foliation: N5ºW, 85ºNE Green rock, mica and plagioclase rich, lithologically similar to Bridge River Complex rocks.
69	50	32	1.2		122	8	59	Hand Sample: Cayoosh Assemblage Foliation: N5ºW, 75ºSE Dark, biotite-rich, highly foliated. Weathers to light grey.
70	50	32	38.5		122	6	27.5	Hand Sample: Unfoliated Granodiorite of the Bendor Plutonic suite.
71	50	35	16.6		122	7	52.5	Hand Sample: Bridge River Complex Along Downton Creek Rd. off Hwy99. Foliation: N30ºW, 60ºSW

72	50	35	22		122	7	19.2	Hand Sample: Bridge River Complex Along Downton Creek Rd. off Hwy99. Foliation: N26ºW, 30ºSW
73	50	35	27.5		122	7	2.7	Hand Sample: Bridge River Complex Along Downton Creek Rd. off Hwy99.
74	50	35	27.9		122	6	57.2	Thin Section: Brew Group Along Downton Creek Rd. off Hwy99. Description in Section 3.6.1.
75	50	37	36.6		122	5	47.5	Hand Sample: Within Brew Group Massive, unfoliated feldspar porphyry, probably of Eocene age.
76	50	39	27.9		121	59	48.5	Thin Section: Bridge River Schist Foliation: N65ºW, 53ºSW Lineation: 11º, S75ºE Description in Sections 3.5.1, 3.5.2.
77	50	39	17.4		122	0	5	Thin Section: Bridge River Schist Foliation: N30ºW, 65ºSW Description in Sections 3.5.1, 3.5.2, and Fig. 62.
78	50	38	30.2		122	1	33.8	Field Stop: Brew Group
79	50	5	41.8		123	0	33.3	Hand Sample: Whistler Pendant Unfoliated, massive, blocky Intermediate-mafic composition.
80	50	5	44.4		123	0	11.5	Hand Sample: Whistler Pendant Foliation: N45ºW, 84ºNE Coarse grained, green to grey rock.
81	50	6	3.1		123	0	2.3	Hand Sample: Whistler Pendant Foliation: N50ºW, 85ºNE Fault present with same orientation as foliation plane
82	50	6	11.4		122	59	53.3	Hand Sample: Whistler Pendant Foliation: N21ºW, 85ºNE
83	50	6	20.9		122	59	28.1	Thin Section: Whistler Pendant Foliation: N5ºE, 77ºSE Plagioclase and quartz phenocrysts in a fine grained biotite, plag, and quartz matrix. Symmetric tails indicate pure shear.

84	NA				NA			Thin Section: Whistler Pendant Foliation: N10ºE, 86ºSE
85	50	7	53.1		122	58	53.6	Hand Sample: Whistler Pendant Foliation: N23ºW, 81ºSW
86	50	8	9.8		122	58	51.2	Thin Section: Whistler Pendant Foliation: N28ºW, 85
87	50	8	8.4		122	58	34.8	Thin Section: Whistler Pendant Foliation: N29ºW, 60ºNE
88	50	10	0.1		122	53	54.9	Hand Sample: Unfoliated chloritic granodiorite adjacent to Whistler Pendant on the east side.
89	50	15	33.1		122	51	51.6	Hand Sample: Dark green, non-penetratively foliated rock intruded by granodiorite. Foliation: N25ºE, 81ºNW
90	50	17	55.8		122	48	50.5	Hand Sample: Non-penetratively foliated intrusive rock, west of Pemberton. Foliation: N20ºW, 70ºSW Fine grained plagioclase, hbl, mica rich rock.
91	50	18	47.1		122	48	22.7	Thin Section: Penetratively foliated intrusive rock, west of Pemberton. Foliation: N36ºW, 72ºSW Very fine grained meta-andesite.
92	50	18	40.8		122	39	2.3	Hand Sample: Cadwallader Group Along Xt'Olacw Road, off Hwy99. Porphyritic andesitic basalt Unfoliated
93	50	18	23.5		122	36	11.6	Hand Sample: Unfoliated granodiorite of the Spetch Creek Pluton at NW end of Lillooet Lake.
94	50	18	11.4		122	35	4.7	Hand Sample: Unfoliated granodiorite of the Spetch Creek Pluton at NW end of Lillooet Lake.
95	50	38	25.9		122	4	24.3	Hand Sample: Brew Group Foliated: N75ºE, 40ºSE

APPENDIX B

Three-Dimensional Block Diagrams

The following diagrams were constructed using a thin section cut parallel to strike and perpendicular to foliation and a thin section cut parallel to dip and perpendicular to foliation. The top of the block represents the strike-parallel section. The front face of the block represents the dip-parallel section.

