KINEMATICS, AGE OF DEFORMATION, AND REGIONAL SIGNIFICANCE OF THE CAYOOSH CREEK FAULT, LILLOOET, BRITISH COLUMBIA

by

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ABSTRACT

The Cayoosh Creek fault, located in the eastern Coast Belt of the Canadian Cordillera, is a low-angle fault truncated by the Marshall Creek fault to the east and the Phair Creek fault to the west. The Marshall Creek and Phair Creek faults are associated with the regionally significant Yalakom and Fraser-Straight Creek fault systems. The upper plate of the Cayoosh Creek fault contains Mississippian to lower Middle Jurassic units of the Bridge River Complex which overlie Middle Jurassic to Lower Cretaceous rocks of the Cayoosh Assemblage. The hangingwall is typically prehnite-pumpellyite to lower greenschist facies, whereas footwall rocks record mid- to upper greenschist grade metamorphism. While the older-over-younger relationship implies contraction, the juxtaposition of low over high metamorphic grade suggests normal faulting. This study seeks to associate the kinematic history and age of deformation of the Cayoosh Creek fault with that of the regional fault systems.

Three phases of deformation have been documented in the study area. D_1 is represented by related southwest vergent isoclinal folds and foliation (S_1). A shallow northeast-dipping mylonitic foliation (S_2), and northwest-trending folds and lineations define D_2. Peak metamorphism during D_2 is constrained to 500°-550° C and 1.8-2.9 kilobars. Steep to upright axial planes of northwest-southeast trending open and gentle folds define a possible third deformational event (D_3). Zircons from a post-kinematic dike, a D_2 syn-kinematic dike, and locally deformed granite were dated using U-Pb radiogenic isotopes. Results yielded ages of 47.0 +/- 0.2 Ma, 47.8 +/- 0.1 Ma, and 48.8 +/- 0.1 Ma respectively.

The D_1 fabrics record mid-Cretaceous (?) southwest-directed contraction and emplacement of Bridge River Complex over Cayoosh Assemblage. The penetrative D_2 fabrics are the result of 10-12 kilometers of top-towards the northwest extension on the Cayoosh Creek fault. D_2 largely occurred between 48.8-47.0 Ma, but may have commenced earlier. D_3 fabrics may have been related to progressive D_2 deformation. The Cayoosh Creek fault is integrally related to the dextral strike-slip fault systems on the Coast Belt-Intermontane Belt boundary. Orogen-parallel extension and translation were the dominant means of accommodation during Early to Middle Eocene oblique-convergence on the plate margin. The Cayoosh Creek fault—as well as the Tatla Lake metamorphic complex, Mission Ridge area, and Ross Lake shear zone—lies within a belt of high metamorphic grade and low-angle ductile deformation that coincides with the axis of the Eocene magmatic arc. The likely cause of regional extension was gravitational collapse of an overthickened and thermally weakened crust, and a shift in relative plate motions. Significant deformation on the Cayoosh Creek fault had diminished by 47.0 Ma but regional strike-slip faulting in the arc-axial belt continued into the Oligocene.

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CHAPTER 1

1.1 INTRODUCTION

Recent field research indicates that extensional and strike-slip fault systems have played important roles in the tectonic evolution of southwestern British Columbia. Regional studies efficiently document extensional tectonics in the Omineca and Intermontane belts (Friedman and Armstrong, 1988; Parrish et al., 1988), but much of the deformation west of the Intermontane Belt is generally attributed to Middle to Late Cretaceous contraction (Monger, 1986; McGroder, 1991). The latest studies recognize extensional and oblique strike-slip structures associated with the Yalakom fault system in the southeastern Coast Belt, including the Mission Ridge and Marshall Creek faults (Coleman, 1990; Journeay et al., 1992; Schiarizza et al., 1997). This study documents the structural setting at the southern limits of these previous studies, in particular the nature of deformation associated with the Cayoosh Creek fault.

The Cayoosh Creek fault has been interpreted as a thrust fault (Coleman, 1990), and as a low-angle extensional fault (Journeay et al., 1992). Thrusting may have occurred during one of the extensive south Coast Belt contractional events during the Middle to Late Cretaceous, whereas normal faulting is postulated to be related to later Eocene extension. The Cayoosh Creek fault places Mississippian to lower Middle Jurassic Bridge River Complex rocks above younger, Middle Jurassic to Lower Cretaceous volcanoclastics and pelagic sedimentary rocks of the Cayoosh Assemblage. Although the juxtaposition of older-over-younger rocks suggests an episode of thrusting, shear fabrics in the footwall of the fault record a predominately extensional shear sense. Coleman (1990) interpreted the Mission Ridge fault, which in many aspects is similar to the Cayoosh Creek fault, as a moderately dipping extensional fault that was active in the Eocene. The Mission Ridge fault juxtaposes relatively high grade and pervasively deformed Bridge River Schist structurally below low-grade, mainly undeformed rocks of the Bridge River Group.

The objectives of this study are to determine the extent, geometry, age, pressure and temperature conditions, and kinematic history of Cayoosh Creek fault deformation. A model of the structural evolution of the study area is developed, including the interaction with the regional fault systems. This was accomplished through field mapping at the 1:20,000 scale, field measurements of linear and planar fabric data, and evaluation of fault continuity and extent. Statistical and spatial analyses of all planar and linear data using equal area stereonet projections characterized the deformation in the hangingwall and footwall assemblages. Macroscopic geometry of the Cayoosh Creek fault and its relationship to associated strike-slip faults aided in tectonic interpretations. Thin section analysis of mineralogy, metamorphic grade, and shear sense indicators helped distinguish penetrative fabrics of different deformational events, and aided interpretation of the latest deformational event.

An absolute age of deformation along the Cayoosh Creek fault is constrained by isotopic dating. U-Pb geochronology, completed at the Geochronology Laboratory at U.B.C., is applied to syn-kinematic and post-kinematic dikes, as well as a previously unmapped pluton. The ages of the dikes establish a time window for fault-related deformation. The age results ascertain which deformational events within the southeastern Coast Mountains were synchronous with movement on the Cayoosh Creek fault. In addition, the pressure and temperature conditions during faulting are constrained through a restrictive mineral assemblage within the footwall.

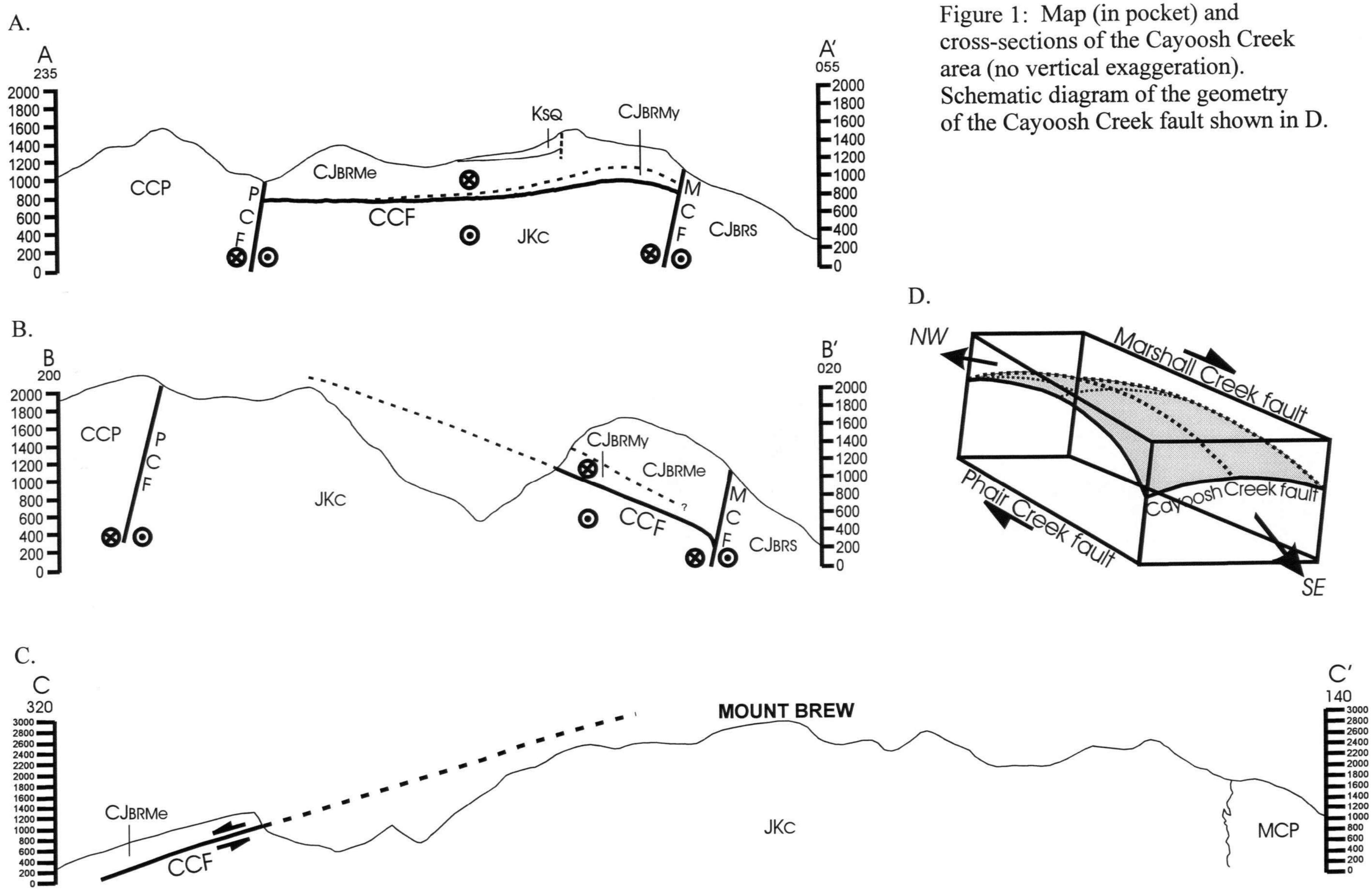


Figure 1: Map (in pocket) and cross-sections of the Cayoosh Creek area (no vertical exaggeration). Schematic diagram of the geometry of the Cayoosh Creek fault shown in D.

This thesis contains four chapters and a 1:20,000 scale map documenting the geology of the northern Cayoosh Creek and Phair Creek areas (figure 1). Chapter 1 includes an abbreviated review of the tectonic evolution of the Coast Mountains, summarized descriptions of regional geology, and descriptions of the lithological units within the study area. An outline of the dominant regional fault systems of the southeastern Coast Belt is presented, including brief descriptions of related structures and kinematics. Chapter 2 includes details of the structural elements affecting the study area. In addition it includes descriptions of metamorphic aspects and results of isotopic data that are relevant to the tectonic evolution of the study area. A conceptual model of the tectonic history of the study area is discussed in Chapter 3 and the final conclusions of this study are presented in Chapter 4.

1.2 TECTONIC SETTING OF THE COAST MOUNTAINS

Details of the tectonic evolution of British Columbia have remained unclear although most authors now agree it is composed of a variety of allochthonous terranes. How the tectonic collage of the Canadian Cordillera originated, in particular the paleogeographic positions of allochthonous terranes, is currently and vigorously being discussed (Cowan, 1994). Included in this debate is the genesis and deformation of the Bridge River Terrane, and the amount of Late Cretaceous to Tertiary fault translations.

The Cordillera is divided into five distinct tectonic belts: Insular, Coast, Intermontane, Omineca, and Foreland, mainly based on lithology, metamorphism, and morphology (figure 2). The study area is located in the southeastern Coast Belt, within the Bridge River Terrane. The Coast Belt represents a geographic and geologic boundary between two complex composite terranes, the Insular and Intermontane belts. From west to

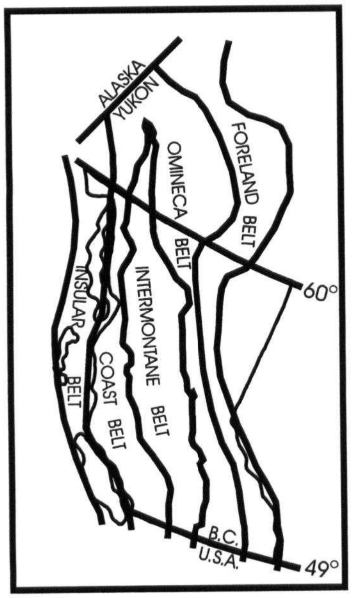
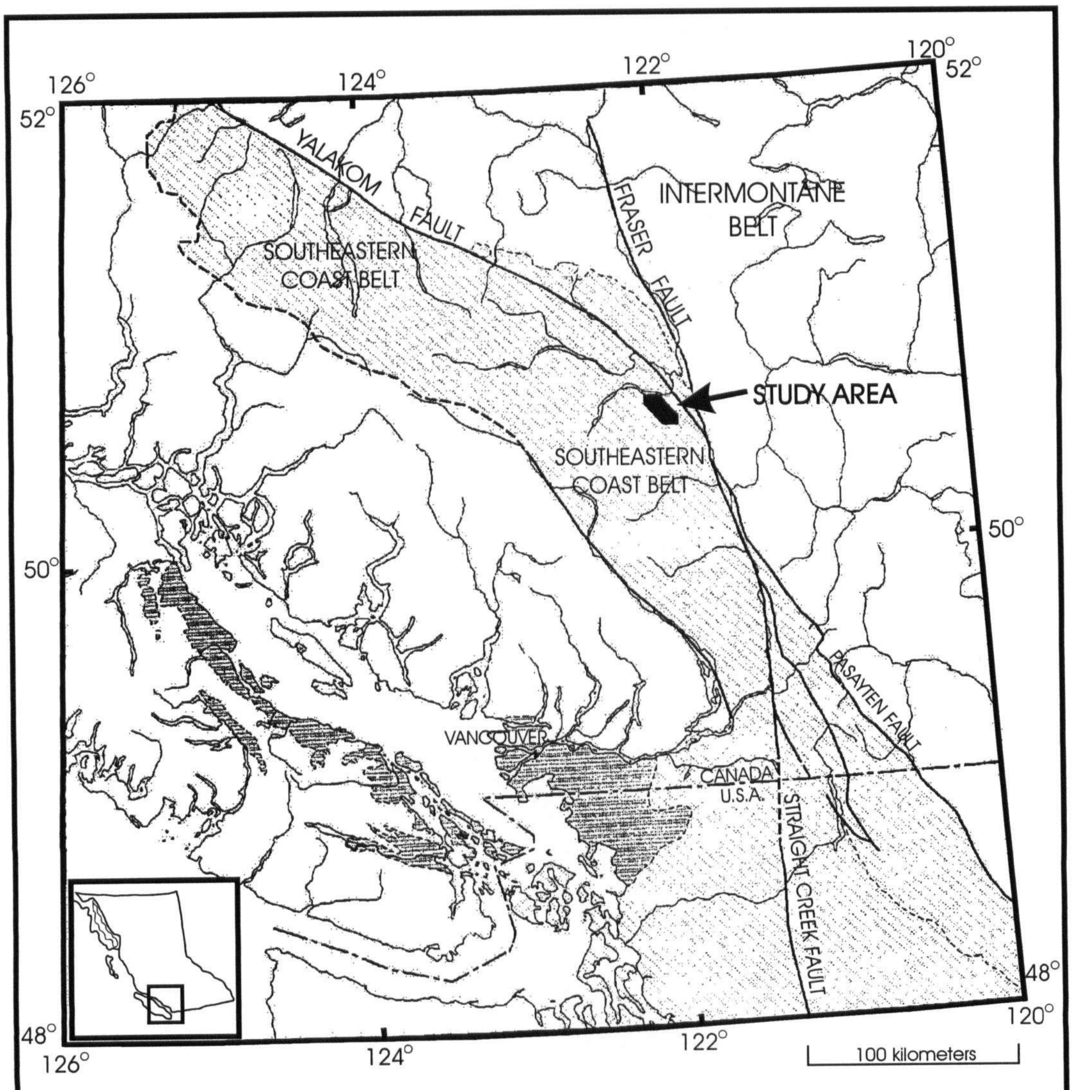


Figure 2: Tectonostratigraphic belts of the Canadian Cordillera (modified from Monger and Journeay, 1994).

Figure 3: Location of study area within the Eastern Coast Belt (modified from Schiarizza et al., 1997).



east supracrustal rocks within the Coast Belt comprise low-grade arc sequences; high-grade island arc, oceanic, and sedimentary rocks; and fault-bounded arc sequences, ultramafics, sedimentary sequences, and syn-orogenic oceanic and clastic rocks (Journeay, 1990; Schiarizza et al., 1990; Monger, 1991). The Coast Belt is also the locus of the Coast Plutonic Complex which resulted from an extensive period of plutonism initiated in the Middle Jurassic (Armstrong, 1988).

Monger and others (1982) characterized the Coast Belt orogen as a collection of terranes containing one or more tectonostratigraphic assemblages. They suggested that the Bridge River Terrane, which contains oceanic sediments, formed as an ocean basin that lay between two east-dipping subduction zones and was closed as the result of the collision between the Insular and Intermontane Belts. They cited a variety of evidence for large horizontal translations between the terranes and the western North American margin, and suggest the Coast Plutonic Complex and Omineca Crystalline Belt represent suture zones. Gehrels and Saleeby (1987) presented paleomagnetic data that suggested the terranes were at southern latitudes during the Jurassic and were accreted to North America through dextral translation in the Mid-Cretaceous.

Based on geologic evidence presented by Journeay and Mahoney (1994), plate motion reconstructions by Engebretson et al. (1985), and paleomagnetic interpretations of Irving and Wynne (1991), Monger and others (1994) proposed that the Bridge River rocks belong to an accretionary complex that became trapped in the Early Cretaceous by a southward moving Insular composite terrane. The Bridge River Terrane contains Mississippian to Middle Jurassic oceanic sediments (Bridge River Complex) which grade upward into clastic rocks of the Cayoosh Assemblage (Mahoney and Journeay, 1993). The presence of blueschist metamorphism, lack of appreciable stratification, and widespread soft sediment deformation provide evidence that parts of the terrane represent an accretionary complex (Potter, 1986), whereas a more coherent greenstone and chert package represents an ocean basin setting (Journeay and Northcote, 1992). Rock units within the Cayoosh Assemblage, which both overlies and is structurally interleaved with the Bridge River Complex, indicate the basin was open to marine sedimentation until at least the Early Cretaceous. Younger units in the sequence are dominantly derived from an emergent volcanic arc (Mahoney and Journeay, 1993; Journeay and Mahoney, 1994).

Monger and Nokleberg (1996), summarizing a complete spectrum of geological and geophysical studies, favor a hypothesis in which the collage comprises fragments of a single marginal arc and accretionary complex which existed in proximity to the North American craton in the early Mesozoic. Beginning in the Early Jurassic, relative North America and Pacific plate motion resulted in the accretion of the arc terranes above a subduction zone. Tectonic reconstructions and paleomagnetic studies support sinistral movement prior to the mid-Cretaceous followed by a short period of near orthogonal convergence (Irving and Wynne, 1991; Kelley and Engebretson, 1994). This contractional event resulted in the intense deformation, metamorphism, and magmatism that characterizes the Coast Mountains and the northern Cascades. Monger and Nokleberg (1996) suspect that all present components of the Cordilleran collage were in place by the early Late Cretaceous.

Late Cretaceous-Early Tertiary dextral-compression and Early Tertiary extension and dextral translation (Parrish et al., 1988; Kelley and Engebretson, 1994) produced a network of fault systems that has since fragmented the collage (Monger and Nokleberg, 1996). Dextral translation during this time was significant, although estimates of displacement vary widely. Geological markers suggest 450-1000 km of displacement (Gabrielse, 1985) but paleomagnetic studies indicate as much as 3000 km. The Fraser-Straight Creek fault system in British Columbia and northwestern Washington alone has an estimated 90-190 km of Eocene translation (references in Monger and Journeay, 1994).

1.3 REGIONAL GEOLOGY

The Coast Belt dominates the geomorphology of the western margin of North America. The Coast Belt, representing the tectonic boundary between the Intermontane and Insular Belts, is constructed of a complicated array of fault bounded terranes most likely accreted during the Middle Jurassic to Early Cretaceous (Monger et al., 1982). It has been further disrupted by the intrusion of the Coast Plutonic Complex, Middle to Late Cretaceous shortening, and Tertiary extension and translation. It is composed of the Coast and Cascade Mountains of British Columbia and Washington, and in southwestern British Columbia is divided into three domains: the Western, Central, and Eastern Coast Belts (Journeay and Friedman, 1993).

The Western Coast Belt contains Middle Jurassic to Miocene rocks of the Coast Plutonic Complex which intrude Middle Triassic to Early Cretaceous supracrustal arc sequences: Bowen Island Group, Gambier-Fire Lake Group, and Harrison Lake Formation (Monger, 1991). The Central Coast Belt includes higher grade island arc and oceanic rocks belonging to the Cadwallader Group, Cogburn Group, and Settler Schist, which are intruded by the Spuzzum and Scuzzy-Mount Rohr plutonic complexes (Monger, 1986). The Eastern Coast Belt comprises tectonic assemblages ranging from Mississippian to Early Tertiary (Rusmore, 1985; Schiarizza et al., 1989, 1990). These assemblages include the Bridge River

Complex, Hozameen Group, Cadwallader Group, Shulaps ultramafic complex, Relay Mountain Group, Cayoosh Assemblage, and Taylor Creek Group.

The study area lies within the Eastern Coast Belt, adjacent to the Coast Belt-Intermontane Belt boundary (figure 3). The Bralorne fault system defines the western margin, demarcating the Central and Eastern Coast Belts. Mid-Cretaceous to Eocene fault systems are responsible for much of the regional deformation. The bulk of the field area is composed of rocks belonging to the Bridge River Complex and the Cayoosh Assemblage. These units are intruded by plutonic suites ranging in age from Late Cretaceous to Eocene.

1.4 FAULT SYSTEMS AND RELATED STRUCTURES

The general fabric of the southeastern Coast Belt is defined by mostly northwest trending structures which overprint an earlier history of oblique convergence and underplating of the Insular Superterrane (Monger, 1986; McGroder, 1991). The major elements affecting the structural pattern of the southeastern Coast Belt are post-Middle Cretaceous to early Tertiary fault systems (figure 4). Regional structures include mid- to Late Cretaceous west-vergent thrust faults and folds, and related east-vergent reverse faults (Rusmore, 1985; Calon et al., 1990, Journeay et al., 1992). These are overprinted by Late Cretaceous oblique-slip faults (Schiarizza et al., 1990) and northeast-vergent thrusts and folds (Garver, 1991). Related dextral-oblique faults of the Yalakom, Mission Ridge, and Marshall Creek fault systems (Coleman, 1990; Schiarizza et al., 1997), and dextral transcurrent faults of the Fraser fault system (Monger, 1989) account for the bulk of Eocene deformation. Limited details of these fault systems are discussed below in order of oldest to youngest.

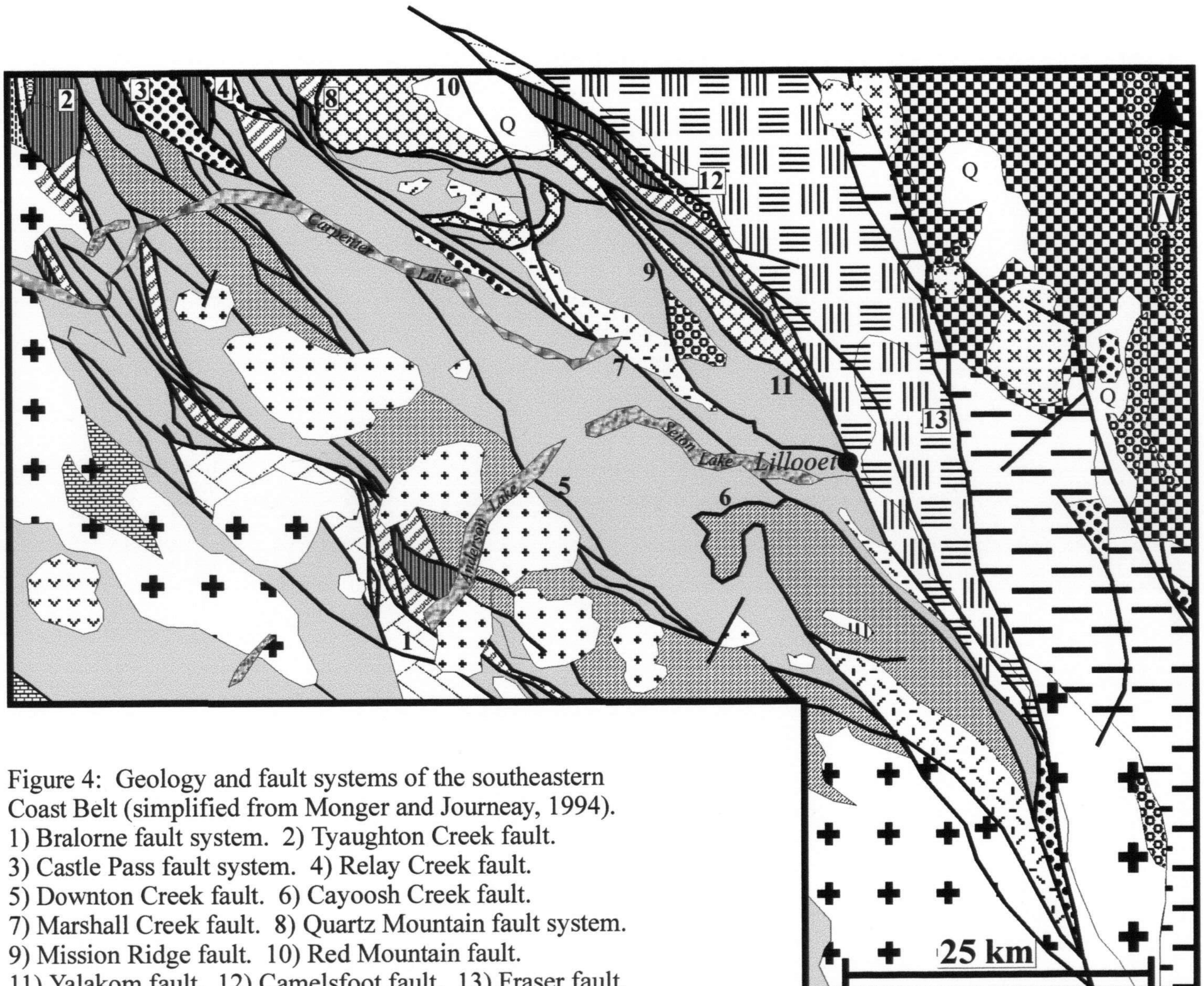


Figure 4: Geology and fault systems of the southeastern Coast Belt (simplified from Monger and Journeay, 1994). 1) Bralorne fault system. 2) Tyaughton Creek fault. 3) Castle Pass fault system. 4) Relay Creek fault. 5) Downton Creek fault. 6) Cayoosh Creek fault. 7) Marshall Creek fault. 8) Quartz Mountain fault system. 9) Mission Ridge fault. 10) Red Mountain fault. 11) Yalakom fault. 12) Camelsfoot fault. 13) Fraser fault.

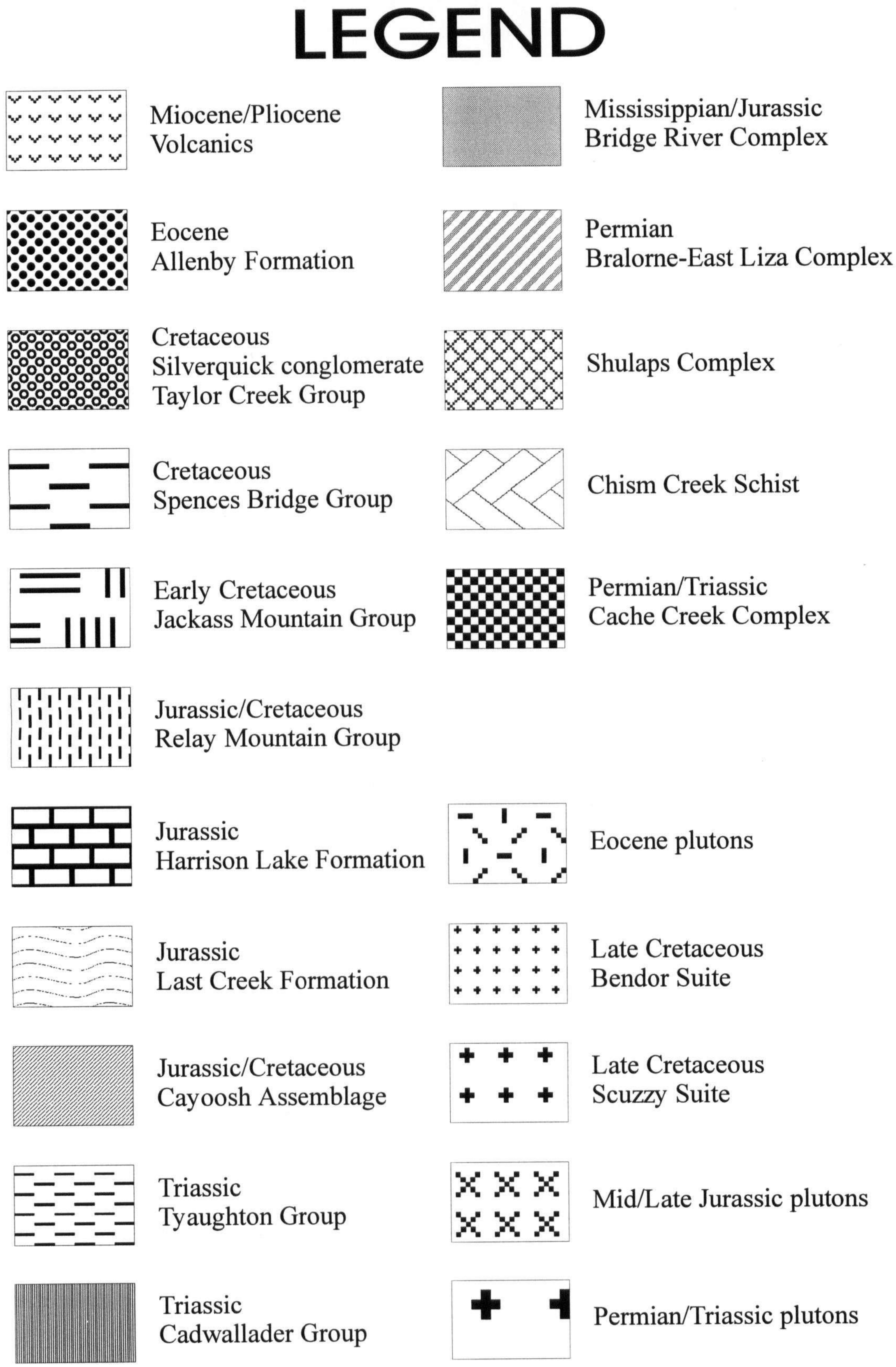


Figure 4: (continued)

1.4.1 Middle to Late Cretaceous

The oldest recognizable structures are typically southwest-vergent imbricate thrust faults and related folds, which include the faults of the Bralorne fault zone and the Shulaps ultramafic complex. Rusmore (1985) constrains this thrusting event to 100-85 Ma. Footwall folds overturned to the west, shear bands in fault rocks, and steeply plunging stretching lineations support west-directed thrusting of Bridge River rocks over the Cadwallader Group (Schiarizza et al., 1990). Upper plate asymmetric folds are tight to isoclinal, and are cut by steeply northeast-dipping axial planar cleavage. Kinematic indicators within the melange of the ultramafic complex support top-to-the-southwest sense of shear (Journeay and Csontos, 1989; Calon et al., 1990). High-angle, west-rooting reverse faults are interpreted as back thrusts related to the eastward rooting thrusts (Journeay et al., 1992). In the McGillivray Pass region the Cayoosh Assemblage has been involved in fault imbrication related to this deformational event.

The Tyaughton Creek fault system is an apparent northwestward extension of the Bralorne fault zone (Schiarizza et al., 1990). West-directed thrusting of the hanging-wall of this northeast-dipping structure supports sinistral transpression involving Bridge River, Cadwallader, Tyaughton, and Relay Mountain groups. Kinematic indicators from the fault near Gold Bridge include asymmetric, west vergent hangingwall folds, shear bands in fault rocks, and footwall folds overturned to the west (Schiarizza et al., 1990).

1.4.2 Late Cretaceous

A system of northeast vergent thrusts and folds affiliated as the Castle Pass fault system is possibly related to the Tyaughton Creek and Bralorne faults (Schiarizza et al., 1990; Garver, 1991). Schiarizza and others (1990) summarize observations of the outwardverging pair of structures as a "positive flower" or "palm tree" structure. Evidence for oblique sinistral shear on the Castle Pass system includes mesoscopic transpressional duplexes and top-to-the-east shear bands (Schiarizza et al., 1990). Journeay and others (1992) document ductile shear fabrics, asymmetry and down-dip stretching lineations to support top-to-the-northeast kinematics. Garver (1989) bracketed deformation attributed to the Castle Pass fault to between 91 and 86 Ma.

The Downton Creek fault is a southwest verging fault that displays evidence for both southwestward thrusting and right-lateral strike-slip displacement (Journeay et al., 1992). The Downton Creek fault may be related to other southwest vergent structures in the Shulaps Complex (Calon et al., 1990; Schiarizza et al., 1990). The fault separates an eastern greenstone-chert melange of the Bridge River Complex from a more coherent greenstone, chert, and argillite package of the same assemblage. Elsewhere, the fault places older, sheared Bridge River rocks above younger, imbricated Cayoosh Assemblage. The exact age and magnitude of deformation associated with the Downton Creek fault remain unknown. The fault offsets folds and thrust faults of the Castle Pass system and is intruded by a pluton of the 63-57 Ma Bendor suite (Roddick, 1987).

1.4.3 Tertiary

The most conspicuous deformation in the immediate vicinity of the Cayoosh Creek fault is due to a group of related faults, all active in the Eocene: the Yalakom, Mission Ridge, Marshall Creek, and Fraser-Straight Creek faults. The Yalakom fault, first described by Leech in 1953, is a prominent regional feature extending northwestward from the Ashcroft map area where it is truncated by the Fraser Fault system (Duffell and McTaggart, 1952; Monger and McMillan, 1989). The Hozameen fault in southwestern British Columbia is likely the offset counterpart of the Yalakom fault, suggesting 90 km of right lateral displacement has occurred along the Fraser fault (Monger, 1985). Schiarizza et al. (1990, 1997) describe the Yalakom as a steeply dipping structure, commonly marked by serpentinite melange. Shear bands, fibrous mineral lineations, extensional vein sets and slickenlines provide evidence of dextral movement on the fault. Miller (1988) suggested a sinistral history for the fault, and Coleman (1990) argued for moderately dipping dextral-oblique movement, however, Schiarizza and others (1997) concluded that both Miller (1988) and Coleman's (1990) study areas lay northeastward of the Bridge River Complex and Yalakom fault zone, and kinematic evidence therefore reflected motion on the Camelsfoot thrust belt.

Although it is speculated that movement on the Yalakom may have begun as early as the latest Cretaceous, the most active period was during the Early to Middle Eocene (Schiarizza et al., 1997). Umhoefer and Schiarizza (1996) suggest that approximately 100 km of the estimated 115 kilometers of Yalakom displacement most likely occurred between 57-45 Ma. Deformation was largely dextral-oblique, as indicated by gently plunging stretching lineations and shear fabrics that record a component of contractional movement. The unroofing of ductile lower plate rocks along moderately dipping faults is interpreted as a shift from transpression to transtension after 46.5 Ma (Coleman and Parrish, 1991; Umhoefer and Schiarizza, 1996). This Late Eocene stage of movement on the Yalakom fault system resulted in the formation of extensional transfer zones between the Marshall Creek and Yalakom faults. The stepovers are represented by the Quartz Mountain fault system, as proposed by Umhoefer and Schiarizza (1996), and the Mission Ridge fault, suggested by Coleman and Parrish (1991). The Yalakom and Mission Ridge faults are both cut by the Red Mountain fault, a splay of the Marshall Creek fault (Umhoefer and Schiarizza, 1996).

The Mission Ridge fault, most of which is located between the Yalakom and Marshall Creek faults, was first described in detail by Coleman (1989), although a northerly segment had previously been interpreted as part of the Shulaps thrust (Potter, 1983). It is a shallowly to moderately northeast-dipping brittle fault which juxtaposes discordant metamorphic grades of Bridge River strata. North of Seton Lake, hangingwall rocks include prehnite-pumpellyite grade Bridge River Complex, a sedimentary package which Schiarizza and others (1997) correlate with the Silverquick formation, and—at the northwest end—the Shulaps ultramafic complex (Coleman, 1990). The footwall is composed of the Mission Ridge pluton and upper greenschist grade Bridge River Complex, which Coleman (1990) designated the Bridge River Schist. Coleman (1989, 1990) also mapped the Mission Ridge fault south of Seton Lake, west of the Marshall Creek fault.

Kinematic evidence for extension on the Mission Ridge fault is provided by the juxtaposition of the Silverquick formation against Middle Triassic to Middle Jurassic Bridge River Schist, slickenside lineations, and the largely brittle nature of deformation in upper plate rocks (Coleman, 1990). The pressure and temperature break between the upper and lower plates of the Mission Ridge fault provides for a minimum of 10.2 km of down-dip displacement (Coleman, 1990). The fault in part crosscuts fabrics within the Bridge River Schist which Coleman (1990) relates to dextral movement on the Yalakom fault, and contains a syn-tectonic pluton in its footwall. U-Pb ages from the Mission Ridge pluton and other deformed granitic bodies within the footwall constrain ductile deformation to 46.5-48.5 Ma (Coleman, 1990; Coleman and Parrish, 1991). The Mission Ridge fault is cut by the Marshall Creek fault (43-39 Ma), indicating the Mission Ridge fault was active during the Middle Eocene. It is significant to note the activity of the Mission Ridge fault ranges from pre- to post-dextral slip on the Yalakom-Marshall Creek-Relay Creek fault system, supporting a transfer or stepover zone hypothesis (Journeay et al., 1992; Umhoefer and Schiarizza, 1996).

The Marshall Creek fault is a single narrow fault zone comprising steeply northeast and southwest-dipping shear zones in the vicinity of the study area (Journeay et al., 1992). Northwestward from Carpenter Lake the fault branches off three dextral splays, then splits into two steeply dipping structures, and at Marshall Lake it merges with the northward trending Quartz Mountain fault system (Schiarizza et al., 1997). It is also apparently in alignment with the Relay Creek fault system to the northwest. Shear sense indicators support dominantly dextral movement on the Marshall Creek fault (Journeay et al., 1992). The juxtaposition of metamorphic facies and some kinematic evidence also implies significant normal movement, at least for the portion of the fault in the study area (Journeay et al., 1992; this study). Coleman (1990) estimates vertical displacement of 3.5 km, but strike-slip movement has yet to be determined. The Marshall Creek fault persists for nearly 100 km along strike, and eventually merges with—or is truncated by—the Fraser fault to the southeast (Monger and McMillan, 1989). To the northwest, the Relay Creek fault system extends an additional 40 km (Schiarizza et al., 1997). Between Carpenter and Seton lakes the Marshall Creek fault cuts the 47.4 +/- 0.3 Ma Mission Ridge pluton (Coleman, 1990). Fission track ages on shear fabrics within the fault zone imply the latest significant movement on the fault occurred 43-39 Ma (Garver et al., 1994).

The Fraser fault system includes the dextral-slip Fraser, Straight Creek, and—possibly—Marshall Creek faults. The Marshall Creek fault appears to merge with the Fraser, but otherwise the Fraser fault cuts all structures related to the Yalakom fault system (Monger and McMillan, 1989). The Straight Creek fault (in northern Washington) was active significantly earlier than the Fraser fault, and may have been active concurrently with the Yalakom, from about 50-44 Ma (Tabor et al., 1984). Umhoefer and Schiarizza's (1996) reconstruction of the Yalakom fault system places the Yalakom at the northern continuation of the Straight Creek fault prior to ~45 Ma. Movement post-45 Ma shifted to the Marshall Creek and Fraser faults (synchronous with Middle Eocene exhumation of the Mission Ridge area) while the Straight Creek fault remained active (Umhoefer and Schiarizza, 1996). The Fraser-Straight Creek fault is cut by the 34 Ma Chilliwack batholith (Coleman and Parrish, 1991).

1.5 LITHOLOGIC UNITS

The two principal map units within the study area are the Bridge River Complex and Cayoosh Assemblage, which together compose the Bridge River Terrane (Mahoney and Journeay, 1993). The Bridge River Complex underlies a large portion of the southeastern Coast Belt (Roddick and Hutchison, 1973, 1975; Potter, 1983, 1985; Schiarizza et al., 1997). Conodonts and radiolarians from the unit range in age from Mississippian to late Middle Jurassic (Potter, 1983, 1986). Internal deformation is generally linked to Mesozoic accretion and subduction (Potter, 1986; Rusmore et al., 1988), although mid-Eocene dextral shear has significantly contributed to regional deformation (Coleman, 1990). Beyond the study area, the Cayoosh Assemblage conformably overlies the Bridge River Complex and represents an overlap assemblage on the closing Bridge River Ocean (Journeay and Mahoney, 1994). Age constraints and stratigraphic correlations support a Middle Jurassic to Lower Cretaceous age (Journeay and Northcote, 1992; Journeay, 1993; Mahoney and Journeay, 1993; Journeay and

Mahoney, 1994). In the study area, both units are unconformably overlain by Cretaceous conglomerates and intruded by Eocene plutons.

1.5.1 Bridge River Complex

The Bridge River Complex commonly displays unorganized, accretion-related structures (Potter, 1986), the exception being on the shores and cliffs bordering the south side of Seton Lake. Mineral assemblages in the upper plate typically indicate prehnite-pumpellyite facies metamorphism, although lower greenschist assemblages of epidote and actinolite are found proximal to the Cayoosh Creek fault in the mylonitic portion of the upper plate of the Cayoosh Creek fault. To maintain distinction from previous discussions of the Bridge River Complex, three subdivisions are used in this thesis. *Bridge River melange* includes the structurally irregular portion of the complex (Coleman's [1990] Bridge River Group), whereas *Bridge River mylonite* is reserved for the section of higher-grade, ductilely deformed rocks. *Bridge River Schist* (Coleman, 1990) is considered distinct from these two varieties, and the term is therefore limited to rocks of the Bridge River Complex within the lower plates of the Marshall Creek and Mission Ridge faults.

Interlayered chert, low-grade metabasalt (greenstone), and argillite characterize the Bridge River Complex in the study area. Limestone and graphitic phyllite crop out locally, but rarely. In the study area the bulk of Bridge River melange crops out as muddy, chaotic masses of chert which display intense late brittle deformation and profuse silicification. It is composed of a dark gray, microcrystalline matrix, and is thoroughly infiltrated by fibrous and planar quartz veins ranging from less than a millimeter to 2 mm in thickness. At the most extreme, chert zones have been completely replaced by the vein material. Outcrops are moderately to weakly competent, especially where they occur in topographic lows and road

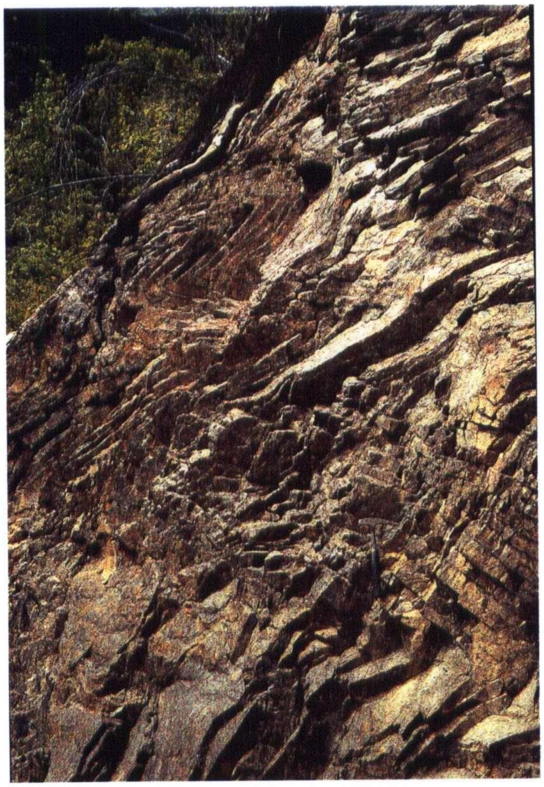


Figure 5: Chert ribbons in the Bridge River Complex.

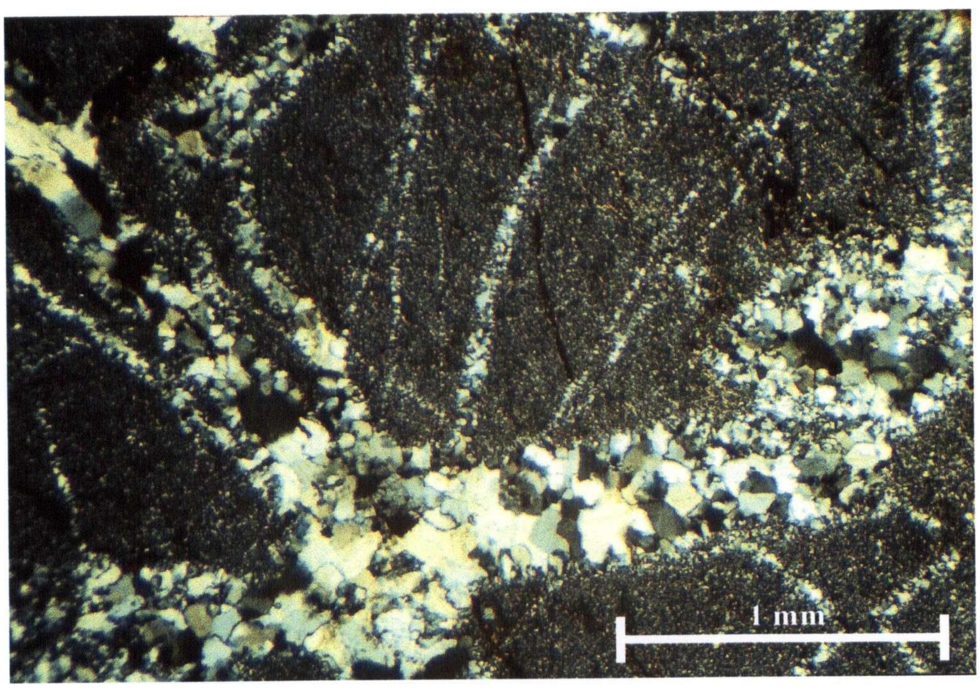


Figure 6: Photomicrograph of chert in the Bridge River Complex.

cuts, suggesting a geomorphological relationship to weathering. Rare occurrences of graphitic phyllite are associated with these more weathered outcrops of chert. Although commonly disrupted, relatively undisturbed ribbons of chert also appear in the melange portion of the complex (figures 5 and 6). The ribbon chert consists of folded layers 3 to 5 cm thick, separated by thin (1-2 mm) layers of argillite. The chert contains extensive fibrous quartz veins and typically has a rusted appearance.

Greenstone ranges from monotonous cliff-face exposures to serpentinized and chloritized lenses and blocks within other sedimentary assemblages. Schistose greenstone is well exposed on the southern shore of Seton Lake. The majority of the exposure (over 200 meters thick) has a continuous, but variably spaced foliation on the order of 20 to 60 centimeters. The rock is aphanitic, with locally preserved plagioclase laths and calcite-filled amygdules (figure 7). It is generally dark green with yellow or orange weathering. Gently folded argillite layers, 2 to 50 cm thick, are interbedded with the greenstone near the base of the cliffs, as is chert and irregular limestone lenses up to 20 cm thick.

In the melange, greenstone appears as large, blocky pods within chaotic argillaceous or chert zones. These blocks are typically highly weathered, do not preserve any features that could be interpreted as primary, and are impregnated with calcite veins. There are three examples, proximal to the fault zone, where ultramafic rocks are associated with the greenstone. Two of these examples are lozenges of serpentinite that are contained within a more massive outcrop of greenstone. The contacts between the more typical variety of greenstone and the ultramafic pod are irregular but abrupt, and appear to be fault bounds. The other example is a relatively wide (3 to 10 m), but diffuse zone of talc that crops out near a fault sliver of down-dropped greenstone within the lower plate of the Cayoosh Creek fault.