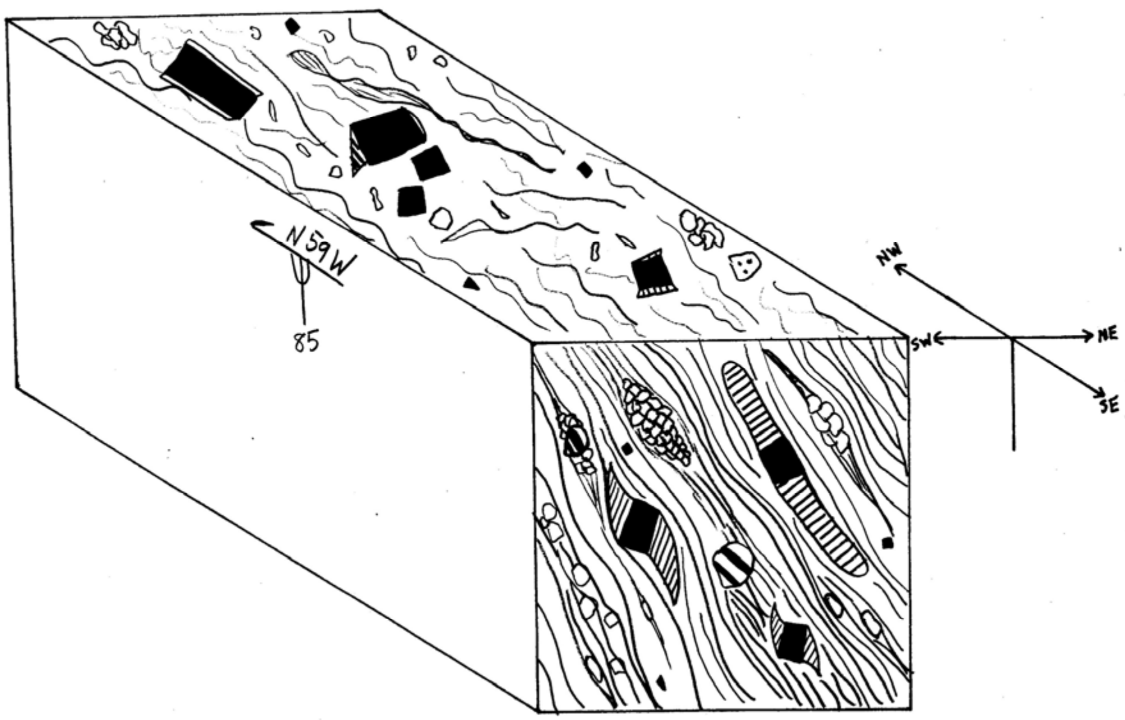

Figure 80. 3-D block diagram constructed from thin sections of Sample #53 of the Whistler Pendant