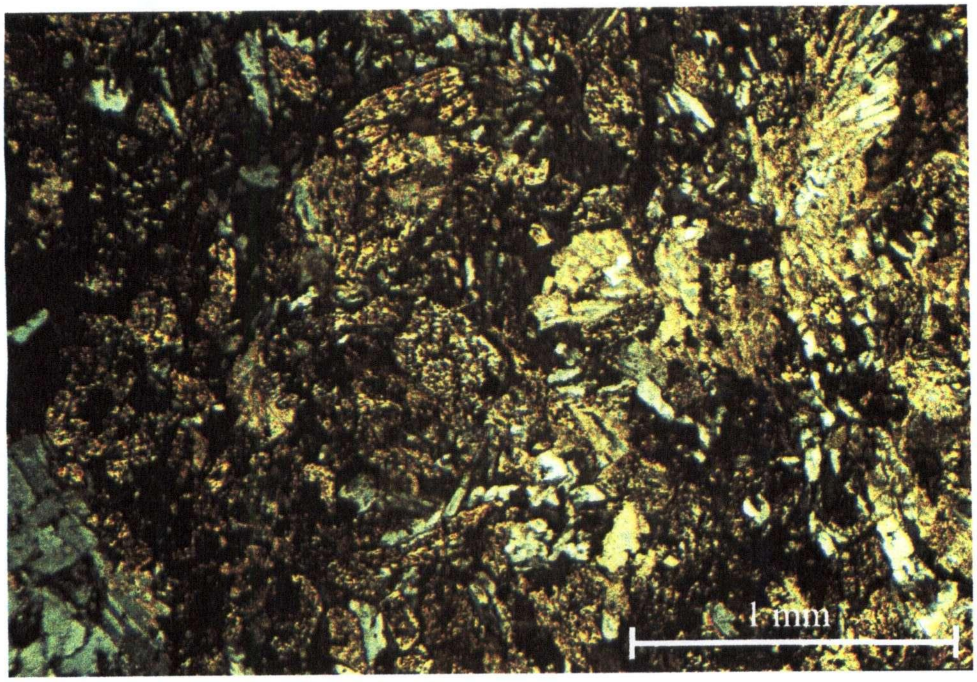


Figure 7: Photomicrograph of greenstone from the Bridge River Complex.

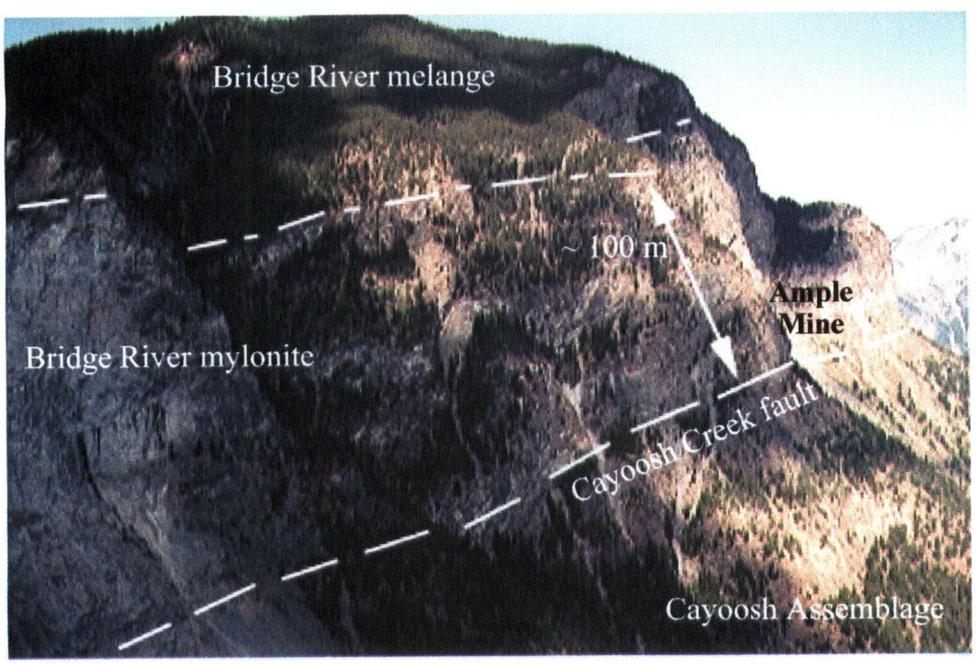


Figure 8: Maximum extent of Bridge River mylonite in the hangingwall of the Cayoosh Creek fault. View looking east.

The talc occurs as thin films defining a foliation within the greenstone, but rare thicker lenses exist.

Mylonitic textures within the hangingwall of the Cayoosh Creek fault are restricted to within 100 m of the fault (figure 8). The mylonite zone is thickest where the fault is also the best exposed, near the Ample Mine. The mylonite pinches out to the west, and thins substantially to the east. Chert mylonite is abundant at the deepest levels of the upper plate, and consists of 1 to 3 mm-thick layers of quartz divided by thin micaceous films. Quartz within greenstone has also experienced dynamic recrystallization, and microcrystalline layers of sericite and calcite define foliation surfaces. The mylonitic foliation is slightly crenellate, and contains an associated mineral lineation defined by elongate quartz stringers. The contact between the mylonite and the surrounding rock is abrupt, and roughly coplanar with the foliation.

1.5.2 Cayoosh Assemblage

The Cayoosh Assemblage composes most of the study area, and contains rocks previously mapped as Brew Group by Duffell and McTaggart (1952) and Mustard (1983). The assemblage is a mid-Jurassic (?) to Early Cretaceous sequence of volcanoclastic and quartzofeldspathic sediments which most likely represent a shift in depositional environments on the North American margin (Journeay and Mahoney, 1994). It is a thick sequence of interlayered metamorphosed sandstone, siltstone, greywacke, shale, turbidites, and tuffs. Primary structures are locally preserved, but are commonly altered by regional metamorphism and deformation. Although regional metamorphism is at sub- to lower greenschist facies, the footwall of the Cayoosh Creek fault mostly contains a mid-greenschist assemblage of chlorite + muscovite + biotite + albite, but reaches amphibolite facies conditions deeper in the section. Mylonite is common in the assemblage. The Cayoosh Assemblage is exposed extensively along the northern Cayoosh Creek valley, the north-facing valley walls, and on Mt. Brew.

Immediately south of the Cayoosh Creek fault, the assemblage consists of light to medium grey phyllitic argillite and siltstone interlayered with grey to light green schistose sandstone (figure 9). Low-amplitude gentle folding pervades the map area. Argillite is primarily composed of quartz and chlorite, and locally contains pyrite and arsenopyrite. The phyllite commonly contains thin, graphitic partings or millimeter-scale quartz layers. Outcrop-scale shear zones and shear bands are commonplace, as well as mineral lineations. Millimeter to centimeter-scale quartz veins are isoclinally folded and attenuated, implying transposition has occurred. Sandstone layers are typically 5 to 30 cm thick, separated by thin phyllitic layers. Chlorite, muscovite, and actinolite are locally abundant, all of which define a strong linearity providing an L-tectonite appearance within individual layers.

On Mt. Brew the assemblage has a slightly fresher appearance, and primary structures can commonly be distinguished in the metamorphosed turbidites (figure 10). Siltstone, sandstone, and tuffaceous layers are common at the northernmost exposures whereas interlayered calcareous sandstone and siltstone characterize the bulk of the ridge system. Fossiliferous sandstone is found on the western slopes of the mountain, which contains bivalves identified as Early Neocomian *Buchia* by Duffell and McTaggart (1952). Metamorphism reaches a peak of amphibolite facies in this section, and biotite, garnet, zoisite, and hornblende porphyroblasts are readily identifiable in hand sample. Close to Molybdenite Creek a metamorphic assemblage of staurolite + andalusite + quartz + biotite

Figure 9: Cayoosh Assemblage near Cayoosh Creek fault. 2-3 mm feldspar phenocrysts near bottom center of photograph.

Figure 10: Meta-sandstone in the Cayoosh Assemblage near Mount Brew.

was discovered and used to estimate pressure and temperature conditions. Folding is similar to other sections of the assemblage, although foliation differs in that it generally dips moderately to the southwest.

1.5.3 Early Cretaceous Conglomerate

Exposed on the southern ridges off Mt. Brew is a matrix-supported conglomerate that was initially mapped as the uppermost unit of the Brew Group (Duffell and McTaggart, 1952; Mustard, 1983). Clasts consist of various sedimentary and volcanic rocks, but plutonic clasts are the most abundant (figure 11). The matrix is composed of microcrystalline to fine grained recrystallized quartz, biotite, and garnet. Bedding is defined by grading in the matrix and by clasts which are rounded, flattened, and appear to be stretched. Garnet and hornblende porphyroblasts overprint the dominant metamorphic fabric, which is defined by an alignment of micaceous minerals and recrystallized quartz. Sizes are typically pebbles and cobbles, but boulder size clasts are present as well. Metamorphic fabric of the conglomerate and the underlying Cayoosh Assemblage are coplanar, yet the lithologic change and the clasts within suggest the presence of an unconformity along the contact between the two units.

Journeay and Mahoney (1994) correlate this unit with the Early Cretaceous conglomerate of the Jackass Mountain Group based on the presence of Late Jurassic granitoid clasts. The Jackass Mountain conglomerate contains well-rounded clasts of dominantly plutonic and volcanic origin, and lesser quantities of chert, clastic sedimentary rocks, and metamorphosed and foliated plutonic rocks (Jeletzky and Tipper, 1968). It alternates with coarse-grained to pebbly sandstone and siltstone. The Jackass Mountain

Figure 11: Stretched pebble conglomerate south of Mount Brew.

Figure 12: Photomicrograph of Silverquick (?) Conglomerate.

Group is a component of the Methow Terrane, a Lower Jurassic to mid-Cretaceous assemblage of volcanic and clastic sedimentary rocks (references in Schiarizza et al., 1997). Some components of the Methow Terrane have been correlated with the upper portion of the Tyaughton Basin (see following paragraphs; Garver, 1989; Schiarizza et al., 1995).

1.5.4 Silverquick Conglomerate

Exposed on the southern shores of Seton Lake and adjacent slopes is an interbedded sandstone and conglomerate unit tentatively correlated with the Silverquick conglomerate. The unit is unconformably overlying the Bridge River Complex, and is cut by the Marshall Creek fault and a possible splay of the fault on the eastern margin. The conglomerate contains rounded to sub-angular clasts of chert, sandstone, greywacke, volcanics, and plutonic rocks (figure 12). Sizes range from pebble to cobble. The sandstone is fine to coarse grained, well bedded, and locally fines upward. It contains grains of quartz, plagioclase, calcite, and less commonly biotite and muscovite in quartz cement.

Schiarizza and others (1997) describe the Silverquick formation in the Taylor Creek area as a thick succession of 80% conglomerate and 20% sandstone and siltstone. The conglomerate is poorly sorted cobbles of chert, sedimentary rocks, volcanics including greenstone, and dioritic plutonic rocks. Sandstone comprises chert, quartz, feldspar, lithic volcanic and sedimentary fragments, and detrital mica. The Silverquick conglomerate is part of the Tyaughton Basin, which may be an overlap assemblage on the Bridge River Complex, equivalent to the Cayoosh Assemblage (Schiarizza et al., 1997). In the Mission Ridge area, the Silverquick formation occupies the core of a northwest plunging syncline unconformably overlying Bridge River rocks (Coleman, 1990). The unit contains moderately sorted chert and volcanic-rich conglomerate interbedded with shale and coarse-grained sandstone. Plant

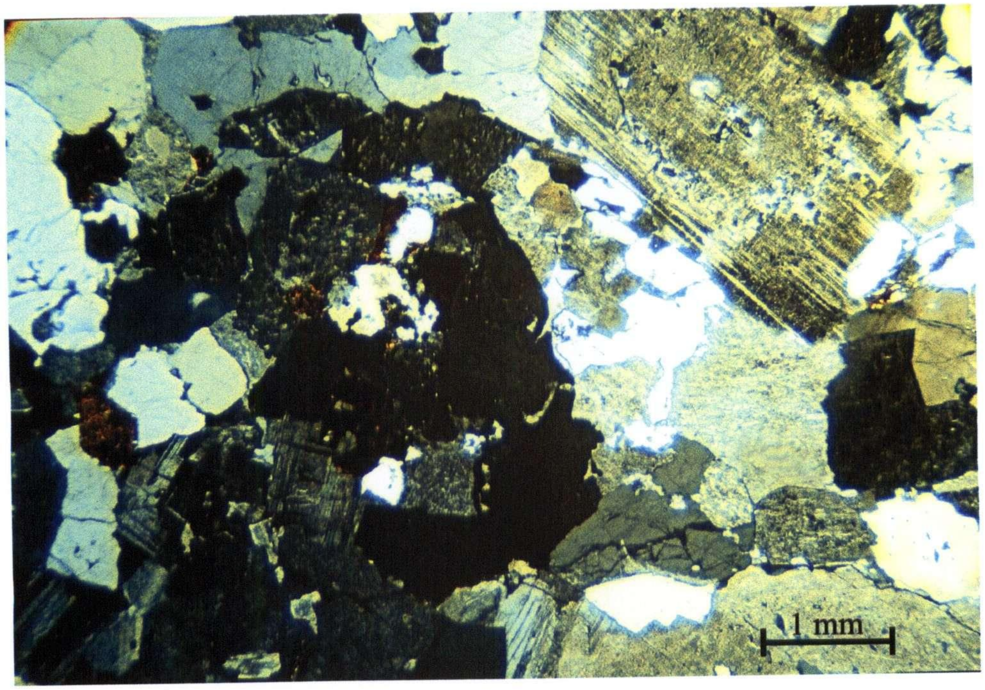
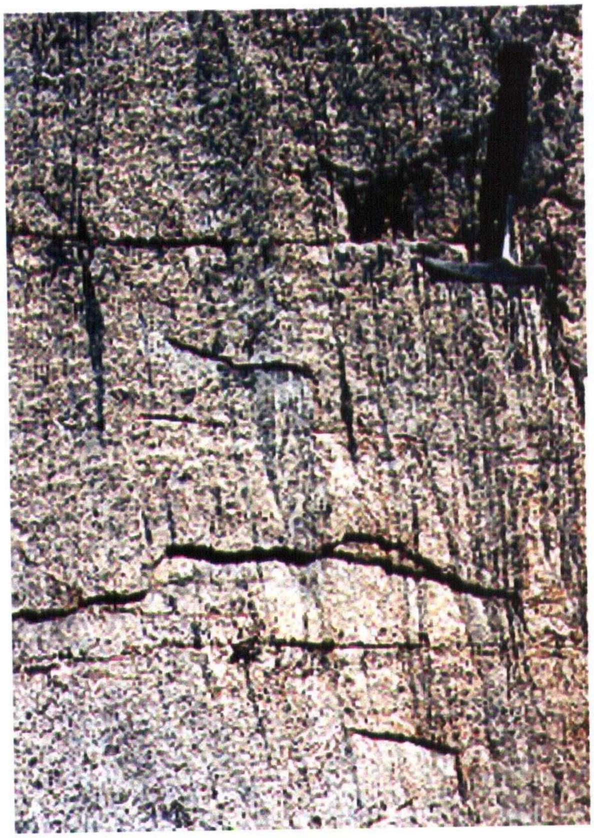


Figure 13: Cinnamon Creek pluton.



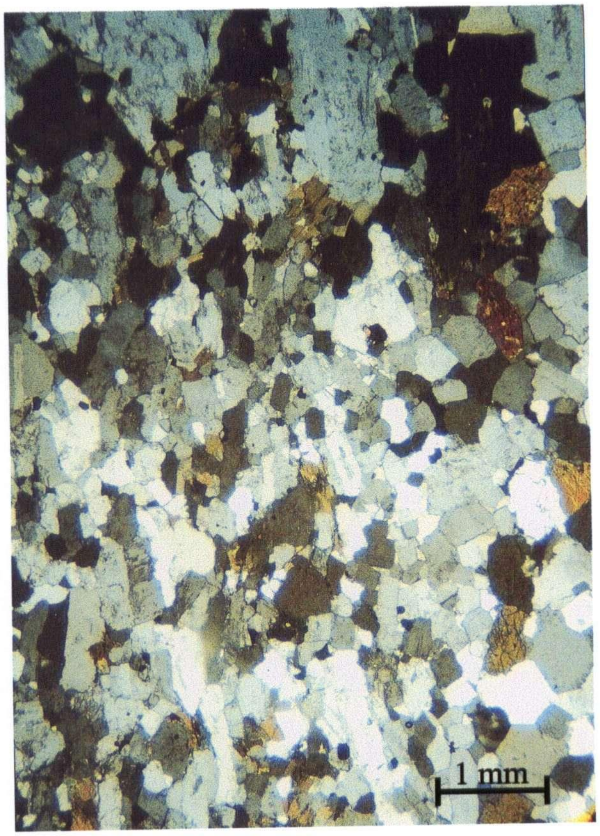


Figure 14: Molybdenite Creek pluton. Magmatic fabric parallel long edge of figures.

fossils and pollen from the Silverquick formation are Early to mid-Cretaceous in age (Schiarizza et al., 1997).

1.5.5 Cinnamon Creek Pluton

The Cinnamon Creek pluton is a mainly homogeneous body of medium to coarse-grained granite and less abundant granodiorite. The pluton intrudes the Bridge River Complex in the western extremity of the study area and is in fault contact with the Cayoosh Assemblage. It has a porphyritic to granitic texture, and contains biotite and hornblende (figure 13). Plagioclase commonly has a sieve texture. Zircons from the pluton, dated using U-Pb methods, indicate a crystallization age of 48.8 ± 0.1 Ma (see Chapter 2). Although the pluton was not mapped in detail, it appears to occur only to the west of the Phair Creek fault. A preliminary outline of the pluton, based on reconnaissance mapping and air photo interpretation, is shown on figure 46.

1.5.6 Molybdenite Creek Pluton

The Molybdenite Creek pluton (also called the Texas Creek pluton) is an elongate body trending northwestward approximately 30 km from its truncation at the Fraser fault near Lytton, B.C. It is a light to medium grey, fine to coarse-grained granodiorite. The pluton has a granitic texture and a locally well developed magmatic foliation (figure 14). An alignment of plagioclase, quartz, and biotite, and zonation of mafic minerals and opaques defines the fabric. Hornblende and biotite are abundant, constituting about 10% of the rock in the most felsic zones. Unpublished U-Pb zircon dating from P. van der Heyden and J.W.H. Monger indicate an age of 47.4 ± 1.0 Ma for the pluton. In the study area the pluton has an intrusive contact with the Cayoosh Assemblage to the east. Near this contact, however, a northwest-striking, nearly vertical ductile shear zone, the extent of which is

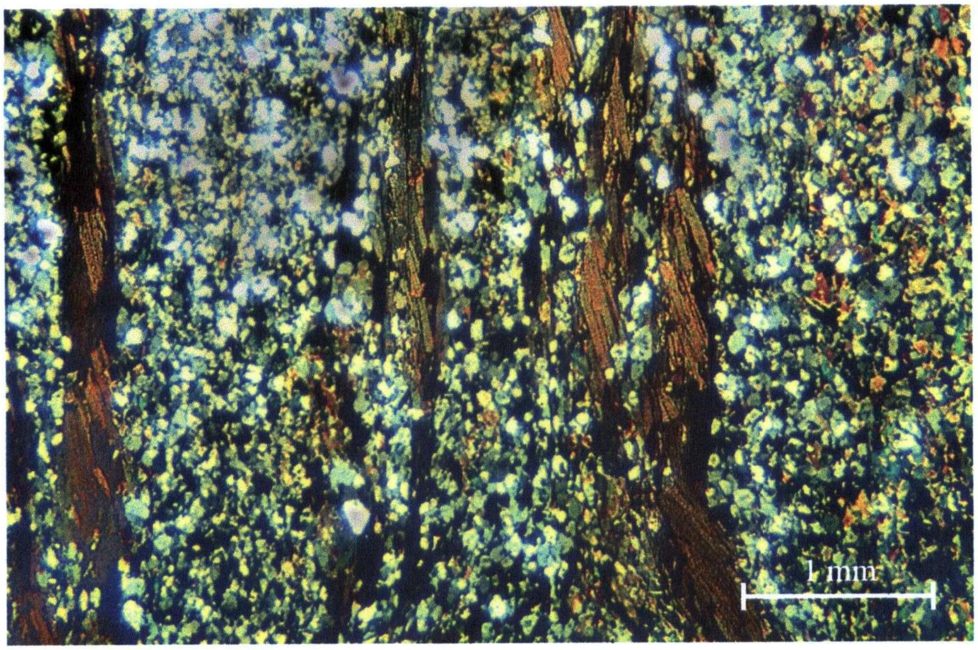


Figure 15: Metamorphic foliation in Molybdenite Creek pluton.

Figure 16: Cayoosh Creek shear zone at the Ample Mine. Cataclasite unit is 30 cm thick.

Figure 17: Cataclasite unit underlying the Cayoosh Creek shear zone.

unclear, deforms the pluton (figure 15). The western margin is ambiguous, but appears to have an intrusive contact with the Bridge River Complex no more than 5 meters outboard of the Phair Creek fault. The fault clearly has plutonic rocks on either side, although shear fabric in the pluton is coincident with fabric orientations in the outlying Bridge River rocks.

CHAPTER 2

2.1 STRUCTURE AND KINEMATICS

Penetratively deformed rocks, primarily restricted to the footwall of the Cayoosh Creek fault compose the bulk of the study area. This package is overlain by dominantly brittlely deformed Bridge River Complex, excluding a large lens of mylonite presently at the lowest structural level of the upper plate. The penetrative fabrics are truncated to the west and east by steeply dipping strike-slip faults. Linear and planar fabric data, shown in figures 20 and 21, were measured in the field to determine the macroscopic geometry of the Cayoosh Creek fault and characterize the deformation in its upper and lower plates. S_1, S_2 and S_3 foliations and related folds have been identified, with S_1 transposed parallel to S_2. Shear sense indicators are interpreted in a manner believed to best represent the bulk regional displacement along the Cayoosh Creek fault. The effect of gentle folding of the predominant S_1/S_2 foliation is that some samples are oriented with southwestern dips while the enveloping surface of the folds dips to the northeast at the outcrop scale. In these cases, an indication of the upper plate moving northward relative to the lower plate is interpreted as extensional. Nearly 100 thin sections were analyzed for microstructures, including shear sense indicators. Thin sections were cut from a plane perpendicular to foliation and parallel to lineation. In ten footwall samples sections were also cut perpendicular to foliation and lineation.

Fabric elements, microscopic and mesoscopic shear sense indicators, field observations of mesoscopic fabric relationships, and interpretations of macroscopic-scale elements are used to interpret a series of deformation events and to document the kinematic history of the Cayoosh Creek fault. The following includes a description of the Cayoosh Creek fault zone, including detailed descriptions of the structures in the upper and lower plates. Descriptions of the two steep bounding faults—the Phair Creek and Marshall Creek faults—and relevant descriptions of the deformation of the two plutonic bodies within the study area are covered here. Metamorphism associated with these structures and the ages of three tectonically significant features in the study area are also discussed.

2.2 CAYOOSH CREEK FAULT

A low-angle fault above the Cayoosh and Phair Creek valleys, originally called the Phair Creek fault, has been more recently designated the Cayoosh Creek fault (Coleman, 1990; Journeay et al., 1992). The fault separates overlying Bridge River Complex from footwall Cayoosh Assemblage (figure 8). Based on the juxtaposition of Mississippian to lower Middle Jurassic age rocks over younger, Middle Jurassic to Lower Cretaceous units, Mustard (1983) and Coleman (1989, 1990) interpreted the Cayoosh Creek fault as a thrust fault. Journeay and others (1992) document kinematic indicators consistent with the previous interpretations, but also cite structures that could be attributed to extension or dextral translation, such as sub-horizontal orientations of stretching lineations, S-C fabrics, and northwest vergent folds.