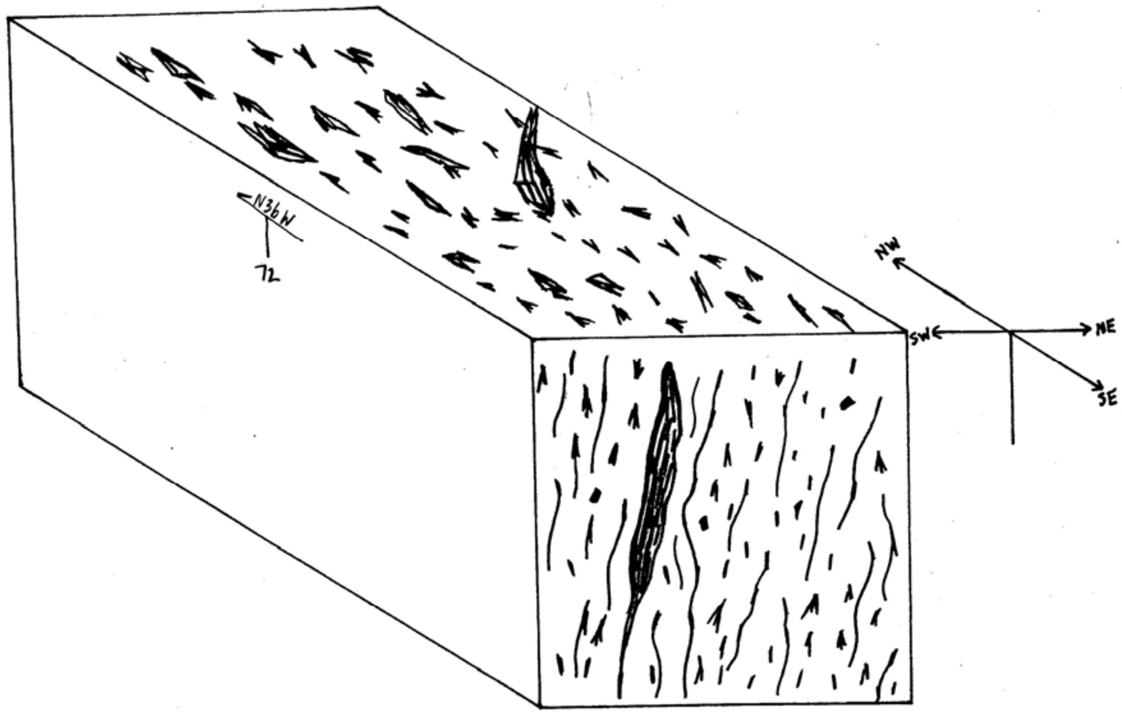

Figure 81. 3-D block diagram constructed from thin sections of Sample #91 within foliated intrusive rocks ~2km west of Pemberton.

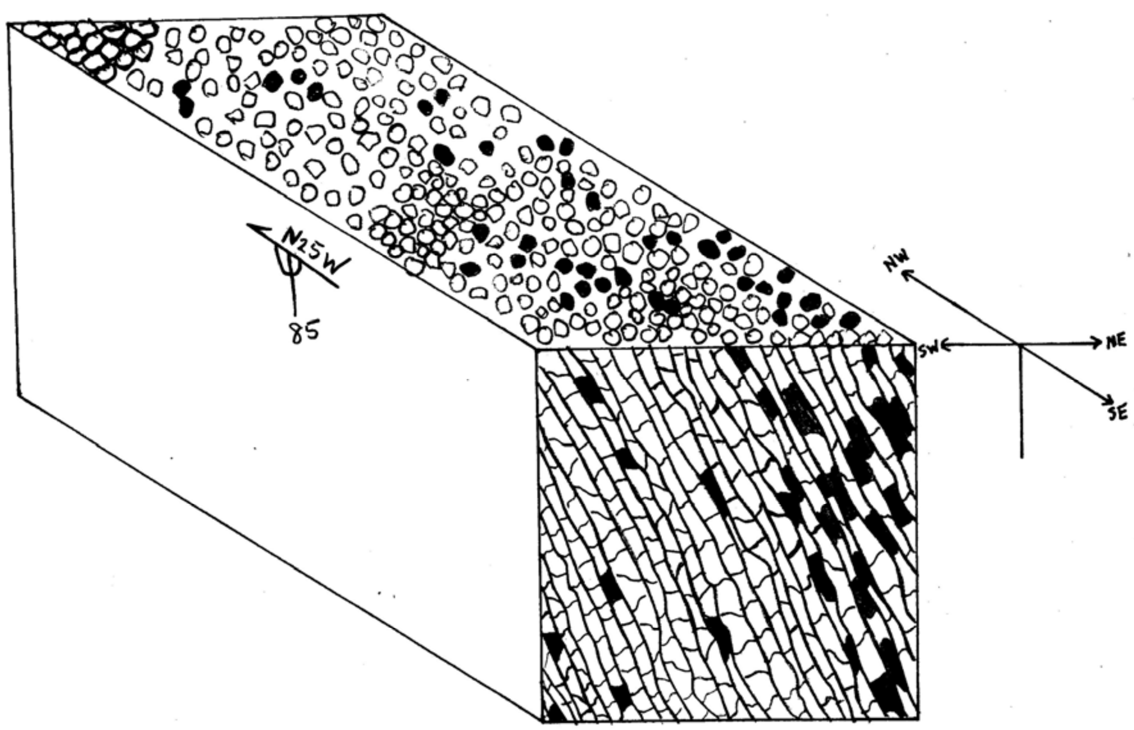

Figure 82. 3-D block diagram constructed from thin sections of Sample #33 of the northeastern belt of Cadwallader Group rocks.

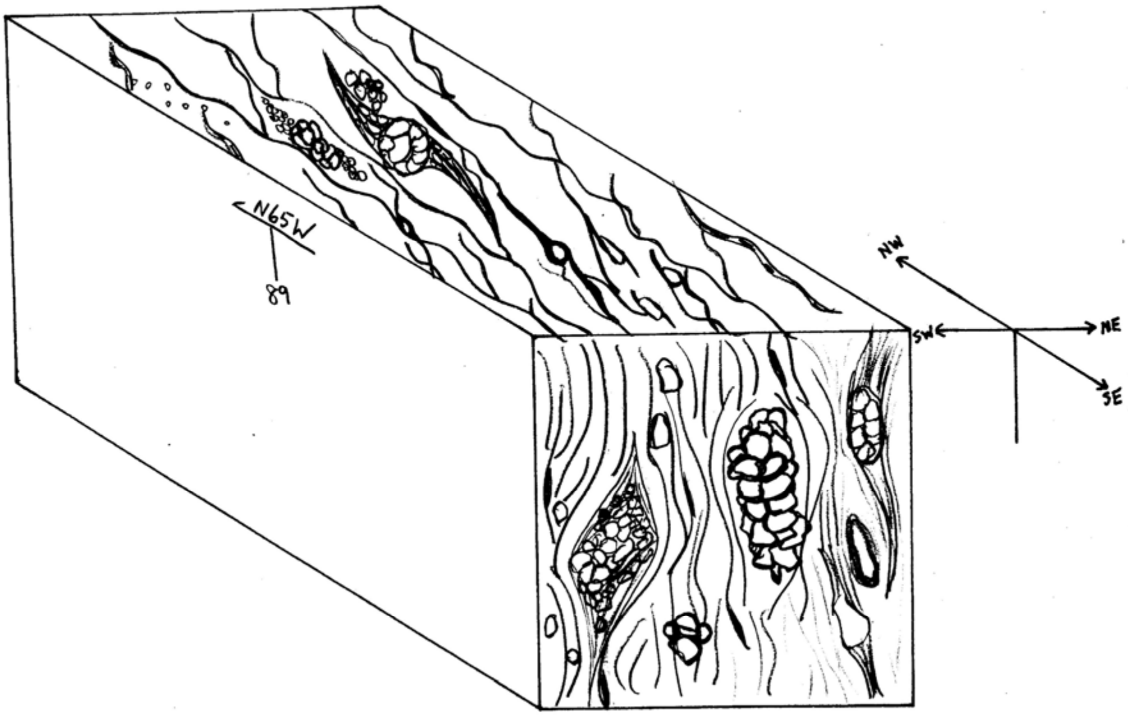

Figure 83. 3-D block diagram constructed from thin sections of Sample #39 of the northern Chism Creek Schist.