The Cayoosh Creek fault is a shallowly north to northeast-dipping structure that has a sinuous trace along topography north of the Cayoosh Creek valley (figure 1). The fault strikes from 260° to 300°, and dips 25° to 35° northward. The fault is best exposed at the old

Ample Mine workings, approximately 8 km west of Lillooet, and was also recognized in drill core from this site. The fault has a slightly domed geometry as it drops in elevation towards both the east and west. There is also evidence that it has been cut and down-dropped by brittle normal faults in the section immediately west of the mine. The fault is easily recognized in the field by a break in slope—the more resistant Bridge River Complex greenstone and chert forming steep slopes and cliffs above modest gradients formed by weathering phyllites and schists. Structurally above the resistant greenstone and chert package (which pinches out to the west), is a less-coherent variety of Bridge River rocks which display many of the characteristics Potter (1986) attributed to initial accretion. A coarse sandstone and conglomerate unit (tentatively grouped with the Silverquick formation) lies unconformably above the melange-style unit. The footwall comprises metamorphosed siltstone, sandstone, and turbidites of the Cayoosh Assemblage.

At the Ample Mine, the Cayoosh Creek fault is characterized by a ductile shear zone at least 20 meters thick (figure 16). The shear zone is defined by mylonitic fabrics that are overprinted by cataclasis, solution transfer, extensive veining, and locally a crenulation cleavage. Mylonitic textures persist for approximately 100 meters into the hangingwall at this location, and are common throughout the footwall. Structures within the shear zone include a 30 cm thick cataclasite layer (figure 17) structurally below a number of imbricated fault duplexes (figure 18). These outcrop-scale faults strike west-northwest to west-southwest and dip shallowly northward (figure 21g). Slickenfibers from two fault surfaces dip shallowly to the northwest. The geometry and stacking of fault horses is suggestive of a thrust duplex but actual offset was indeterminable. The shear zone also contains numerous

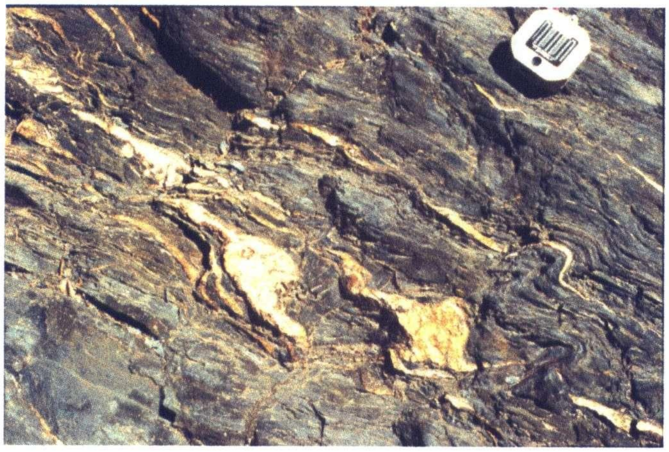


Figure 18: Folded and boudinaged quartz and calcite veins within a fault horse at the Cayoosh Creek shear zone.

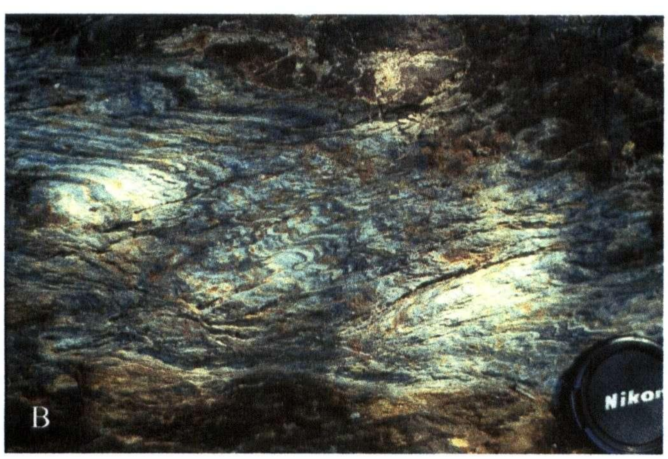


Figure 19: Cleavage development parallel to axial planes of folds within the Cayoosh Assemblage. Vergence is towards the south.

folds which are geometrically similar to folds elsewhere in the assemblage, but locally an axial planar cleavage is developed on southwest verging tight to isoclinal folds (figure 19).

Mesoscopic semi-brittle features, such as outcrop-scale faults and Riedel shears, also increase in the vicinity of the main fault. Within the duplexes there is an extensive array of folded, boudinaged, and planar quartz and calcite veins, which increase in concentration with proximity to the Cayoosh Creek fault (figure 18). Mulligan (1998) concluded that episodic fluid flow resulted in at least three distinct sets of fault-related veins within the shear zone at the Ample Mine.

The latitudinal extension of the fault is a little over 4 km. It is truncated to the east by the southwest-dipping Marshall Creek fault, and therefore resides in its hangingwall (figure 1). Towards the Marshall Creek fault the foliation steepens until it is nearly vertical, which may be an indication of a relationship between the ductile fabrics of the Cayoosh Creek and Marshall Creek faults. To the west, the fault is truncated by another northwest-striking, steep shear zone. Extensive scree slopes conceal the culmination of these two faults, however, approximately 100 meters above the projected contact the steep shear zone clearly cuts hangingwall fabrics that are attributed to Cayoosh Creek fault deformation. As with the Marshall Creek shear zone, a transition from shallow to steep foliations exists near this west-bounding fault. This crosscutting shear zone was traced southward into the Phair Creek valley, until it becomes obscure near Molybdenite Creek. This structure closely coincides with the previously mapped extension of the Cayoosh Creek fault, the Phair Creek fault, but this study establishes they are distinct and separate structures.

Figure 20: Equal-area stereonet projections of linear and planar fabric data.

a) Poles to foliation in Bridge River melange; upper plate of Cayoosh Creek fault.
b) Poles to foliation in Bridge River mylonite; upper plate of Cayoosh Creek fault.
c) Poles to axial surfaces in upper plate of Cayoosh Creek fault. Open circles are isoclinal to tight folds, dots are close to open folds.
d) Fold axes in upper plate of Cayoosh Creek fault. Open circles are isoclinal to tight folds, dots are close to open folds.
e) Mineral lineations in upper plate of Cayoosh Creek fault. Open circles are from Bridge River melange, dots are from Bridge River mylonite.
f) Poles to fault planes in upper plate of Cayoosh Creek fault (dots). Open circles are slickenlines.
g) Poles to foliation within the Marshall Creek shear zone.
h) Poles to foliation in Bridge River schist; lower plate of Marshall Creek fault.

Figure 21: Equal-area stereonet projections of linear and planar fabric data.

a) Poles to foliation in Cayoosh Assemblage; lower plate of Cayoosh Creek fault.
b) Poles to foliation in Cayoosh Assemblage less than 200 meters below Cayoosh Creek fault zone.
c) Poles to foliation in Cayoosh Assemblage more than 1 kilometer below Cayoosh Creek fault zone.
d) Poles to axial surfaces in lower plate of Cayoosh Creek fault. Open circles are tight to isoclinal folds, dots are close to open folds.
e) Fold axes in lower plate of Cayoosh Creek fault. Open circles are tight to isoclinal folds, dots are close to open folds.
f) Mineral lineations in lower plate of Cayoosh Creek fault.
g) Poles to fault planes in Cayoosh Assemblage (dots). Open circles are slickenlines, squares are from Cayoosh Creek fault duplexes.
h) Poles to foliation within the Phair Creek fault zone (dots). Open circles are slickenlines, squares are mineral lineations.

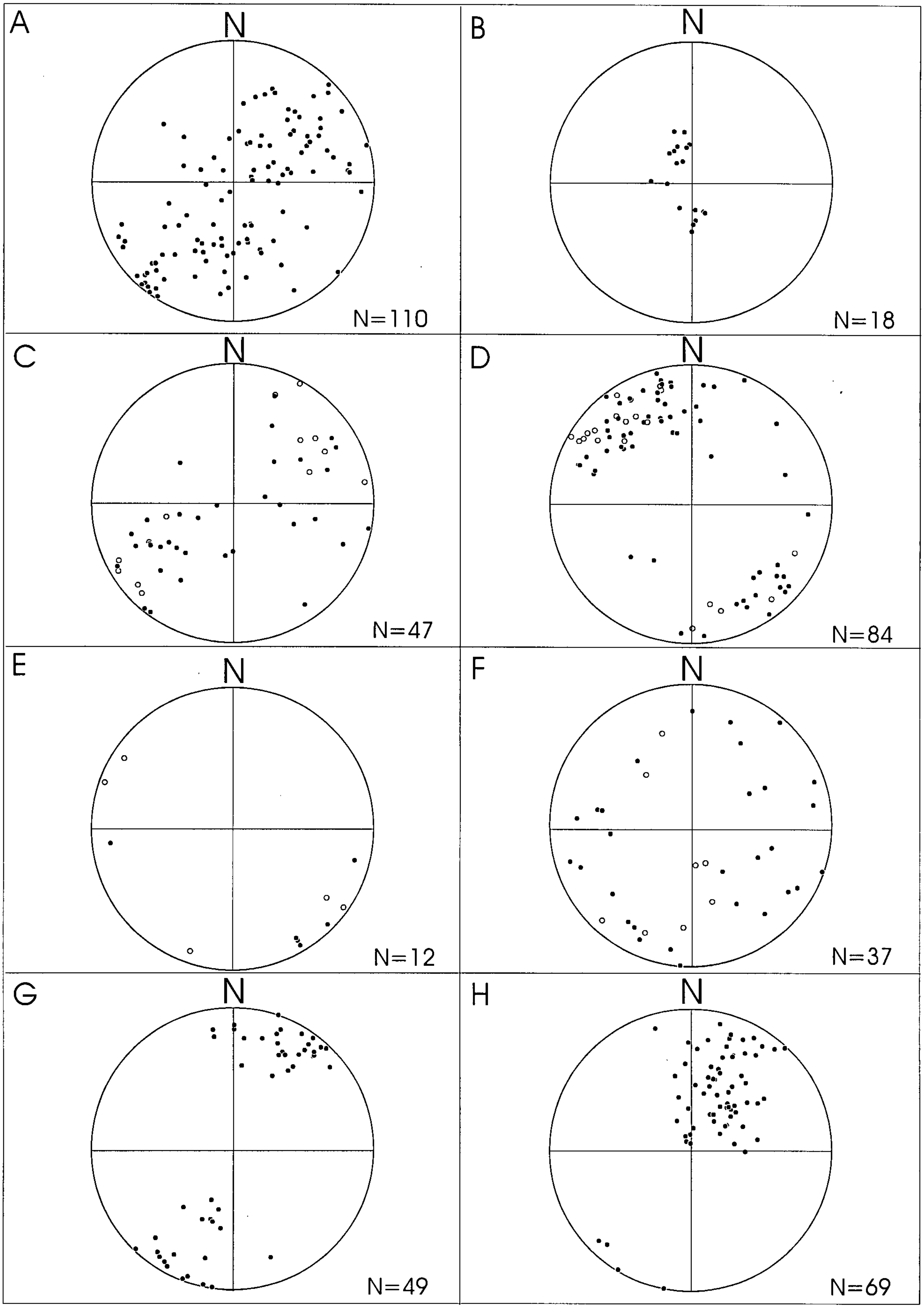


Figure 20: Equal-area stereonet projections.

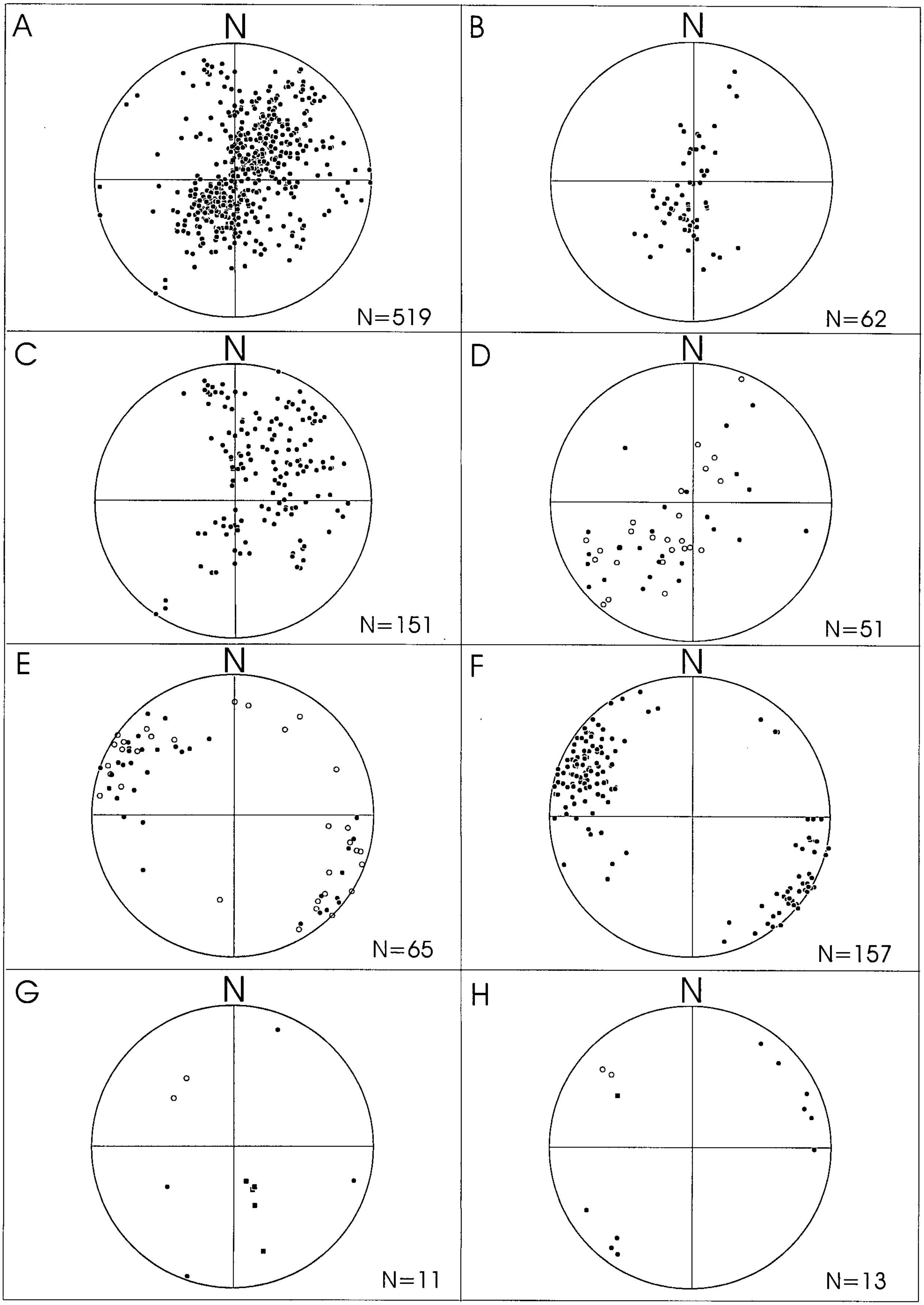


Figure 21: Equal-area stereonet projections.

2.2.1 Hangingwall

The hangingwall of the Cayoosh Creek fault is mainly composed of the Bridge River Complex. Immediately above the main shear zone (figure 16), deformation in the Bridge River Complex is mostly the result of ductile mechanisms, including grain size reduction through dynamic recrystallization, flattening, and resultant asymmetry. This lens of mylonite is nearly 100 meters thick above the shear zone at the Ample Mine (figure 16), but is less than 10 m thick near the termination of the Cayoosh Creek fault at the Marshall Creek fault, and pinches out to the west. Foliation (S_2) has an east-northeast strike, and dips shallowly to the north and south (figure 20b). The change in dip direction is a reflection of gentle folding, which has a wavelength on the order of 5 to 10 meters. Fracturing and solution transfer become the dominant deformation types with increasing elevation from the shear zone.

Above the mylonite is the mostly brittle Bridge River melange. Bedding (S_0) is extremely rare in this unit. Folded chert ribbons are the only bedding recognized locally, and are found at one site within the melange-like portion of the complex. Thin sections reveal the chert layers are almost entirely replaced by quartz—and to a lesser degree, calcite—veins. No primary structures or radiolaria are recognized. Where measurable, the foliation (S_1) is defined by clay-rich seams or brittle fractures, but is typically confined to small, discontinuous outcrops. Foliation typically strikes northwest-southeast, but dips vary considerably, possibly due to folding, slumping, or faulting (figure 20a). Mesoscopic folding of the foliation is relatively common, but the continuity of these structures at a larger scale is unclear considering the abundance of shear zones within this unit. The melange is overlain by the Silverquick (?) conglomerate, which in the study area appears relatively undisturbed.

Upright, open to gentle folds are the most common folding style within the hangingwall. Folds verge both to the southwest and northeast, and typically have a moderate to steeply dipping axial surface (figure 20c). Hinges are rounded to sub-angular. Fold axes plunge shallowly to moderately to the northwest and southeast (figure 20d). Plunge direction could not be spatially linked to any particular structural domain, in fact, southerly and northerly plunging folds can be found within single outcrops. In the mylonitic portion of the Bridge River Complex adjacent to the fault, fold axes plunge northerly, with one southeast plunging exception. Isoclinal to tight folds also exist within the hangingwall, though far less frequently. The axial surfaces and fold axes of these tighter folds are coaxial with the more common, open folds, and also verge both to the southwest and the northeast.

Mineral lineations exist sporadically in the hangingwall. Only five examples were discovered in the structurally less-coherent portion of the complex, and six within the mylonitic portion (figure 20e). Within the melange-like rocks the lineation is defined by elongate quartz stringers, and in one case by aligned tremolite fibers, lying within the foliation plane. In the mylonite immediately above the fault zone the lineation is defined by fine-grained muscovite, aligned within the mylonitic foliation. The lineations plunge shallowly, both to the northwest and to the southeast.

Outcrop-scale brittle faults pervade the hangingwall of the Cayoosh Creek fault (figure 20f). As the Bridge River Complex is mostly homogeneous, offset on these faults is difficult to determine. No marker beds were available to calculate slip amounts, but in a few cases relative slip directions were resolved. Of the 32 faults measured (many more were observed), deflected foliation planes revealed three normal faults and one reverse. Three occurrences of slickenfibers indicated normal movement. At seven locations mesoscopic

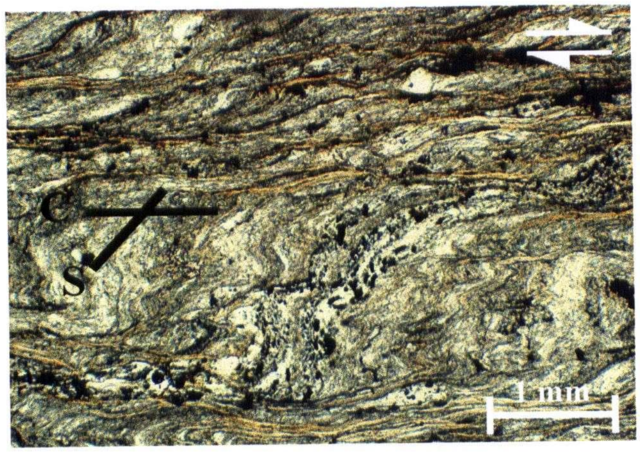


Figure 22: S/C fabric in Cayoosh Assemblage.

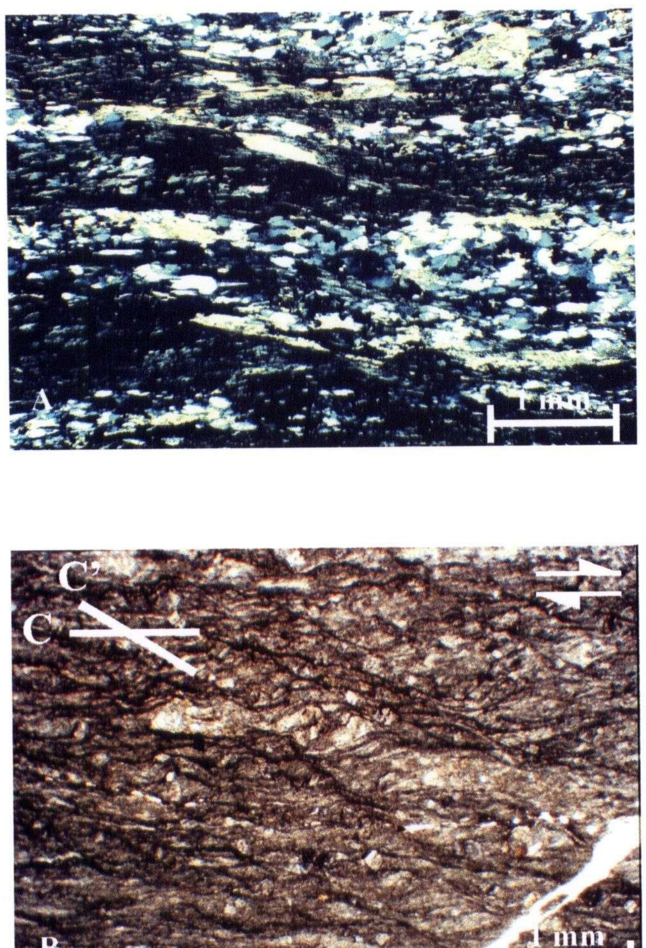


Figure 23: S_2 fabric in Cayoosh Assemblage. A) Incipient C' fabric defined by chlorite. B) Well developed C' fabric.

kinematic indicators (including heterogeneously deformed dikes, winged inclusions, asymmetric folds, and shear bands) imply extensional deformation has occurred and one implies contraction.

Microstructures in the Bridge River melange are limited to a coarse, anastomosing foliation defined by solution transfer seams, pressure solution, and profuse veining. Solution transfer seams are the locus of opaque material, often graphite, or micaceous minerals, including chlorite and sericite. Undulose extinction and angular quartz grains are common, and in a few samples grain boundary migration has occurred. Vein geometries are variable and in some cases recrystallized, suggestive of numerous generations. Kinematic indicators are extremely rare in the hangingwall (figure 30). Only two samples contained microscopic indicators reliable enough to be included in this analysis. Shear bands, asymmetrical porphyroclasts, and fold vergence imply normal separation. One of the samples also contained a sub-horizontal mineral lineation that—if used as an indicator of slip direction—suggests a component of dextral slip as well.

Coleman (1989, 1990) placed the counterpart of the Mission Ridge fault—offset by normal movement on the Marshall Creek fault—at the transition from Bridge River mylonite to Bridge River melange (her Bridge River Group). Although a shift exists from ductile mechanisms to primarily brittle deformation in the hangingwall, this study found no evidence of faulting at this contact, and the metamorphic grade does not appear to approach the upper greenschist to amphibolite facies found in the footwall of the Mission Ridge fault to the north.

Figure 24: Large scale folds in the lower plate of the Cayoosh Creek fault. Views looking north. A) F_1/F_2 folds. Cliff face is ~150 m tall. B) F_3 fold. Field of view is ~20 m wide.

Figure 25: Outcrop scale folds in the lower plate of the Cayoosh Creek fault. A) F_1/F_2 folds overprinted by upright F_3 folds. B) F_1/F_2 folds with coaxial stretching lineation.

2.2.2 Footwall

The lower plate of the Cayoosh Creek fault is primarily composed of the Cayoosh Assemblage. Near the shear zone the Cayoosh Assemblage contains microstructures typical of shear zones which have passed through the brittle-ductile transition, including fractured clasts and cataclasite, pressure solution, flattening, and dynamically recrystallized grains. Brittle features commonly overprint ductile features, although veining occurred throughout shearing (Mulligan, 1998). The dominant foliation is defined by a mylonitic foliation (S_2), but rare examples of bedding (S_0) and compositional layering (S_1) are present within the study area.