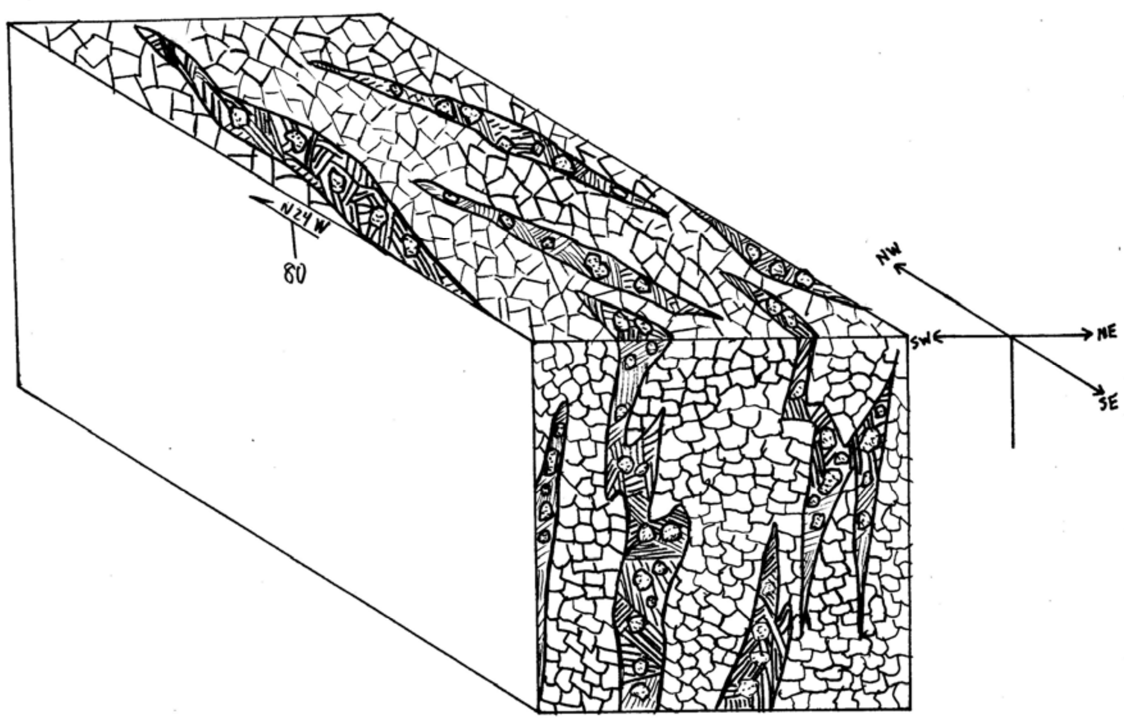

Figure 84. 3-D block diagram constructed from thin sections of Sample #24 of the southern Chism Creek Schist.

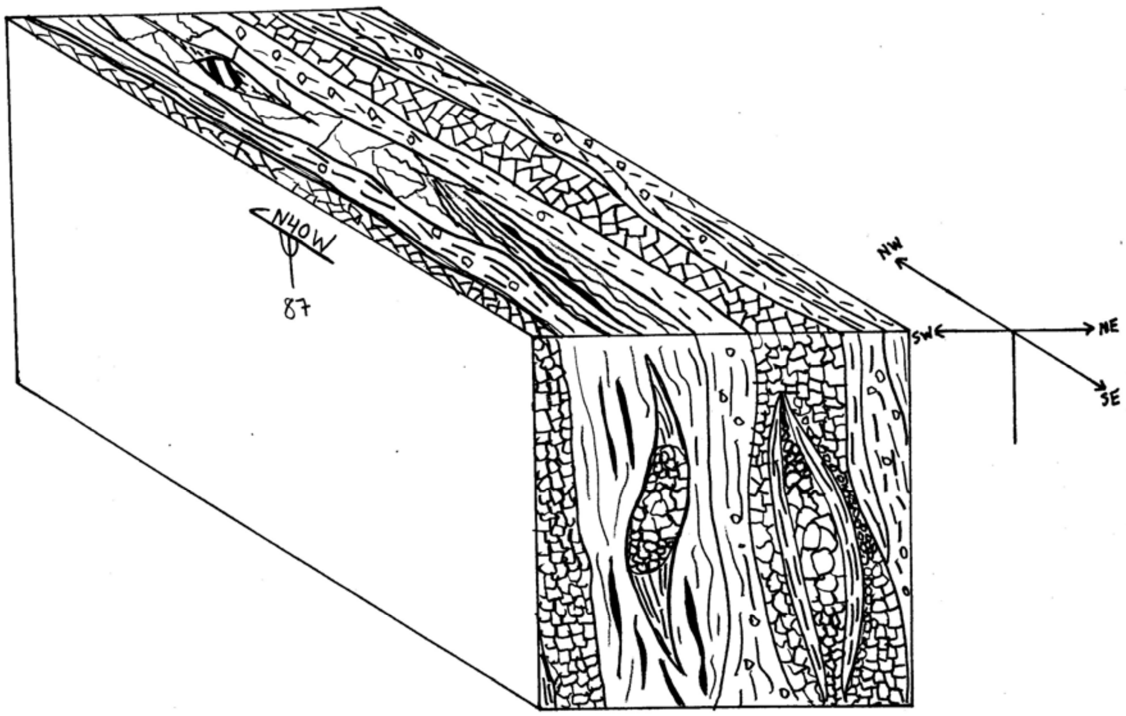

Figure 85. 3-D block diagram constructed from thin sections of Sample #25 of the southern Chism Creek Schist.