Foliation ranges from phyllitic to schistose and is commonly mylonitic. Compositional layering (S_1) is visible only at the microscopic scale, usually in samples where microshear surfaces (C surfaces) have wider spacing (figure 22). C surfaces define a mylonitic foliation in many of the lower plate rocks (not all samples contain discrete C surfaces) and are visible in the field as thin partings of graphite within relatively quartz rich phyllite. Aside from the rare areas where S_1 is oblique to the microshear zones, mylonitic foliation (S_2) is parallel to S_1. S_2 is defined by quartz lenses and layers of fine-grained micas, feldspar, and opaques, and is commonly anastomozing in appearance (figure 23). Foliation generally has a northwest strike and dips shallowly to the northeast and southwest (figure 21a,b). Exceptions occur near the Marshall Creek fault and the Molybdenite Creek pluton, where the foliation steepens to nearly vertical. Foliation attitudes also become steeper and more variable with distance from the Cayoosh Creek fault (figure 21c). South of Mt. Brew foliation is dominantly southwest dipping. Bedding is recognizable in outcrops near Mt.

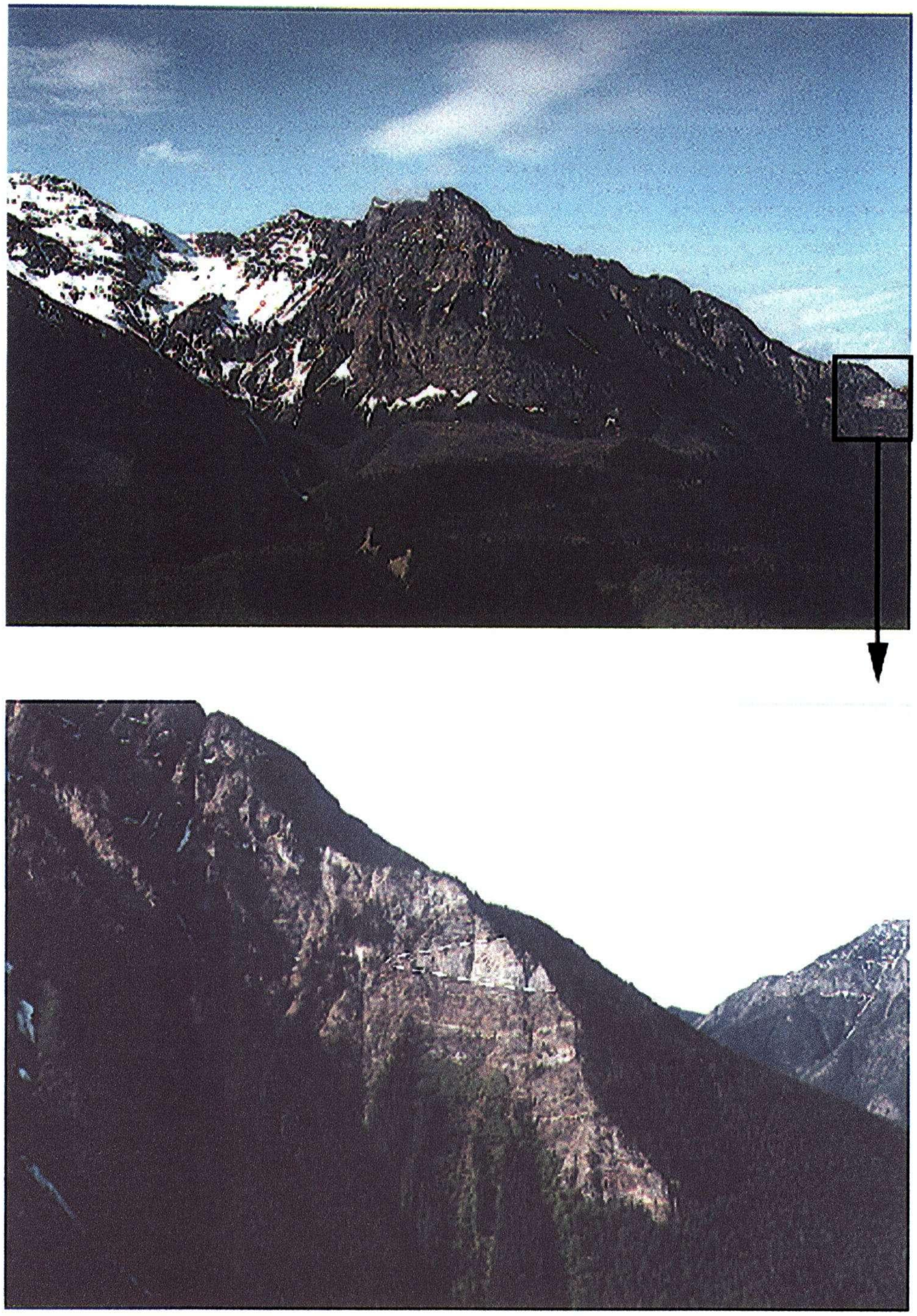


Figure 26: Macroscopic isoclinal fold in the lower plate of the Cayoosh Creek fault. Northwest flank of Mount Brew. View looking south.

Brew, but is not perceptible elsewhere. Orientations (S_0) are coplanar with metamorphic foliation (S_1/S_2) and cleavage (locally).

Both isoclinal and open mesoscopic folds are common in lower plate rocks (figure 24). Folds typically verge southwestward and have gently dipping to steep axial surfaces (figure 21d). Both northwest and southeast plunging fold axes are common, but are generally sub-horizontal (figures 21e, 25). Fold hinges are sub-angular to sub-rounded. Tracing individual folded layers at the outcrop scale reveals that they refold an earlier fold that is now coaxial and geometrically similar. Macroscopic folds, visible on cliff faces north and south of Mt. Brew, are isoclinal with sub-horizontal axial surfaces and have wavelengths on the order of hundreds of meters (figure 26). On the basis on graded bedding, outcrop pattern, and cleavage-bedding relationships, Mustard (1983) interpreted that the conglomerate unit on Mt. Brew represents the core of an isoclinal recumbent fold.

Mineral and stretching lineations are common in the lower plate of the Cayoosh Creek fault. They are more prevalent in fine-grained and phyllitic samples, but are also found in coarse, schistose rocks. Lineations are defined by micaceous minerals, actinolite, and elongate quartz aligned on the foliation surfaces. Lineations are typically sub-parallel to the strike of S_1/S_2, and plunge gently to the northwest and southeast (figure 21f). Also defining a lineation are stretched clasts in the matrix-supported conglomerate exposed on Mt. Brew. Aspect ratios measured on the long axes of the clasts range from 3:10 to 8:10. Perpendicular to the long axis, ratios vary from 1:1 to 1:4. Lineation orientations do not vary with distance from the Cayoosh Creek fault or any other major structure in the study area. The attitude of stretching lineations in the study area is remarkably consistent, and therefore

Figure 27: Heterogeneously deformed dike in the lower plate of the Cayoosh Creek fault. View is looking north.

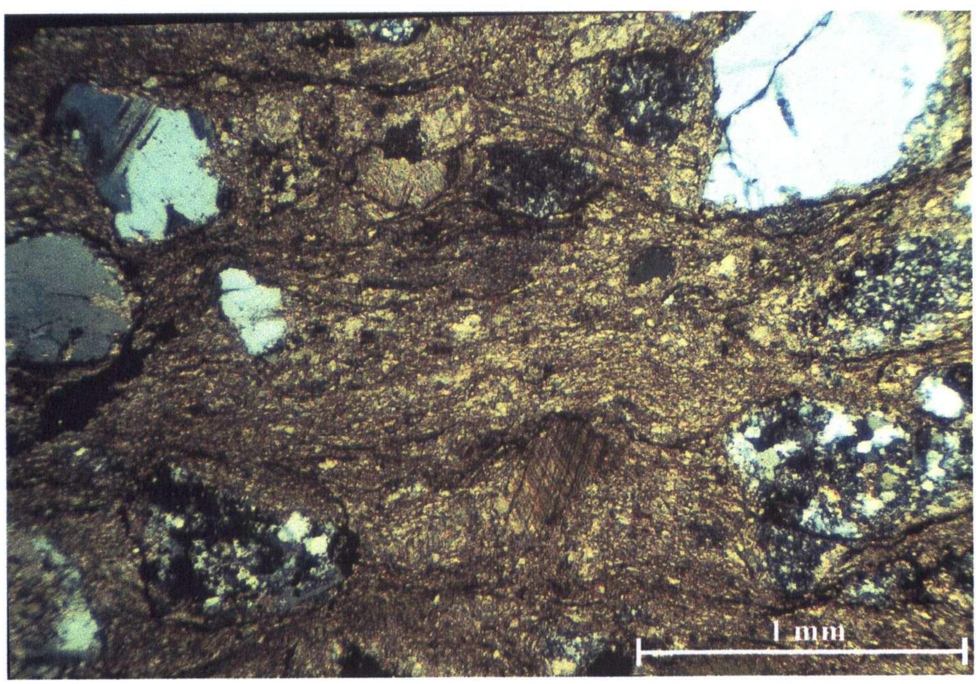


Figure 28: Thin section of cataclased Cayoosh Assemblage from drill core sampled at the Ample Mine. Matrix is dominantly calcite.

they are used as an indication of slip direction. This, in conjunction with other kinematic indicators, is used to interpret the strike-slip component of shear sense (figure 30b).

Mesoscopic kinematic indicators consist of shear bands, asymmetrical folds, and winged inclusions (figure 27). Only folds and winged inclusions that show consistency within a structural domain are included in the kinematic analysis. Mesoscopic indicators predominately imply normal slip (figure 30a). All examples of shear bands are indicative of normal offset. Contractional deformation is recorded at five stations in the footwall, indicated by rotated and winged inclusions and fold asymmetry. Aside from mesoscopic shear bands and the faults at the Cayoosh Creek fault zone, few outcrop scale shear zones were observed in the Cayoosh Assemblage. Of the two ductile shear zones and two brittle faults examined, all suggested normal slip. Macroscopic isoclinal folds, visible in cliff faces south of Cayoosh Creek, are suggestive of regional southwest vergent nappe-style thrusting in the Coast Belt (Figure 26; Journeay et al., 1992).

Microstructures include fractured clasts, folds, winged inclusions, crenulation cleavage, and extensional shear bands. Monoclinic symmetry is best viewed in the plane perpendicular to foliation and parallel to lineation. Fracturing occurs proximal to the Cayoosh Creek fault and is especially evident in cataclasite sampled at the Ample Mine and in consolidated breccia in drill core samples (figure 28). Cataclasis of felsic minerals, mainly in distinct microshear zones, coexists and overprints evidence of ductile deformation mechanisms such as grain boundary migration, subgrains, and shear bands. Microfolds are rare, but have the same geometry as mesoscopic folds. When observed with other dependable shear sense indicators they are included as a kinematic indicator.

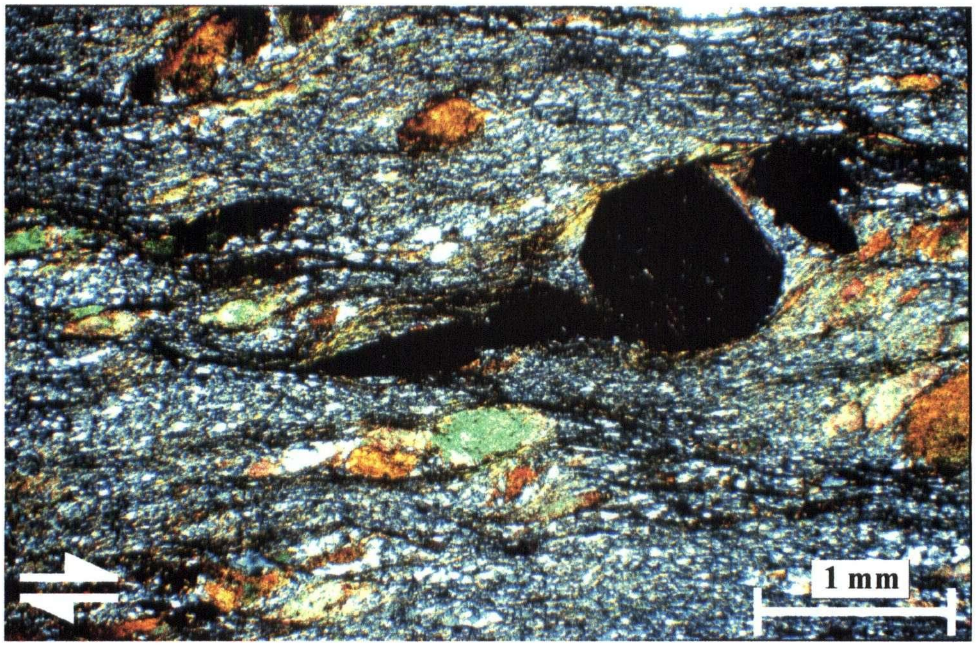


Figure 29: Thin section displaying distinctive monoclinic symmetry and typical shear sense indicators. Shear sense is labeled at lower left.

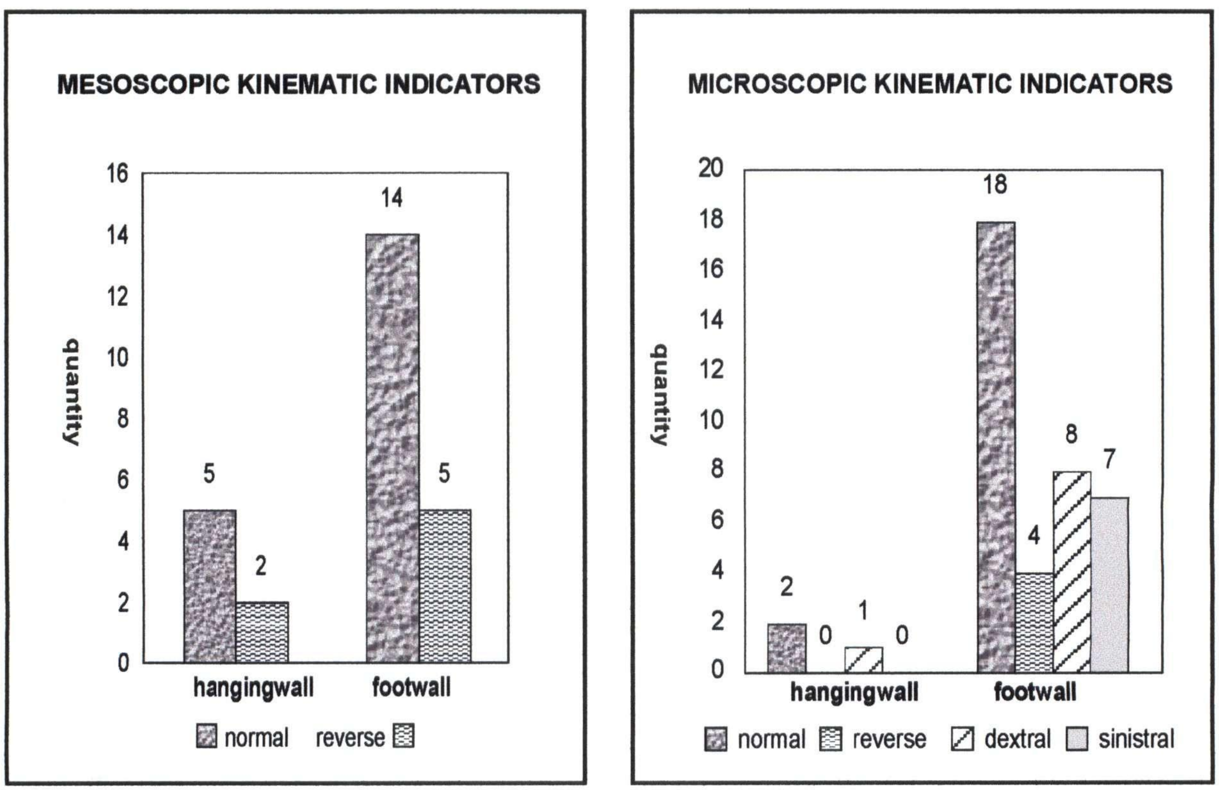


Figure 30: Histograms showing quantity of sample locations vs. shear sense.

Winged inclusions are present in many of the lower plate samples. Natural examples of winged porphyroclasts in samples from the study area were compared to experimental shapes to interpret the bulk sense of shear. Pressure shadows and winged porphyroblasts (mica fish) were used as kinematic indicators if other concurring shear sense indicators were present in the thin section. Monoclinic symmetry of a winged inclusion reflects the rotation of a stiff material in a relatively softer matrix while experiencing dynamic recrystallization (see Hanmer & Passchier, 1991). Passchier and Simpson (1986) and Van den Driessche and Brun (1987) have favorably modeled the response of stiff inclusions in a soft matrix. The models simulate the expected shapes of wings resulting from progressive simple shear.

Although the majority of inclusions did not have remarkable asymmetry or internal foliation, twenty samples contained winged porphyroclasts or porphyroblasts with distinctive monoclinic symmetry (figure 29). Normal separation is indicated by 82% of the kinematic samples, whereas 18% indicate reverse offset (figure 30b). Lineations are present in 13 of the porphyroclastic samples and reveal 8 examples of normal-dextral motion, 3 of normal-sinistral, and one each of reverse-dextral and reverse-sinistral. Monoclinic symmetry was not visible in thin sections cut perpendicular to foliation and lineation.

Two fabrics were found to crosscut the mylonitic foliation in lower plate rocks. The first is an incipient crenulation cleavage that is found in samples proximal to the Cayoosh Creek fault. The cleavage is approximately 50°-90° to the compositional and mylonitic foliation and is defined by opaque minerals or the axial planes of folded microlithons. The other type of fabric is by far more common. It is aligned 15°-30° to the compositional and mylonitic foliation. It is defined by the locus of opaques or micas, generally chlorite, but muscovite and biotite as well (figure 23b). This foliation is typically discontinuous and

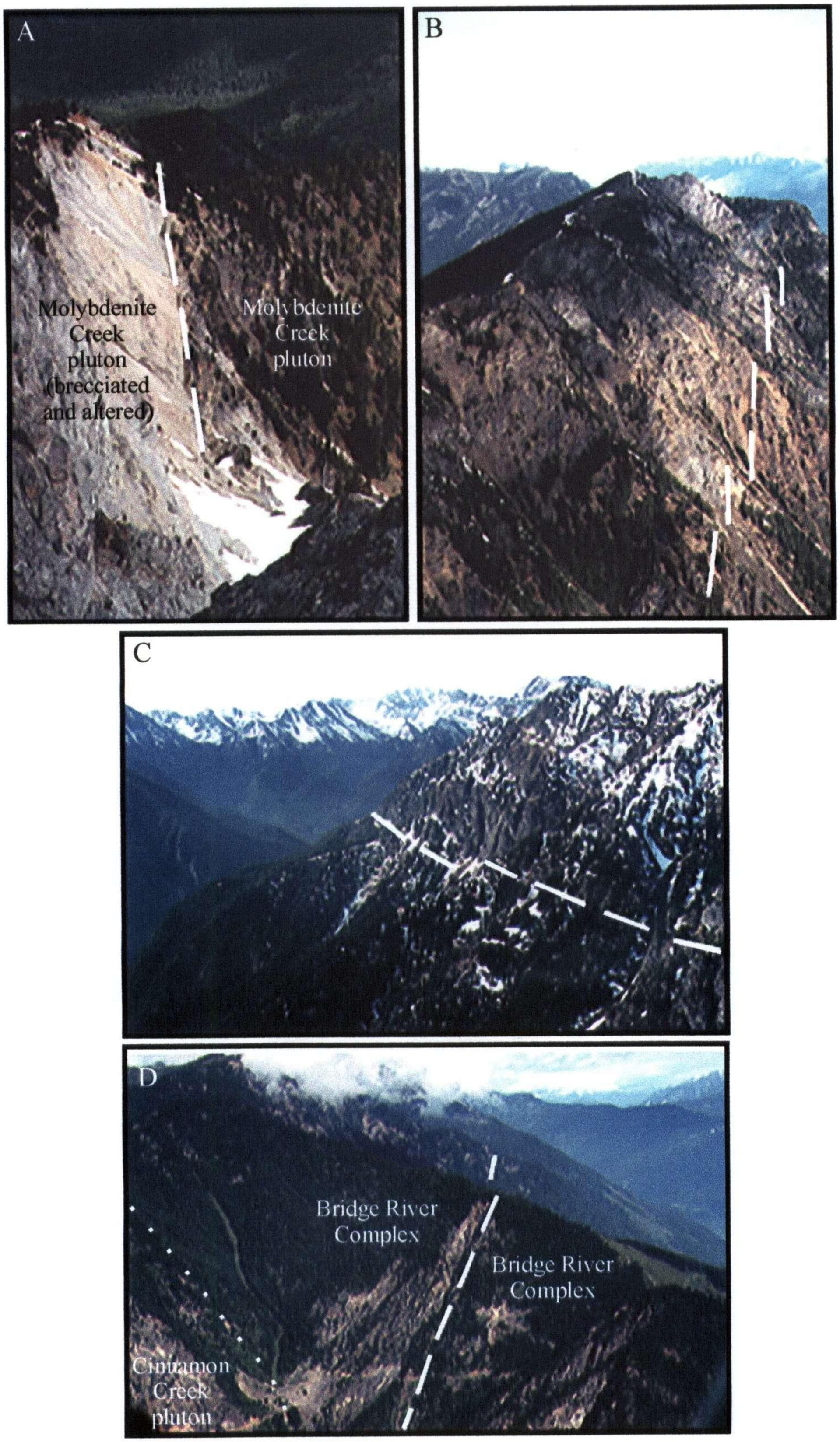


Figure 31: Phair Creek fault. A) Phair Creek fault near the headwaters of Phair Creek. View looking north. B) Vertical foliation in the Bridge River Complex on the western slopes of the Phair Creek valley. View looking north. C) Same as B; view looking south. D) Phair Creek fault north of Cayoosh Creek. View looking northwest.

irregularly spaced. Based on its composition and geometry, this fabric has been interpreted as an extensional shear band and used as a shear sense indicator (White et al., 1980; Hanmer & Passchier, 1991). Of the twelve thin sections containing shear bands, eleven suggested normal-oblique slip and one implied reverse slip. The one showing reverse slip was sampled within 100 meters of the Cayoosh Creek fault.

2.3 PHAIR CREEK FAULT

The Phair Creek fault is a steeply southwest-dipping to vertical structure that has a structural and geomorphic linearity for over 15 kilometers (figure 31). Colluvium conceals the relationship between the Cayoosh Creek and Phair Creek faults, but approximately 100 meters above the projected contact the Phair Creek fault clearly cuts shallow to moderate fabrics within the Bridge River Complex that are attributed to Cayoosh Creek fault deformation (figure 32). The Phair Creek fault juxtaposes Bridge River Complex in its hangingwall against Cayoosh Assemblage in its footwall, which—due to the structural inversion in the study area—indicates a degree of normal separation. 1:250,000 scale regional mapping by the Geological Survey of Canada inferred this fault was continuous with the shallowly dipping structure now recognized as the Cayoosh Creek fault (Monger and McMillan, 1989). This study does establish the exclusivity of these two structures, but does not attempt to map the fault north of Seton Lake or south of Molybdenite Creek.

North of Cayoosh Creek, the fault is characterized by an approximately three meter thick zone of cataclasite and silicification. Fault rocks have an anastomozing foliation, defined by solution transfer seams and a brittle cleavage (figure 33). The shear zone strikes roughly 330° and is steeply dipping to vertical (figure 21h). Semi-brittle fabrics—including slickenlines and Riedel shears—imply dextral-oblique slip has occurred. Surrounding the

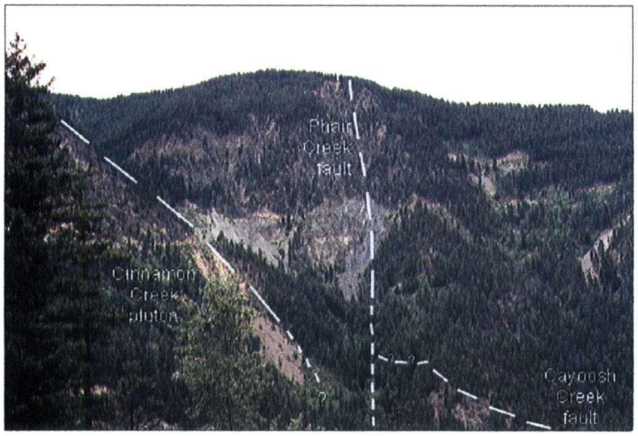


Figure 32: Relationship between the Cayoosh Creek fault, Phair Creek fault, and Cinnamon Creek pluton. View is to the north.