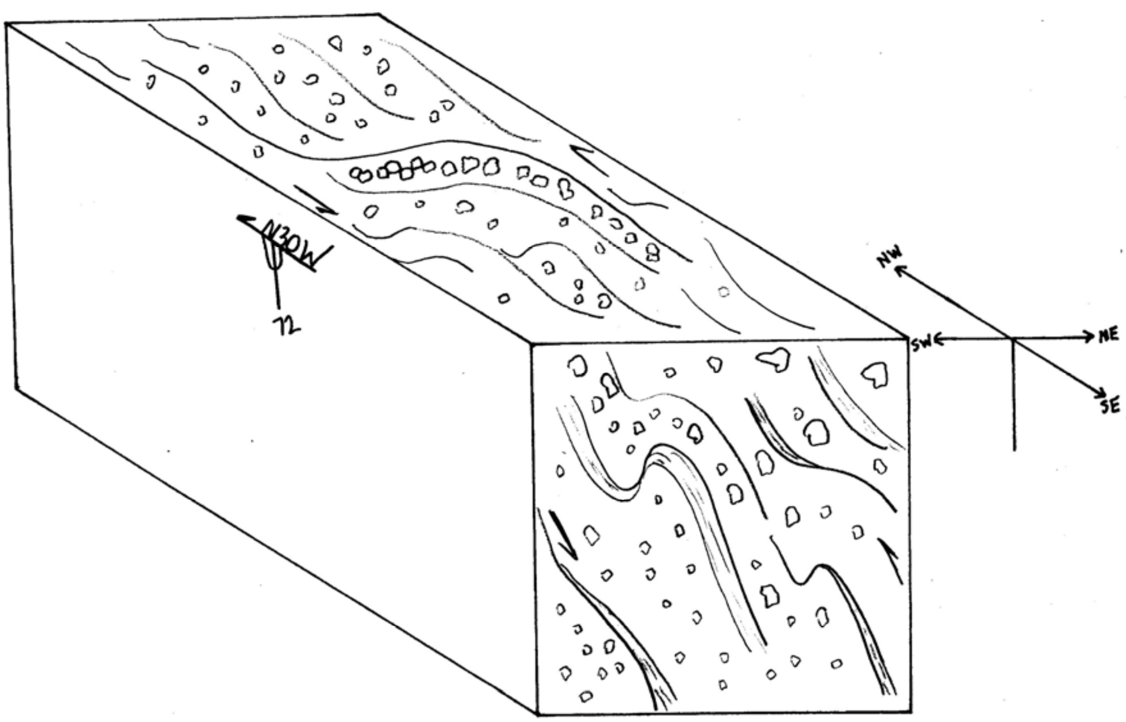

Figure 86. 3-D block diagram constructed from thin sections of Sample #61 of the southern Chism Creek Schist.

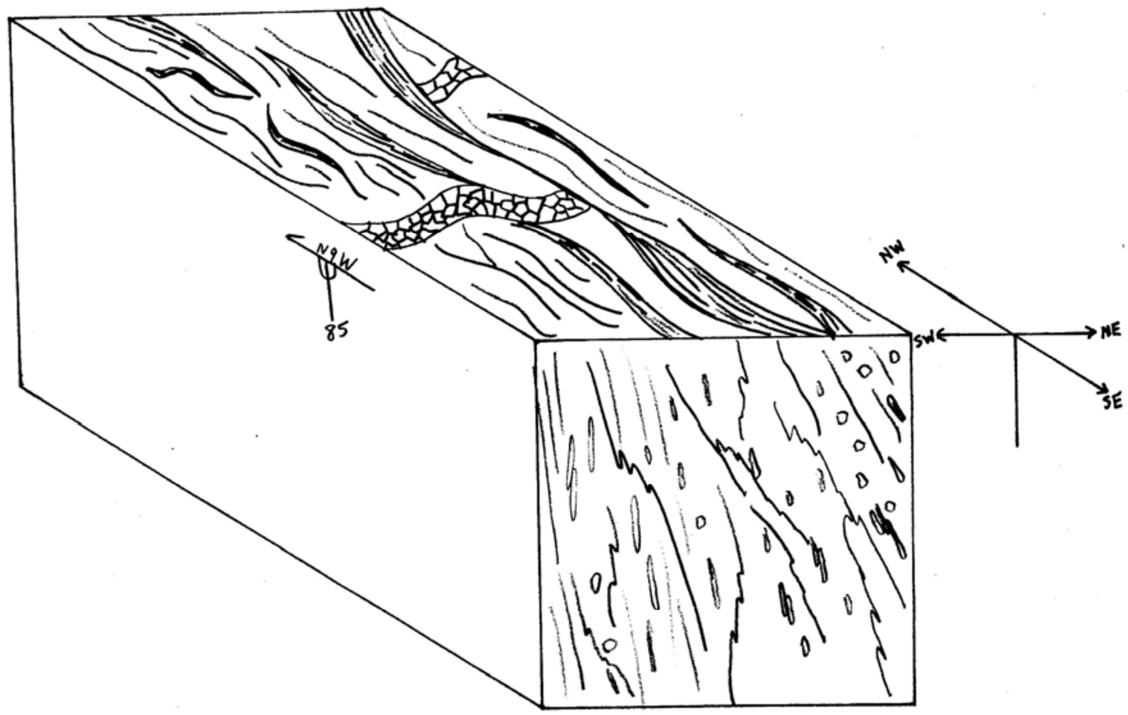

Figure 87. 3-D block diagram constructed from thin sections of Sample #26 of the Cayoosh Assemblage.

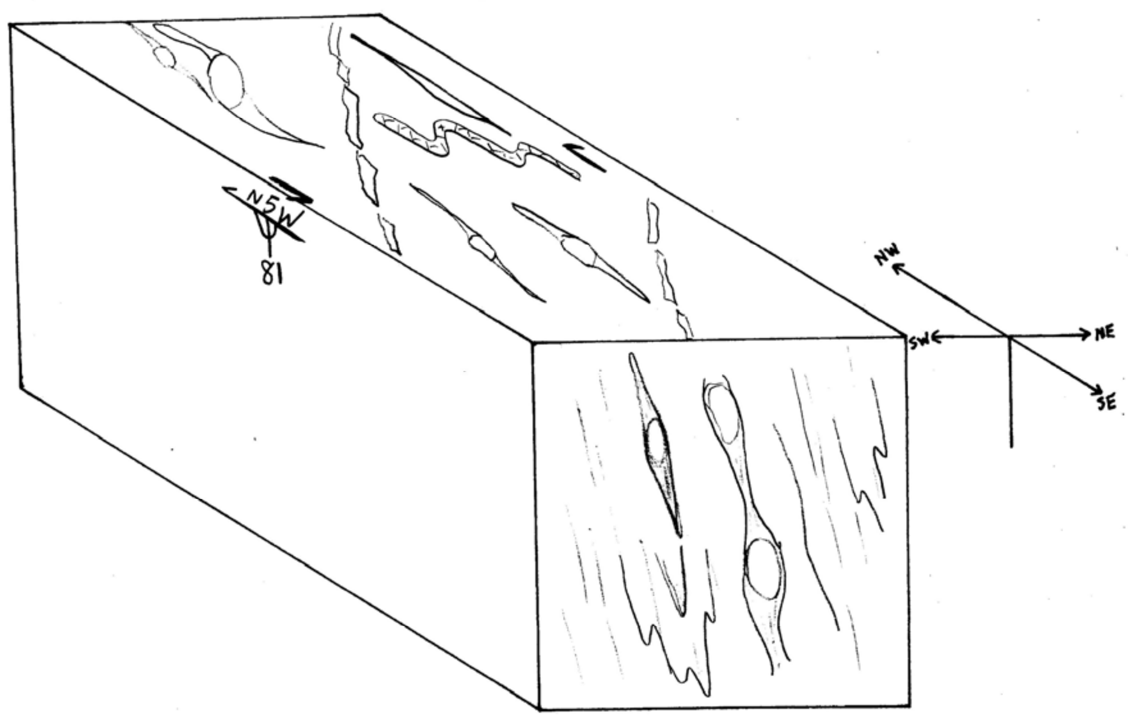

Figure 88. 3-D block diagram constructed from thin sections of Sample #27 of the Cayoosh Assemblage.