Figure 33: Phair Creek fault zone north of Cayoosh Creek. Fabric is vertical. Shear sense of fault shown at bottom left.

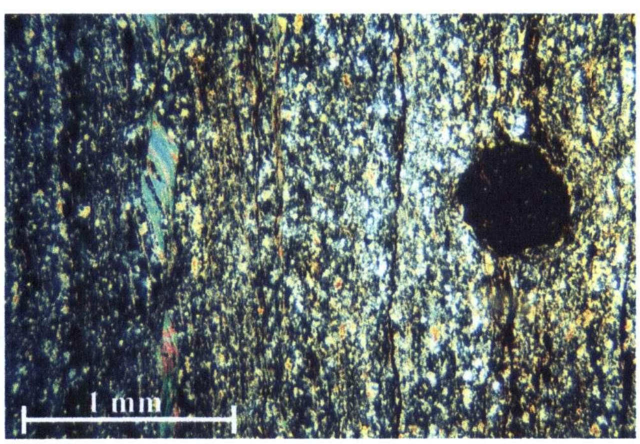


Figure 34: Mylonitic foliation in Molybdenite Creek pluton south of Texas Creek.

main fault zone is a concentration of mesoscopic brittle faults that persists for at least 10 meters to the west and east. These faults offset shallowly and moderately dipping fabrics within the Bridge River Complex.

For approximately 3 km south of Cayoosh Creek the fault is not exposed. However, rare outcrops of silicified granitic rocks occur near the inferred continuation of the fault, just east of homogeneous exposures of the Cinnamon Creek pluton. Alteration is extensive at this location, but a vertical foliation is preserved. Thin sections of a mylonite, sampled 400 meters east of the pluton, contain relict igneous textures and may be further evidence for the fault in this vicinity. The fault is again exposed on the western cliffs of the Phair Creek valley, and at the headwaters of Phair Creek the fault clearly cuts through the western margin of the Eocene Molybdenite Creek pluton (figure 31b). Here the fault occurs as a 10 meter thick, vertical zone of consolidated and unconsolidated breccia, wholly within the granodiorite. No more than five meters to the west of this margin is the Bridge River Complex-Molybdenite Creek pluton contact, which is characterized by hydrothermal alteration and a steep, penetrative ductile fabric. The intrusive contact is exposed to ridge south of the headwaters of Phair Creek, but the fault is not.

There are two other examples of steeply dipping shear zones involving the Molybdenite Creek pluton, but the relationship between these faults and the Phair Creek fault is indistinct. Near the confluence of Molybdenite and Texas Creeks the pluton has an intrusive contact with the Cayoosh Assemblage; however, the pluton has been internally deformed by a northwest-striking, nearly vertical ductile shear zone very near this margin (figure 15). South of Texas Creek, beyond the southern boundary of the study area, there is a vertical, northwest-striking shear zone that appears to be on strike with the Phair Creek fault to the north. Here the pluton has been dynamically recrystallized and has a strongly developed mylonitic foliation (figure 34). These two exposures may provide further evidence linking the Molybdenite Creek pluton to Eocene tectonism.

2.4 MARSHALL CREEK FAULT

In the study area the Marshall Creek fault is characterized by a steeply southwest-dipping mylonite zone in some places as wide as 30 meters (figure 20g). The shear zone is visible throughout the study area, and the linearity of separate exposures attests to the near-vertical geometry of the fault. Mesoscopic features such as winged augens and shear bands indicate a dextral-normal sense of shear. The fault cuts penetrative fabrics of the Bridge River Complex (Bridge River schist), which composes the footwall of the Marshall Creek fault within the boundaries of this study. The bulk of the study area is within the hangingwall of the Marshall Creek fault.

Lower plate foliation is defined by a schistose fabric and typically contains lower to middle greenschist facies metamorphic assemblages. Foliation generally strikes northwest and dips moderately to the southwest and northeast (figure 20h). Lineations are defined by aligned micas, and typically plunge shallowly to the southeast. The Bridge River schist does not display any of the melange-like characteristics typical in the hangingwall of the Cayoosh Creek fault. Felsic dikes can be observed when viewing Mission Ridge to the north from the southern shore of Seton Lake, which reveal the Bridge River schist is macroscopically isoclinally folded.

2.5 METAMORPHISM

The purpose of this section is to describe the metamorphism that accompanied deformation along the Cayoosh Creek fault. Textures of syn-deformational metamorphic minerals are used to estimate a temperature range during deformation. The common mineral assemblages within each map unit are used to evaluate peak metamorphic conditions, and pressure and temperature conditions of the lower plate of the Cayoosh Creek fault are constrained from a diagnostic mineral assemblage.

2.5.1 Hangingwall

Metamorphic grade is dominantly sub-greenschist in most of the study area. A typical mineral assemblage includes quartz, chlorite, albite, and often muscovite. Other common constituents are illite, graphite, prehnite and calcite. As both pelitic and metabasic rocks are present in the complex, the absence of actinolite and biotite suggests metamorphism is generally chlorite zone or prehnite-pumpellyite facies. Samples of the upper plate mylonite typically contain quartz, chlorite, muscovite, and albite, and less commonly biotite and epidote. Tremolite was identified in one sample of chert mylonite. These assemblages indicate peak metamorphism reached—but probably did not exceed—lower greenschist facies conditions.

Deformation of the hangingwall is expressed mainly through extensive quartz and calcite veining, solution transfer, and brittle fracture. Crack-seal geometries in quartz veins are not uncommon. Evidence for solution transfer includes illite and graphite seams, and pressure shadows on quartz and albite. Quartz in the rock matrix and in veins displays undulose extinction and rare serrate grain boundaries, indicating temperatures in the 200°-300° C range (Passchier and Trouw, 1996). Calcite twins are typically type I, indicative of temperatures less than 200° C, and rarely type II (~200°-300° C) (Burkhard, 1993). Quartz textures (including serrated grain boundaries and subgrains) in the upper plate mylonite are more indicative of temperatures in the 400° C range (Passchier and Trouw, 1996).

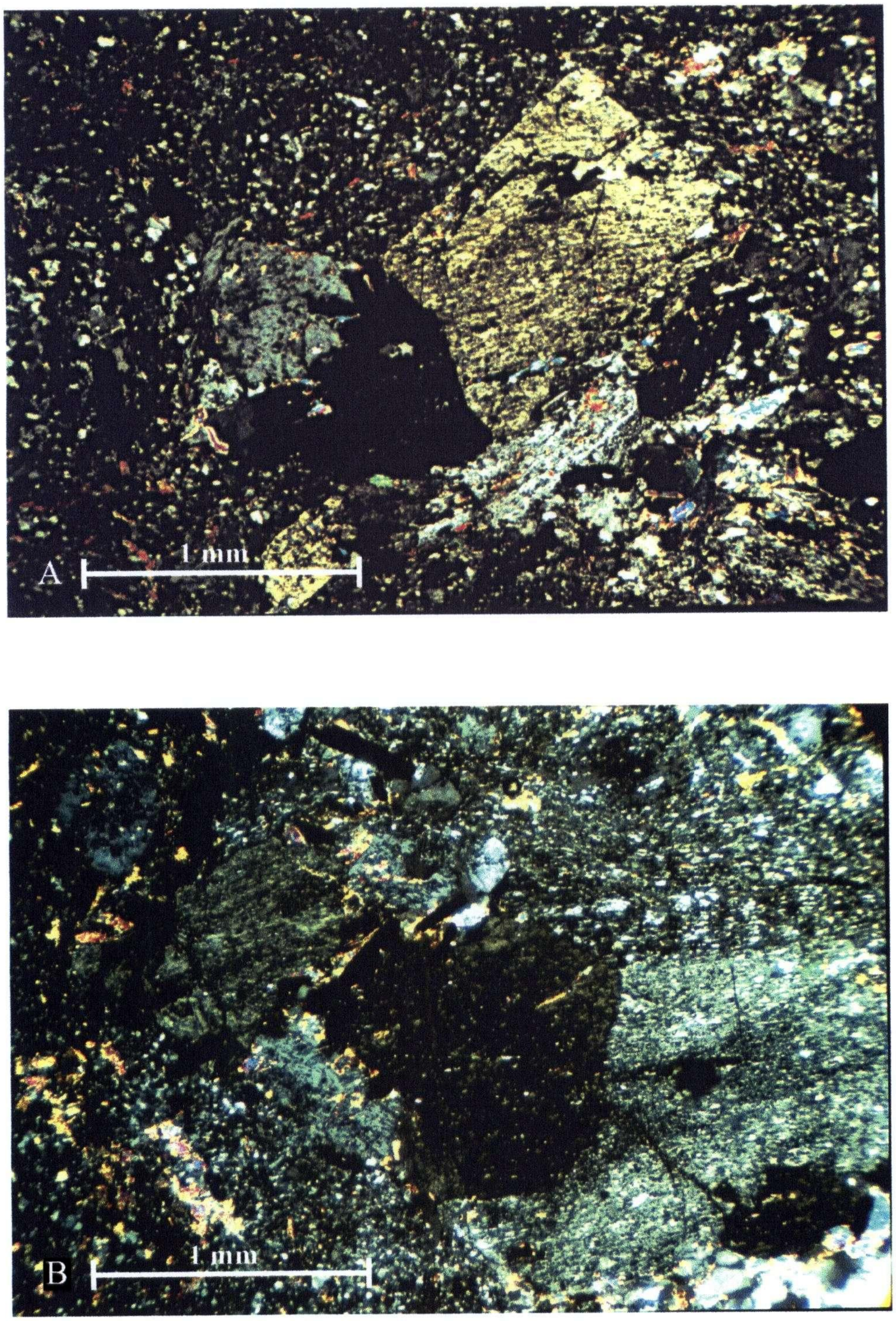


Figure 35: Photomicrographs of pressure-temperature assemblage. A) Large staurolite in center (partially extinct) with andalusite intergrowth at left. B) Staurolite in center, andalusite at upper left. Both have a groundmass of quartz and biotite.

2.5.2 Footwall

A greenschist mineral assemblage, including quartz, chlorite, muscovite, biotite, and albite is typical in most lower plate rocks. Also present are actinolite, hornblende, garnet, zoisite, staurolite, and andalusite, indicating metamorphism attained a peak of amphibolite facies in the footwall of the Cayoosh Creek fault. An assemblage of staurolite + andalusite + quartz + biotite was sampled approximately one kilometer east of the Molybdenite Creek pluton. The assemblage is syn-tectonic with foliation development in both the pluton and adjacent footwall rocks. The assemblage, shown in figure 35, constrains conditions in this portion of the footwall during peak metamorphism to between 550°-590° C and 1.8-2.9 kilobars (figure 36; Richardson, 1968; Holdaway, 1971; Spear, 1993).

Deformation textures in quartz in the lower plate include undulose extinction, flattened and elongate crystals, subgrains, and recrystallized grains with sutured grain boundaries—all indicative of dislocation creep (Passchier and Trouw, 1996). Feldspars display core and mantle structures which are believed to occur during dynamic recrystallization at temperatures greater than 400° C (Tullis and Yund, 1987). All types of calcite twins appear in Cayoosh Assemblage samples. Together, these textures are indicative of temperatures from 400° to 500° C. This is assumed a more reasonable temperature range for most lower plate metamorphism considering the previously mentioned assemblage would have been influenced by contact metamorphism.

2.6 GEOCHRONOLOGY

The crystallization ages of three intrusive bodies are discussed in this section. U-Pb zircon ages from two dikes and from the Cinnamon Creek pluton were determined in order to constrain the age of deformation attributed to the Cayoosh Creek and Phair Creek faults. A

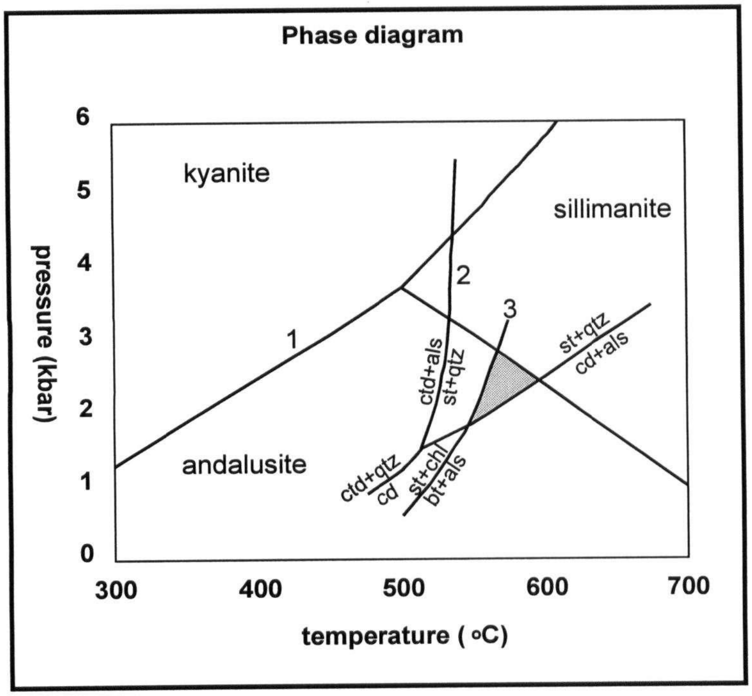


Figure 36: Phase diagram. Shaded where the assemblage staurolite +andalusite + quartz + biotite would be stable.
1) Holdaway, 1971.
2) Reactions II, III, and VI of Richardson, 1968.
3) Spear, 1993.

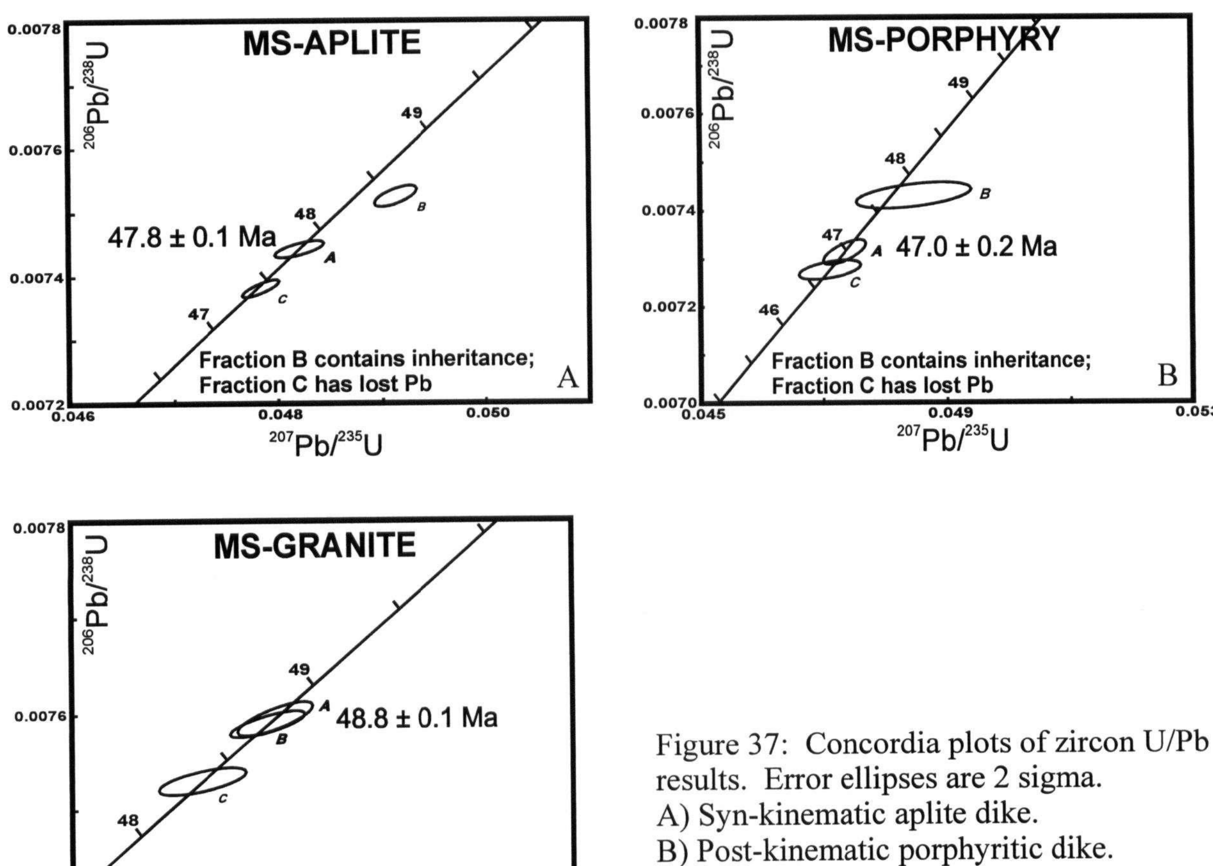


Figure 37: Concordia plots of zircon U/Pb results. Error ellipses are 2 sigma.
A) Syn-kinematic aplite dike.
B) Post-kinematic porphyritic dike.
C) Cinnamon Creek pluton.

strongly deformed aplite dike (MS-aplite) was chosen as a syn-kinematic feature, and a crosscutting and weakly deformed porphyritic dike (MS-porphyry) was chosen to provide an upper limit to movement on the Cayoosh Creek fault. Both dikes were sampled from the upper plate of the fault, and sample locations were within 400 meters of each other (figure 1). The Cinnamon Creek pluton (MS-granite) is cut by the Phair Creek fault and possibly contains ductile deformation related to fault movement. Analytical results are shown in figure 37 and analytical methods are described in Appendix 1.

2.6.1 Aplite Dike

Sample MS-aplite is a quartz-potassium feldspar dike that has been isoclinally folded within the hangingwall of the Cayoosh Creek fault. The dike has a shallow, southwest vergent axial surface and axial planar cleavage and best estimates of the fold axis indicate it trends northwest-southeast (figure 38). This is coaxial with most folds in the upper and lower plates of the fault. The sample location is latitude 50° 38.7', longitude 122° 5.7', and is approximately 150 m above the fault zone (figure 1). Three strongly abraded zircon fractions were analyzed.

Fraction A is concordant with a $^{206}Pb/^{238}U$ age of 47.8 ± 0.1 Ma. Fraction B shows evidence of inheritance, and plots below concordia at 48.5 Ma. Fraction C plots on concordia slightly below fraction A, at 47.4 Ma, and is interpreted to have experienced minor Pb loss. As fraction A represents the very best zircons available for analysis in this sample, 47.8 ± 0.1 Ma is considered the best estimate for the crystallization age of this dike.

2.6.2 Porphyritic Dike

Sample MS-porphyry is a quartz-feldspar-biotite porphyry dike with chlorite and calcite alteration. It is located at latitude 50° 38.9', longitude 122° 5.5', and is approximately

Figure 38: Hinge zone of an isoclinally folded aplite dike. Axial plane is parallel to the bottom edge of the photograph. Limb thickness approximately 2 m.

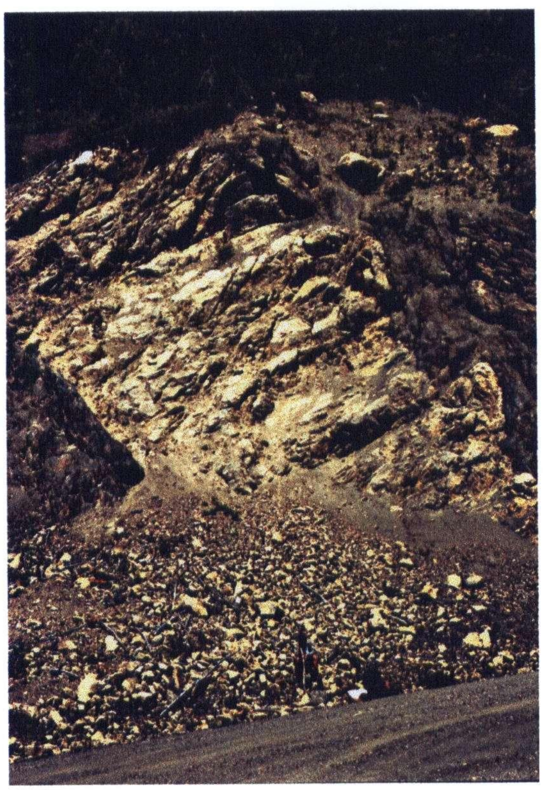


Figure 39: Crosscutting porphyritic dike. Wall rock foliation dips shallowly to the right (northeast).

200 m above the fault zone (figure 1). The dike crosscuts the phyllitic foliation of the surrounding wall rocks, but in places the contact between dike and country rock has been pulled obliquely into the foliation (figure 39). Three fractions of strongly abraded zircons were analyzed.

Fraction A yielded a concordant date of 47.0 ± 0.2 Ma. The error ellipse for fraction B overlaps concordia at 47.7 Ma, but is interpreted to contain a minor inherited zircon component. Fraction C plots slightly below, and overlaps with fraction A at 46.8 Ma. The slightly younger age is suggestive of minor Pb loss. The age of fraction A is therefore considered representative of the crystallization age of MS-porphyry, and implies that ductile displacement on the Cayoosh Creek fault had for the most part ended by 47.0 ± 0.2 Ma.

2.6.3 Cinnamon Creek Pluton

Sample MS-granite is a biotite and hornblende porphyritic granite to granodiorite. The sample was collected at latitude 50° 37.5', longitude 122° 06' (figure 1). The pluton is cut by, and is located in, the hangingwall of the Phair Creek fault. A thin section of a mylonite sampled near the projected extension of the fault in an area of poor outcrop shows relict igneous textures. Three fractions of strongly abraded zircons were analyzed.

Fractions A and B yielded overlapping concordant dates of 48.8 ± 0.1 Ma, indicating an Eocene crystallization age. Fraction C has lost Pb, and plots on concordia below A and B at 48.4 Ma.

CHAPTER 3

3.1 STRUCTURAL EVOLUTION

Three phases of deformation have been recognized in the study area. S_1 fabrics, defined by compositional layering, are interpreted to be the result of initial transposition of bedding probably related to the emplacement of older Bridge River Complex rocks above younger sediments of the Cayoosh Assemblage. The formation of S_1 occurred prior to the 48.8 Ma intrusion of the Cinnamon Creek pluton. It is likely that S_1 fabrics were generated during extensive mid-Cretaceous contraction of the Coast Belt, although for the most part these fabrics have been obliterated by later deformation. Macroscopic recumbent folds, including a kilometer-scale overturned antiform on Mt. Brew, are further indications of a regional thrusting event (Mustard, 1983; Journeay et al., 1992).

D_2 fabrics are the dominant structures in the study area. S_2 is represented by pervasive mylonitic deformation, L_2 by mineral and stretching lineations, and F_2 by northeast and southwest vergent isoclinal folds. D_2 fabrics must have begun to form prior to intrusion of both the Cinnamon Creek and Molybdenite Creek plutons. It is possible that intrusion of the plutons was largely syn-tectonic with D_2, as garnet, hornblende, staurolite, and andalusite porphyroblasts are both concordant with and overprint the foliation in areas proximal to the eastern margin of the Molybdenite Creek pluton. In addition, a syn-tectonic dike (47.8 Ma) records axial planar foliation and a fold axis coaxial with F_2 folds.

Whether D_2 was initially compressional or extensional is not explicit. Folds can occur from either mechanism, however, axial planar foliation (as seen within the 47.8 Ma aplite dike) is typically attributed to contraction. Some ductile kinematic indicators also record contraction. However, the dominant indicators in the ductile fabric suggest northwest or southeast directed extension. It is possible that the folding of the syn-tectonic dike, as well as the contractional indicators resulted from extension. Jiang and White (1995) advise *anticipation* of conflicting structures within the body of a shear zone since natural geologic situations are characteristically heterogeneous.

The dominant sense of shear on the Cayoosh Creek fault during D_2 was top-down-towards the northwest extension on a shallow, northeast-dipping foliation. Extension of the study area led to unroofing of higher grade metamorphic rocks in the lower plate of the Cayoosh Creek fault. The extension is possibly related to dextral strike-slip faulting on the Marshall Creek fault, shown by the very systematic transition of ductile fabrics between the two faults and an invariable lineation orientation. The brittle nature of the Phair Creek fault and the lack of constraints at the confluence of the Phair Creek and Cayoosh Creek faults preclude a definite kinematic link between these two faults.

The amount of displacement on the Cayoosh Creek fault is difficult to estimate because of the lack of pressure constraints in the upper plate of the fault. Temperatures in the hangingwall are constrained to 200°-300° C based on mineral assemblages and microstructures, and the absence of actinolite suggests the lower end of this range (Nitsch, 1971). Using an elevated continental geothermal gradient of 30° C/km, 200°-250° C corresponds to a depth of 6.6-8.3 kilometers. The footwall was deformed at depths of 7-11 kilometers, corresponding to a pressure gradient of 3.8 km/kbar (Bott, 1982). Using the same geothermal gradient above, temperatures of 400°-500° C are indicative of depths from 13-18 kilometers. Pressures are assumed to have been slightly higher at the onset of deformation, based on the interpretation that some fabric development preceded the intrusion of the Molybdenite Creek pluton and the country rock (footwall Cayoosh Assemblage) would have experienced some uplift prior to the crystallization of the staurolite + andalusite + quartz + biotite assemblage. Therefore, using an average footwall depth of 13 kilometers, the vertical separation of juxtaposed upper and lower plate rocks is 4.7-6.4 kilometers. With an average dip of 30°, this corresponds to a horizontal displacement of 8.1-11.1 km and 9.4-12.8 km of down-dip displacement on the Cayoosh Creek fault.

The latest pervasive deformation in the study area is represented by northwest and southeast trending open to gentle folds (F_3) with steep to upright axial planes (S_3). Mesoscopic F_3 folds (which have wavelengths on the order of meters to tens of meters) deform all D_2 fabrics and are probably responsible for the gentle fluctuations in foliation and lineation orientation. Although these fabrics deform D_2 structures, the coaxial orientations of fold axes and the absence of pervasive axial planar fabrics suggests D_3 may not be a distinct event, but somehow related to D_2.

3.2 TRANSPORT DIRECTION

Fabric orientations and shear sense indicators, largely found in the lower plate of the Cayoosh Creek fault, present an enigmatic account of fault deformation. Foliation attitudes, especially proximal to the main fault zone, are particularly shallow, in some areas horizontal. This could be expected for some dip-slip faults (low-angle normal faults and ramp-flat geometry of thrust faults). However, stretching lineations are strike-parallel to shallowly plunging, not down-dip. Horizontal to shallow lineations are expected for strike-slip faults, which are not typically shallowly dipping structures (Sylvester, 1988). It is generally accepted that the finite maximum extension direction of the strain ellipse is represented in nature by stretching lineations, and that with increasing strain linear elements will rotate towards parallelism with a shear zone boundary (figure 40; Ramsay, 1980).

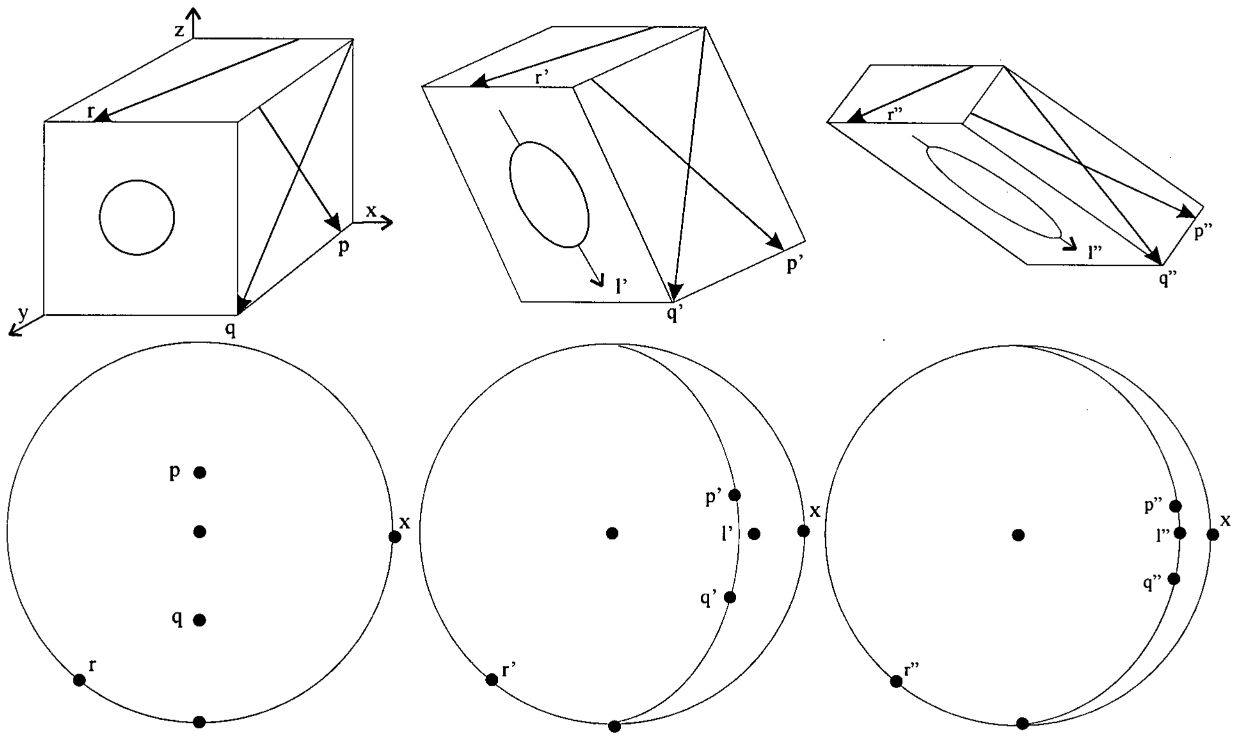


Figure 40: Deformation of lineations in ductile shear zones (from Ramsey, 1980). Shear is directed towards "x".

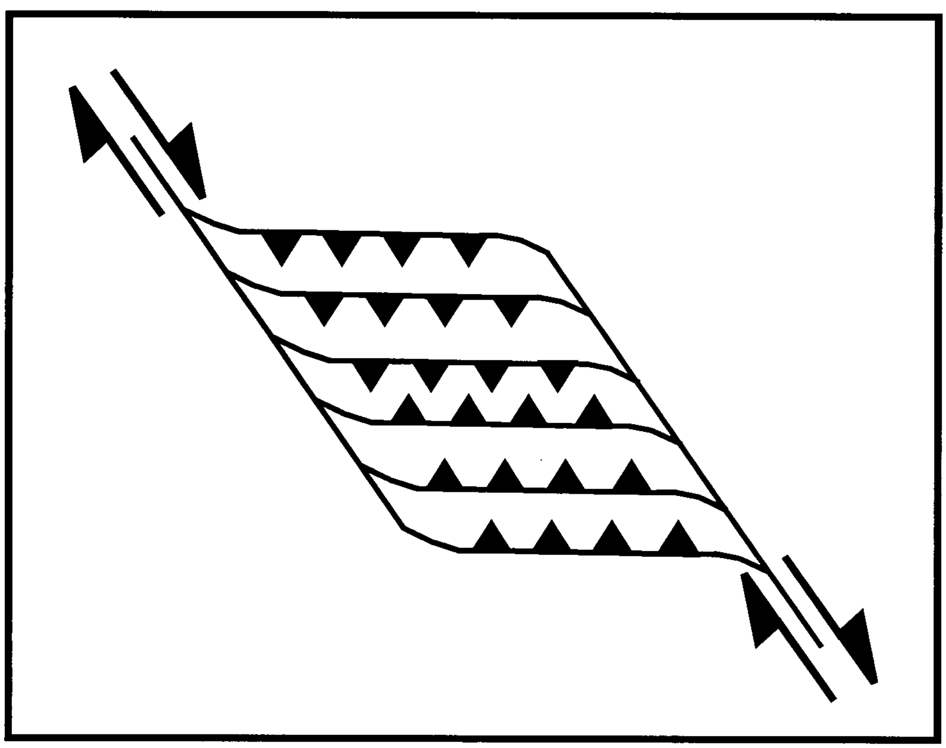


Figure 41: Left-stepping contractional duplex between two dextral strike-slip faults (modified from Twiss and Moores, 1992).

Lineations are often used to indicate slip direction, although whether they are a reliable indication of regional displacement direction is uncertain (McDonough & Simony, 1989; Ratschbacher et al., 1989; Tikoff & Teyssier, 1994; Miller & Paterson, *in prep.*). Whether pre-existing planar and linear features will rotate during progressive simple shear is mathematically tested by Skjernaa (1980). The model concludes that all linear elements will rotate towards the shearing direction (the extensional axis of the incremental strain ellipse), although very large shear strains are needed to reorient the features parallel the shearing direction. Planar features have complex rotations depending on the initial difference between the orientations of the plane and the shear zone, and the amount of shear strain. The strong maxima of mineral and stretching lineations throughout the study area, in addition to microstructural evidence, attests to the high degree of northwest-southeast directed strain in the lower plate of the Cayoosh Creek fault and therefore the attitude of stretching lineations is a reasonable assumption of transport direction.

3.3 DISCUSSION

There is no question that the study area is located within a complex structural regime. The study area lies at the eastern margin of the Coast Belt thrust system and at the western margin of the transcurrent Fraser fault system, both of which played significant roles in the deformation of this part of the Cordillera (figure 4). Additionally, extensional tectonics have been invoked for the Mission Ridge area to the north and the Intermontane Belt further east. The remainder of this chapter will address the origin of the predominant D_2 fabrics in the lower plate of the Cayoosh Creek fault. The regional significance of the Cayoosh Creek fault and how the study area relates to adjacent structural domains will also be discussed. Previous field-based, theoretical, and experimental studies are compared and contrasted with structures seen in the field area. Metamorphism, chronology, and regional influences in the southeastern Coast Belt in addition to structural evidence are used to formulate a conceptual model and geologic history of the Cayoosh Creek shear zone.

Three hypotheses are considered for the creation of the ductile D_2 fabrics. First, the low-angle fabrics in the footwall of the Cayoosh Creek fault may have been generated by a stepover between two overlapping bounding faults, the Marshall Creek and Phair Creek faults. Secondly, the shallowly dipping structures may be the result of oblique strike-slip movement on one or more bounding faults. A third model suggests that the low-angle fabrics were generated by ductile extension on the Cayoosh Creek fault itself.

3.3.1 Stepover model

Many mature strike-slip fault systems are characterized by broad zones across which movement occurs synchronously on different fault segments (Sylvester, 1988). Stepovers occur when slip is transferred between strike-slip fault segments through a series of distributed contractional or extensional features. Activity on the bounding faults overlaps, with concurrent deformation partially accommodated by structures in the stepover zone (Aydin and Nur, 1985). The attitudes of structures within the stepover zone depend on the geometric orientation of the overlapping fault segments or the obliquity of shear stresses (Sylvester, 1988; Krantz, 1995). Assuming the Phair Creek-Cayoosh Creek-Marshall Creek fault system was active synchronously, the geometric orientation of the Cayoosh Creek fault is ideal for a contractional stepover, since the Cayoosh Creek fault represents a left-step between two dextral-slip faults (figure 41). The transition of shallow to steep fabrics towards each of the bounding strike-slip faults suggests this is a reasonable assumption, at least for the latest movement on the Cayoosh Creek fault.

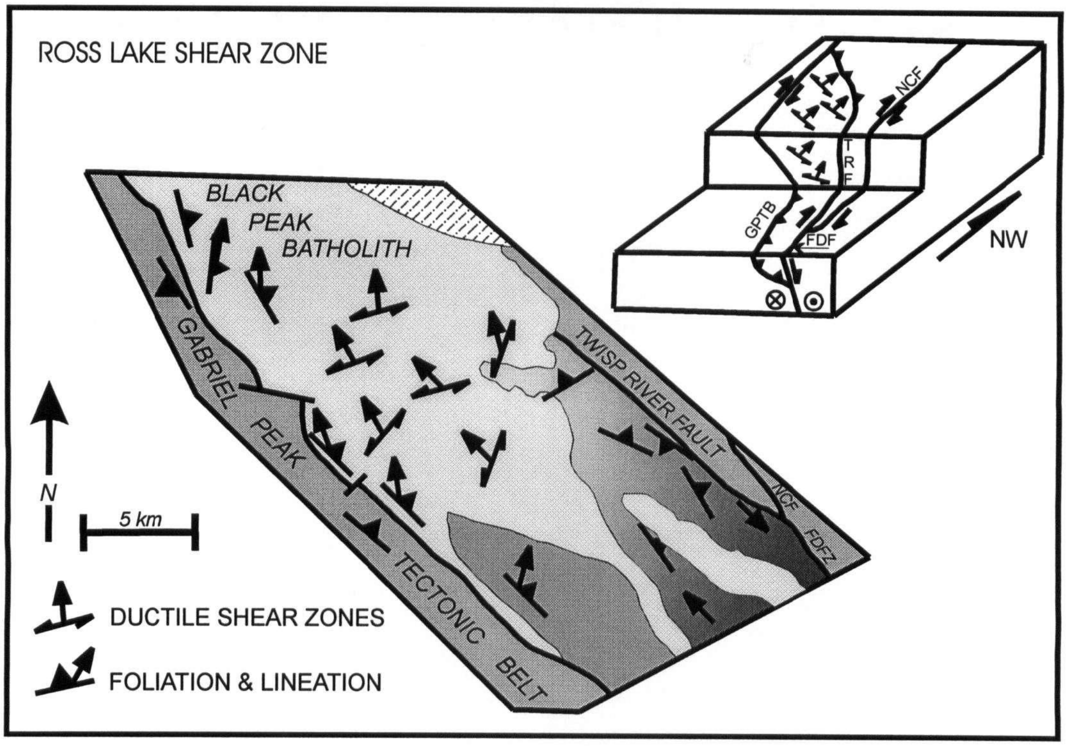


Figure 42: Ross Lake shear zone (from Miller, 1994).

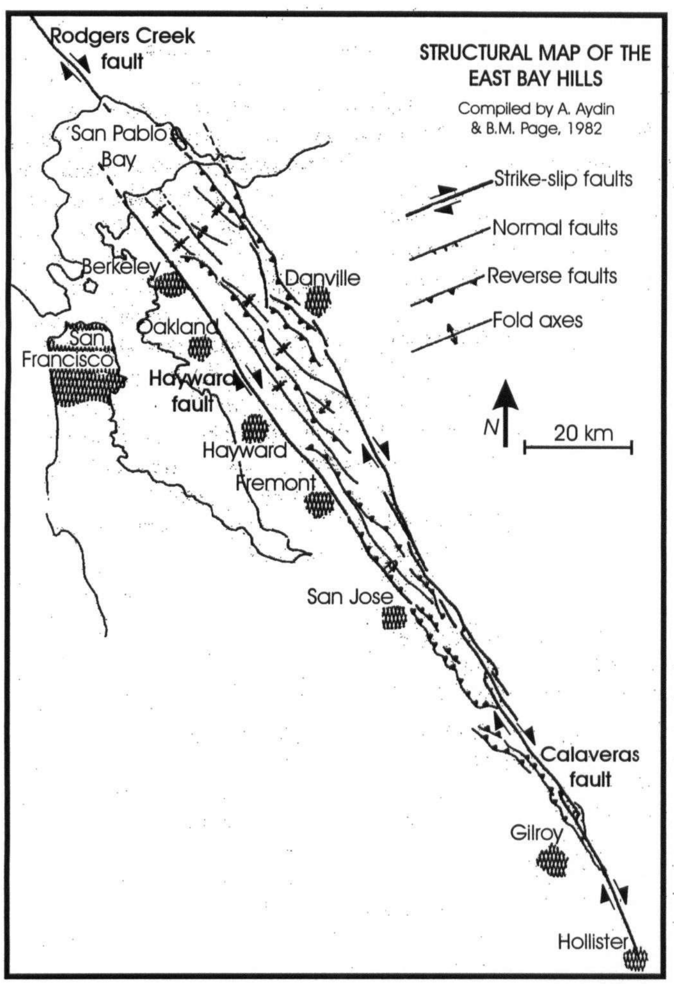


Figure 43: East Bay Hills compressional domain between the Calaveras and Hayward-Rodgers Creek fault zones (from Aydin and Page, 1984).

The Ross Lake fault zone, located in the northern Cascade mountains, is an appropriate model to illustrate a left-stepping dextral strike-slip shear zone (figure 42). The shear zone includes moderately to steeply dipping dextral transcurrent faults bounding an interior region of thrust faults and ductile shear zones. Miller (1994) presents a scenario in which Cretaceous-Paleogene strike-slip faulting, thrust faulting, and plutonism have an interactive relationship at mid-crustal levels. Evidence in support of a transfer of movement between the two northwest striking bounding structures—the Twisp River fault zone and the Gabriel Peak tectonic belt—includes geochronologic results, the left-stepping geometry of the system, abundance of otherwise rare mylonitic shear zones within the Black Peak batholith, and a change in structural orientations beyond the stepover zone. Reverse and dextral slip are believed to have occurred synchronously, demonstrated by a systematic transition from strike-parallel to down-dip stretching lineations within the Black Peak batholith, one of the plutonic bodies that occupies the core of the Ross Lake fault zone.

Unlike the Ross Lake fault zone, lineations in the footwall of the Cayoosh Creek fault have a consistent northwest-southeast trend, sub-parallel to strike, and only where there has been an isolated reorientation of foliation attitude do they ever plunge towards the dip direction. In addition, synchronous deformation in the core of the stepover zone and on the bounding faults—which is inherent in a stepover model—has not been definitively established for the Phair Creek-Cayoosh Creek-Marshall Creek fault system. Finally, the geometry of the system is ideal for a contractional stepover, yet ductile fabrics dominantly record extension. For these reasons a stepover-generated origin for the D_2 fabrics in the study area seems unlikely.

3.3.2 Oblique strike-slip model

Common results of oblique strike-slip fault zones are en echelon folds, push-up structures, reverse faults, or pull-apart basins and normal faulting. Contractional and extensional structures often develop simultaneously, in predictable orientations oblique to the through-going strike-slip faults (Wilcox et al., 1973; Krantz, 1995; Tikoff and Peterson, 1998). En echelon folds—widely studied because of their importance as hydrocarbon traps—are stretched parallel to their axes and compressed perpendicular to their axes. This is confirmed in many field-based and experimental studies (Wilcox et al., 1973; Tikoff and Peterson, 1998). The simultaneous formation of strike-slip and dip-slip faults during oblique strike-slip has also been demonstrated by physical experiments (Richard and Cobbold; 1989, 1990).

The East Bay Hills domain (east of San Francisco Bay) is a good example of an elongate zone of oblique strike-slip deformation (figure 43). Aydin and Page (1984) describe the area as a diffuse zone of dextral slip in which motion is accommodated not only on steeply dipping transcurrent faults, but also on high and low-angle thrust faults, folds, and normal faults. The Hayward and Calaveras faults both trend northwest to form a left-stepping configuration. Between the bounding faults are numerous north-northeast and south-southwest dipping thrust faults and en echelon folds. Fold axes are typically parallel to the trend of thrust faults, indicating some deformation must be oblique to the trend of the bounding faults. A concordance of thrust fault and fold vergence led Aydin and Page (1984) to conclude that the reverse faults and folds resulted from compression due to the overlapping geometry of the bounding faults.

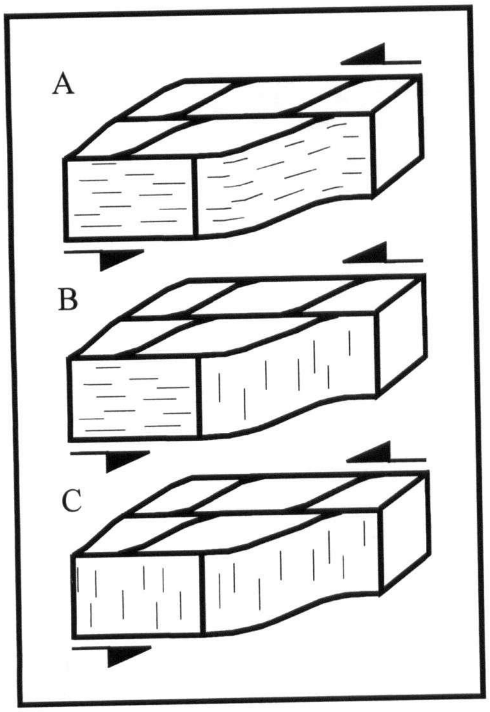


Figure 44: Possible lineation orientations in transpressional shear zones (from Tikoff and Greene, 1997). A) Simple shear dominated transpression. B) Partitioned simple shear and pure shear transpression. C) Pure shear dominated transpression.

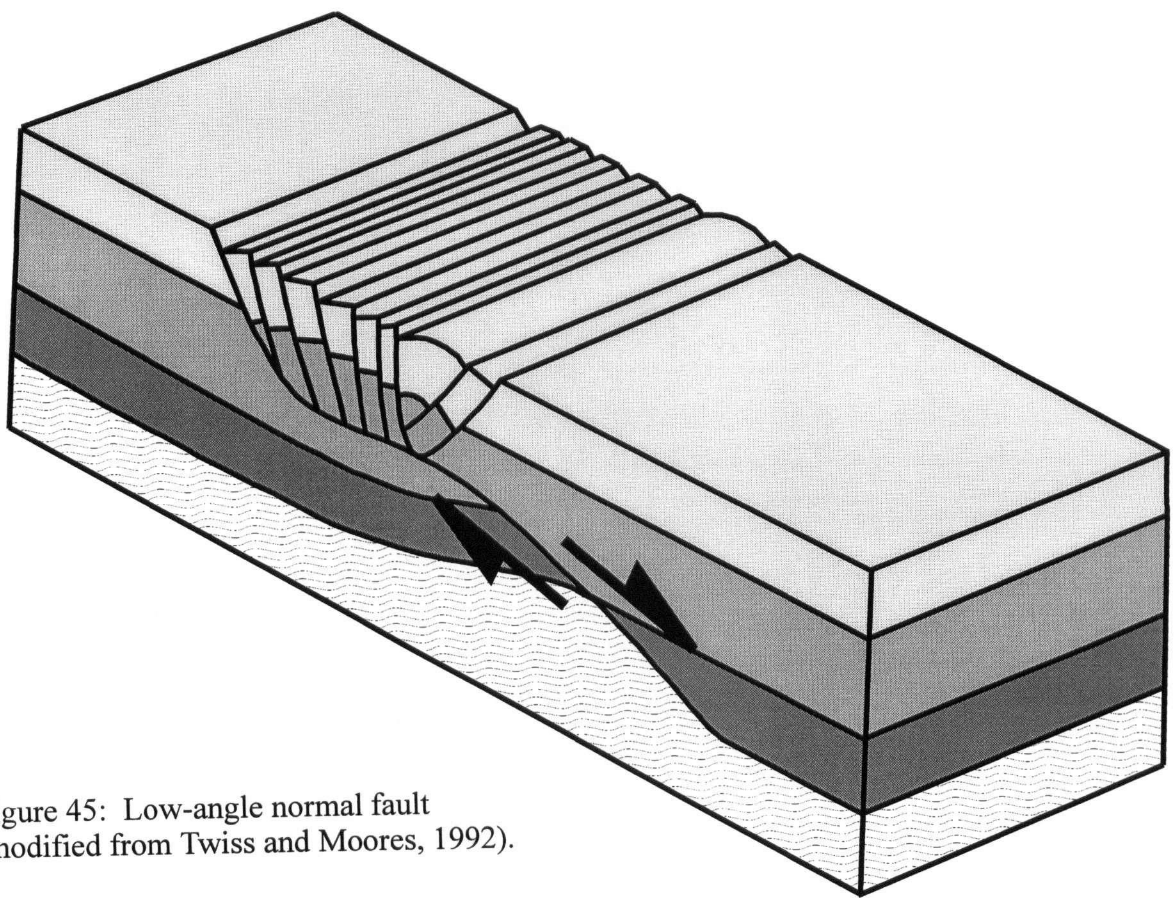


Figure 45: Low-angle normal fault (modified from Twiss and Moores, 1992).