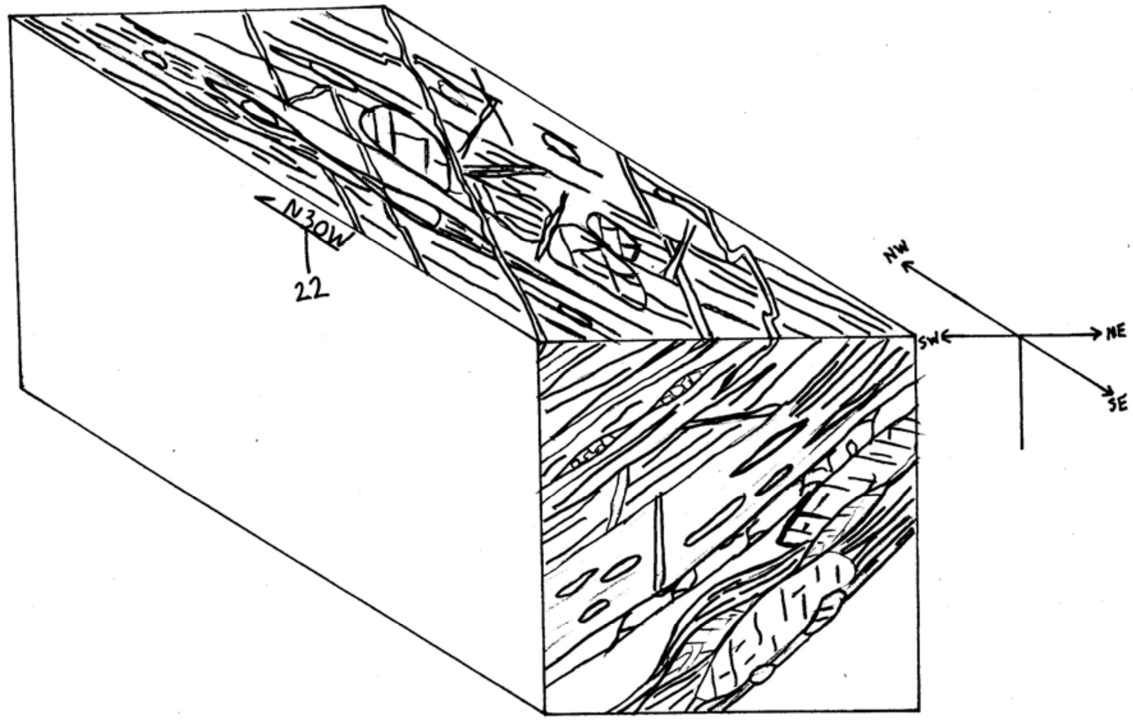

Figure 89. 3-D block diagram constructed from thin sections of Sample #74 of the Brew Group.

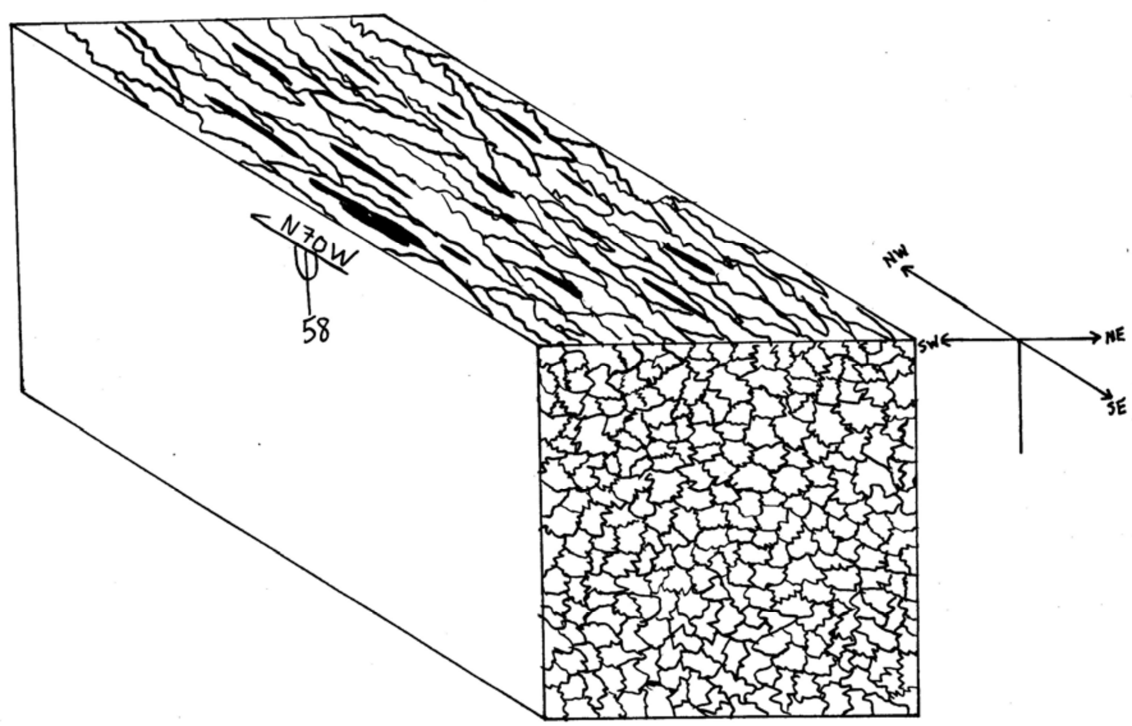

Figure 90. 3-D block diagram constructed from thin sections of Sample #30 of the Bridge River Schist.

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