Transpression and transtension, as defined by the most recent analyses, are distinct from oblique slip. They are classes of strike-slip deformation in which a component of horizontal shortening or extension is accommodated by sub-vertical extension or shortening, respectively (Tikoff and Teyssier, 1994; Tikoff and Greene, 1997; Dewey et al., 1998). Stresses are accommodated partially by pure shear and partially by simple shear, the proportions depending on the angle of convergence or divergence. Lineation orientations would depend on the dominance of one type of shear over the other, with vertical lineations forming in response to pure shear and horizontal lineations forming in response to simple shear (figure 44). Both orientations of lineations should occur, partitioned into areas dominated by pure or simple shear, if neither mechanism is favored by the bulk shear zone (Tikoff and Greene, 1997; Dewey et al., 1998).

The oblique strike-slip model shares some similarities with structures in the study area. There is a prevalence of folds and shear zones slightly oblique to the bounding strike-slip faults. Also, the trend of fold axes coincides with the trend of stretching lineations, implying overall extension has occurred parallel to the fold axes. However, there is a general rarity of contractional kinematic indicators and a distinct lack of contractional indicators perpendicular to F_2 axes. And, as mentioned previously, kinematic and chronologic evidence associating the Phair Creek fault with the Cayoosh Creek fault is inconclusive.

Transpression, as defined in the preceding paragraph, is also eliminated as a model for the study area because neither vertical lineations nor a change in lineation orientation have been documented. Field studies of a sub-vertical transpressional shear zone show that the trend of horizontal lineations rotates slightly between discrete shear planes as a result of slip transference (figure 44; Tikoff and Greene, 1997).

3.3.3 Low-angle extensional fault model

Cordilleran detachment faults, commonly associated with metamorphic core complexes, are low-angle extensional faults which typically juxtapose unmetamorphosed or low-grade metamorphic rocks above high-grade mylonites (Crittenden et al., 1980; Wernicke, 1981; Davis and Lister, 1988). Detachment faults typically accommodate large horizontal displacements (tens of kilometers) and are temporally associated with considerable magmatism. The faults are characterized as shallowly dipping ductile shear zones commonly with a brittle overprint (figure 45). Superposition of brittle over ductile microstructures occurs as the mylonites pass through a brittle-ductile transition as they are exhumed from beneath the extending hangingwall (Davis et al., 1986). The shear zones can be tens of meters thick, typically contain rocks originating in the lower plate, and are often underlain by a thin layer of cataclasite (Davis and Lister, 1988). Upper plate rocks are extended in a brittle manner, while the lower plate characteristically forms mylonitic gneisses.

The geometry of the Cayoosh Creek fault and nature of deformation in the upper and lower plates of the fault are similar in many respects to well-documented metamorphic core complexes (e.g. the Whipple detachment fault in the southwestern U.S.). Similarities include juxtaposition of lower metamorphic grade on higher metamorphic grade rocks, an intensely fractured upper plate, a mylonitic lower plate, parallel lineations and fold axes, and a low-angle shear zone composed of rocks containing both brittle and ductile deformation mechanisms (Davis et al., 1986). Davis and Lister (1988) propose that lineation-parallel folds in the lower plate of low-angle detachment faults are primary corrugations that develop during faulting. Fletcher and Bartley (1994) also point out the prevalence of these structures, but attribute them to constrictional strain parallel to the maximum extension direction.

The Cayoosh Creek fault has a domed geometry parallel to strike, another common feature of low-angle extensional faults (Davis et al., 1986). This is thought to result from thinning of the upper plate at faulting progresses, coupled with prevalent igneous activity below the shear zone (Lister and Davis, 1989). The geometry of the Cayoosh Creek fault perpendicular to strike is more difficult to ascertain (figure 1). Proximal to the shear zone the foliation is slightly reoriented and dips more north than northeast. Although the foliation is gently folded, enveloping surfaces of the mesoscopic folds typically dip to the north-northeast. However, there is a large structural domain from Mt. Brew south in which foliation dominantly dips to the southwest, implying that there is a structural culmination as well as an elevation peak at Mt. Brew.

Steep to vertical foliation attitudes are also unique to the southeastern portion of the study area. Thin sections of the Cayoosh Assemblage between the Molybdenite Creek pluton and the Marshall Creek fault display both a large degree of flattening and southeast-directed shear. Petrologic analyses from this area indicate syn-tectonic development of mylonitic fabrics in the 47.4 Ma Molybdenite Creek pluton and surrounding country rock. The geometric, metamorphic, and kinematic aspects of the Cayoosh Creek fault—as well as the occurrence of syn-deformational plutons—suggests the low-angle extensional fault model is an appropriate model for the evolution of the study area.

3.4 REGIONAL COMPARISONS

3.4.1 Mission Ridge area

The study area shares many similarities with the Mission Ridge area (figure 46). Ductile fabrics in deformed dikes and the Mission Ridge pluton in the lower plate of the Mission Ridge fault have been dated by U-Pb methods, and yield ages of 48.5-46.5 Ma

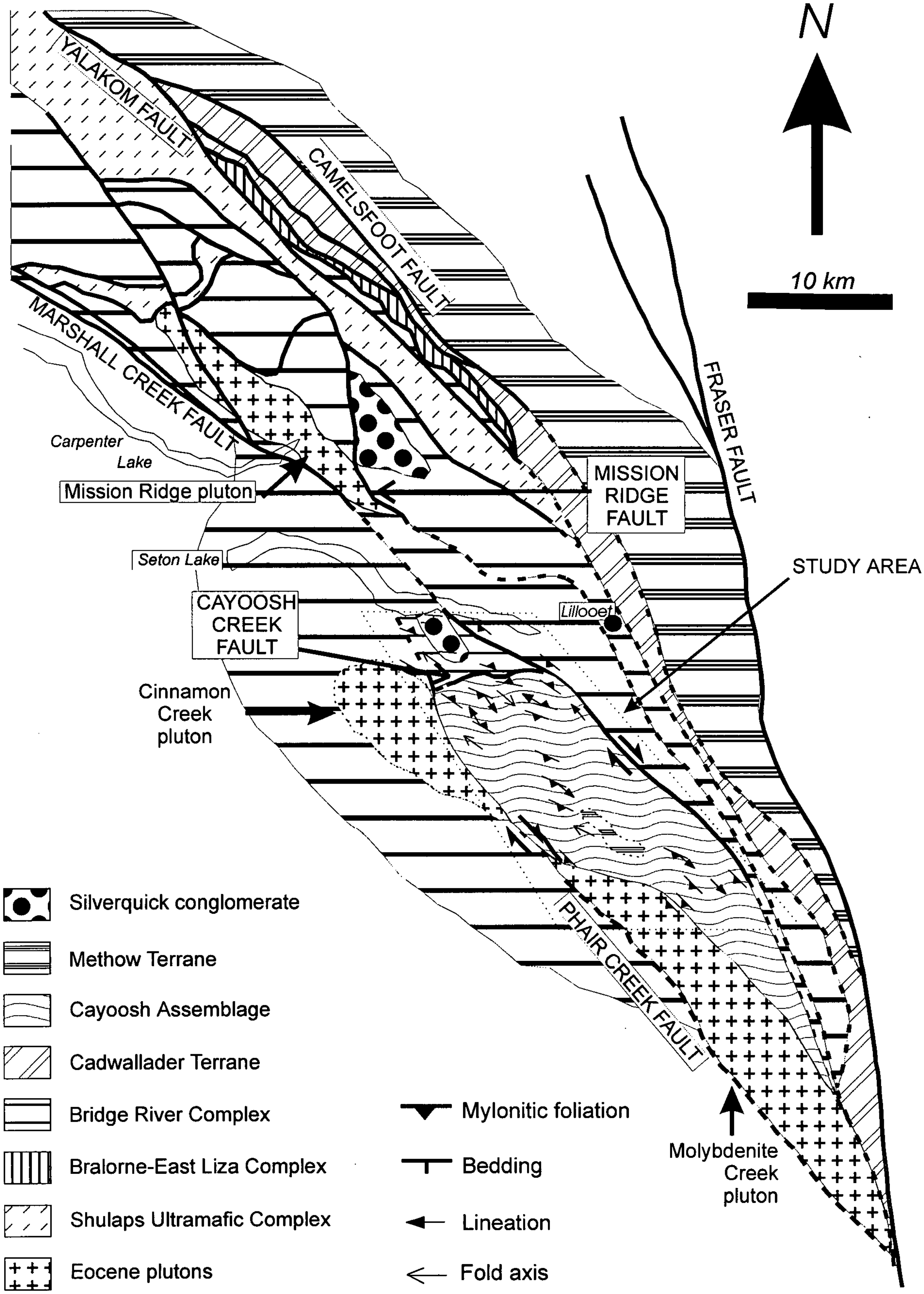


Figure 46: Geology and fault systems of the Mission Ridge and Cayoosh Creek areas (modified from Schiarizza et al., 1997).

(Coleman, 1990). Stereoplots of planar and linear data within the footwall of the Cayoosh Creek fault are nearly identical to those for the footwall of the Mission Ridge fault. The Mission Ridge fault also marks a metamorphic omission and juxtaposes prehnite-pumpellyite metamorphic grade rocks above upper greenschist facies rocks in its footwall. A conspicuous difference between the lower plates of the Cayoosh Creek and Mission Ridge faults is the interpretation of ductile extension in the footwall of the Cayoosh Creek fault.

The Bridge River schist and the Mission Ridge pluton, which constitute the lower plate of the Mission Ridge fault, both contain ductile northwest- and southeast-directed shear sense indicators (Coleman, 1990). Contrary to this study, Coleman (1990) and Coleman and Parrish (1991) conclude that the penetrative deformation and shear sense indicators in the lower plate of the Mission Ridge fault were derived from dextral-compression on the Yalakom fault. In support of dextral-compression on the Yalakom fault, Coleman (1990) concludes the moderately-dipping foliations in the lower plate of the Mission Ridge fault are the kinematic connection to a moderately-dipping Yalakom fault, however, Umhoefer and Schiarizza (1996) point out that Coleman's (1990) Yalakom fault was more likely a strand of the Camelsfoot thrust system (figure 4).

Top-down-to the northeast extension on the Mission Ridge fault is interpreted through an omission of metamorphic grades, slickenside lineations, and brittle normal faults parallel to and slightly above the Mission Ridge fault—but not by ductile elements (Coleman, 1990). Coleman (1990) and Coleman and Parrish (1991) believe the Mission Ridge fault was responsible for unroofing the higher grade and penetratively deformed fabrics in its footwall, but was not kinematically linked to the formation of the fabrics. Umhoefer and Schiarizza (1996) suggest that the Mission Ridge fault resulted from an extensional stepover from the Yalakom to the Marshall Creek fault. However, this fault system has a left-stepping geometry, which is a better position to accommodate compression. Schiarizza and others (1997) acknowledge this discrepancy, but point out that the commonly concordant brittle overprint on ductile structures may indicate that stresses involved in this transfer exploited the pre-existing anisotropy developed during the Early to Middle Eocene.

Alternatively, it is possible that the Mission Ridge fault is a brittle—and therefore shallow—expression of regional extension at deeper levels. Evolving metamorphic core complexes typically contain numerous brittle normal faults which actively extend colder, upper plate rocks while the lower plates are deformed by ductile mechanisms (Davis and Lister, 1988). In this interpretation, it is not necessary to invoke extension imposed on a geometry better suited for compression.

3.4.2 Tatla Lake metamorphic complex

The study area also shares metamorphic, geometric, kinematic, and chronologic similarities with the Tatla Lake metamorphic complex (figure 47). The complex, which is approximately 250 km northwest of the study area, contains a low metamorphic grade upper plate, a 1-2.5 km thick anticlinorial mylonitic shear zone, and an underlying gneissic and migmatitic core (Friedman and Armstrong, 1988). Structures in the shear zone include shallowly northwest and southeast plunging fold axes and stretching lineations on shallowly northeast and southwest dipping foliations. Metamorphism and deformation in the mylonitic shear zone has been constrained to 55-47.5 Ma (U-Pb zircon geochronology; Friedman and Armstrong, 1988). The age of the underlying migmatitic and gneissic rocks is constrained by the 79 ± 6 Ma One Eye Tonalite.

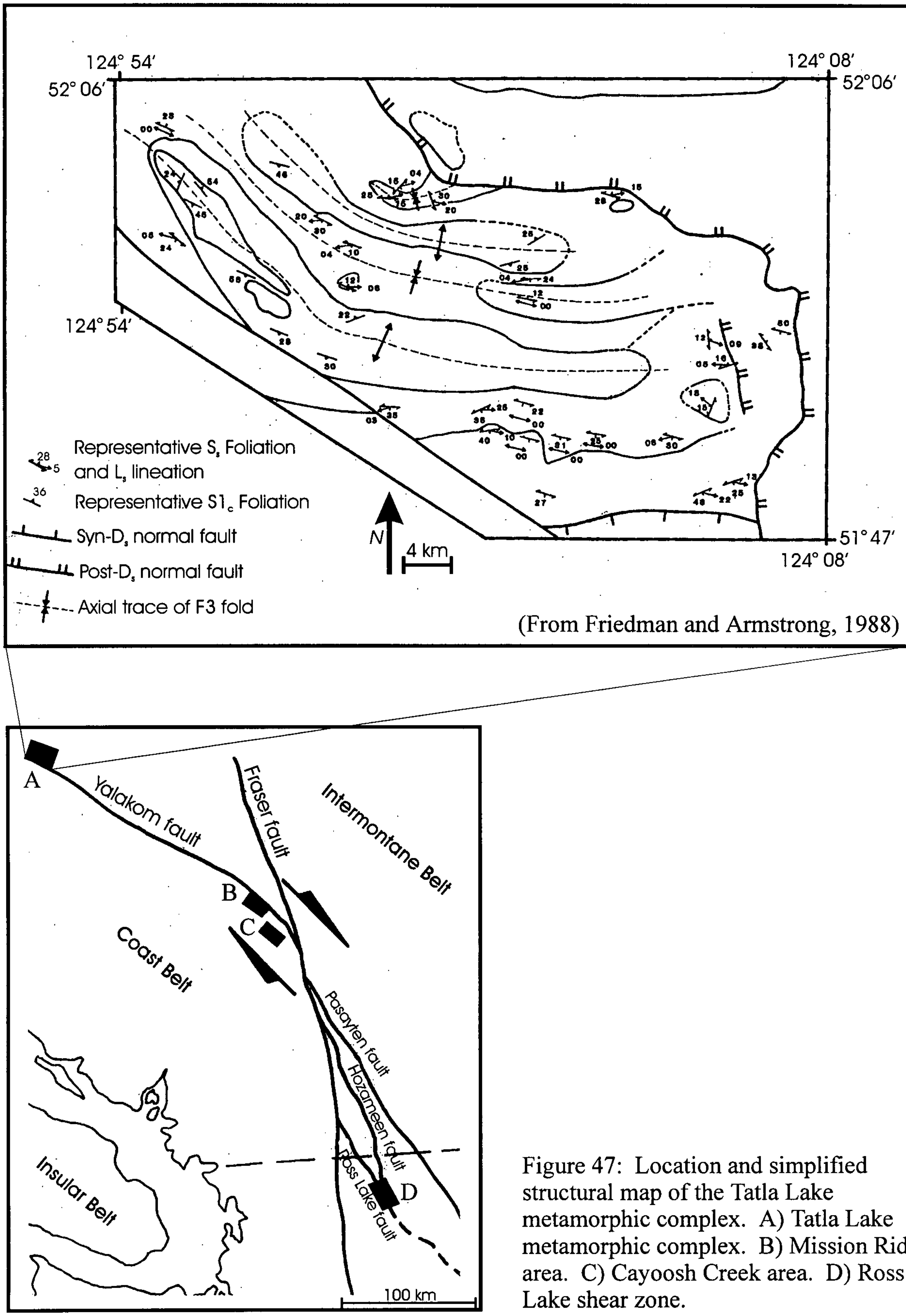


Figure 47: Location and simplified structural map of the Tatla Lake metamorphic complex. A) Tatla Lake metamorphic complex. B) Mission Ridge area. C) Cayoosh Creek area. D) Ross Lake shear zone.

Based on shear sense indicators and mesoscopic fold vergence, Friedman and Armstrong (1988) deduce a top-down-to the northwest sense of shear during the early to middle Eocene deformation event. They postulate that Cretaceous deformation in the gneisses (including the late syn-kinematic One Eye Tonalite) is related to regional compression. Overthickening in conjunction with thermal weakening from Eocene magmatism are suggested as driving forces behind extension in the Tatla Lake area (Friedman and Armstrong, 1988). Crustal thickening in the region probably occurred during an east-vergent contractional event in the Cretaceous (van der Heyden, 1982; Glover and Schiarizza, 1987; Rusmore and Woodsworth, 1988).

3.5 REGIONAL SIGNIFICANCE

After restoring Eocene offset on the Yalakom, Hozameen, and Fraser-Straight Creek fault systems, the study area lies in an elongate, northwest-trending metamorphic belt that coincides with the axis of the Eocene magmatic arc (figure 48). This metamorphic belt stretches from the Tatla Lake metamorphic complex to the northeastern Cascades metamorphic core (Umhoefer and Miller, 1996). Fabrics in the above mentioned regimes are generally similar. Foliation typically has a northwest-southeast strike and dips moderately to shallowly to the northeast and southwest. Lineation attitudes are often shallowly plunging and sub-parallel to foliation strike, except where isolated reorientation occurs in stepover zones (Umhoefer and Schiarizza, 1996; Miller, 1994). Apart from brittle down-to the northeast extension on the Mission Ridge fault, orogen-parallel extension and/or translation have been documented throughout this northwest-trending metamorphic regime.

Dextral translation was the dominant shear sense in the Ross Lake shear zone from 65-45 Ma, including contractional stepovers from 65-57 Ma and dextral-normal displacement

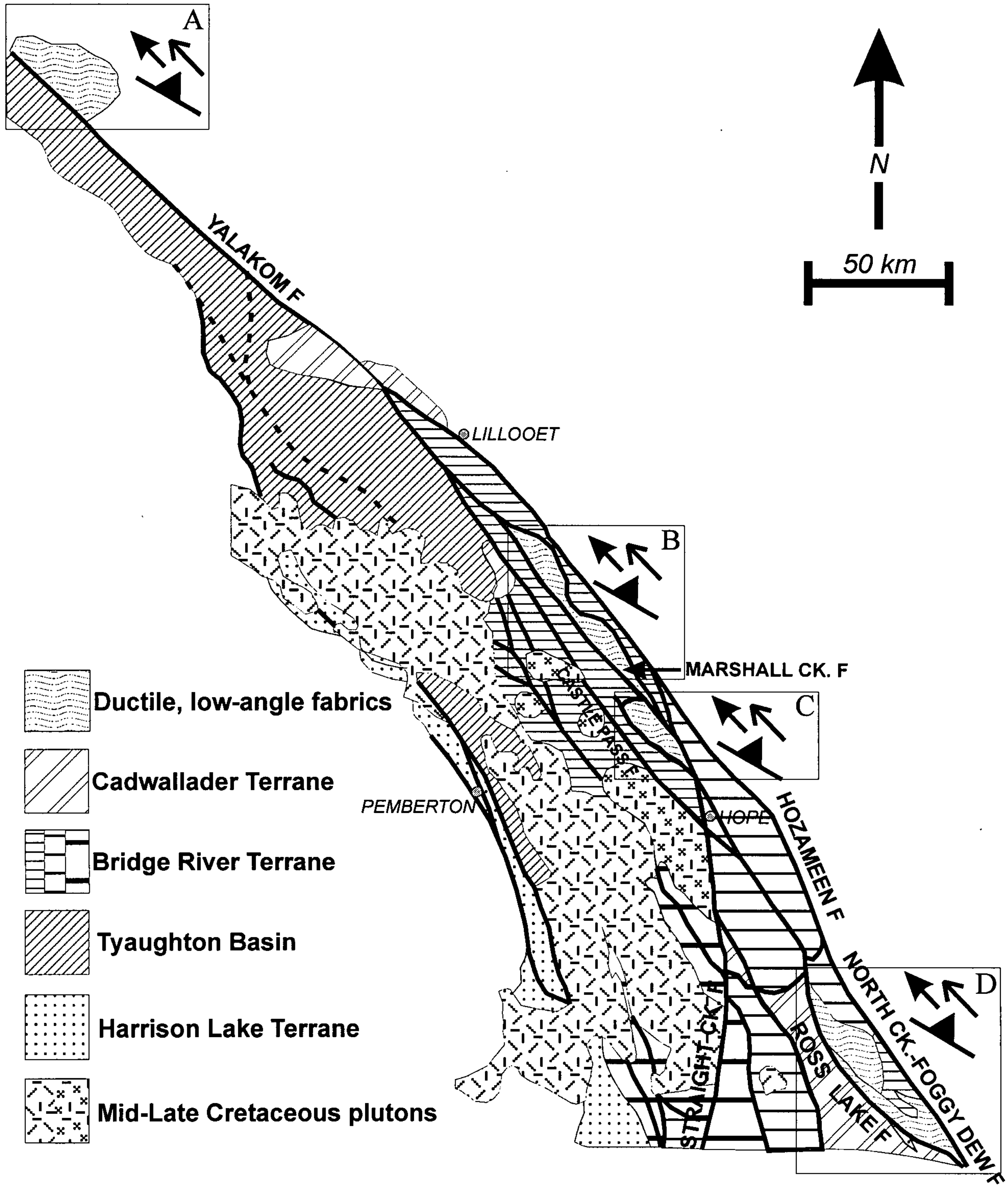


Figure 48: Reconstruction of Fraser, Yalakom, and Hozameen faults to post-Cretaceous locations (modified from Umhoefer and Miller, 1996). A) Tatla Lake metamorphic complex. B) Mission Ridge area. C) Study area. D) Ross Lake shear zone.

from 57-48 Ma (Miller and Bowring, 1990; Miller, 1994). The bulk of deformation on the Yalakom fault is constrained to 57-45 Ma, shifting from dominantly dextral strike-slip to dextral translation and extension around 46.5 Ma (Umhoefer and Schiarizza, 1996). Penetrative fabrics recording top-towards the northwest extensional shear in the Tatla Lake metamorphic complex were generated from 55-47.5 Ma (Friedman and Armstrong, 1988). Ductile fabrics in the Mission Ridge area were formed between 48.5-46.5 Ma, and extension on the Mission Ridge fault is younger than 46.5 Ma (Coleman, 1990; Coleman and Parrish, 1991). Penetrative deformation in the Cayoosh Creek area partially predates 48.8 and 47.4 Ma intrusions, but is mainly synchronous with the latter. Extension on the Cayoosh Creek fault had mostly ended by 47 Ma. Dextral strike-slip on the Marshall Creek fault post-dates the Cayoosh Creek and Mission Ridge faults and is principally constrained between 43 and 39 Ma (Garver et al., 1994).

Structural, kinematic, and chronologic affinities within this northwest-trending metamorphic belt support orogen-parallel extension and translation as dominant means of accommodation in the Early to Middle Eocene magmatic arc. Oblique-convergence on the plate margin was partitioned into inter-plate dip-slip and translational motion. Extension, accompanied by rapid exhumation, commonly follows compression and crustal thickening in many compressional orogenic belts (Platt and Vissers, 1989; Ratschbacher et al., 1989; Sosson et al., 1998). According to numerical models, extensional structures, as well as strike-slip and contractional, should form in response to oblique-convergent stresses (Sanderson and Marchini, 1984; Krantz, 1995). During the Early Eocene there was a slight change in the convergence angle between the North American and Pacific plates, which may have facilitated orogen-parallel extension and translation by alleviating some of orogen-normal stress (Engebretson et al., 1985).

Although extensional stepovers (Schiarizza et al., 1997) and brittle faulting (Coleman, 1990) may have instigated local unroofing and exhumation, the primary cause of regional extension was likely due to gravitational collapse of an overthickened and thermally weakened crust. Extension had significantly diminished by about 47 Ma, while dextral translation on the Coast-Intermontane margin continued into the Oligocene (Coleman and Parrish, 1991; Garver et al., 1994; Schiarizza et al., 1997).

CHAPTER 4

4.1 CONCLUSIONS

At least two phases of deformation are recorded by the Cayoosh Creek fault. D_1 placed Bridge River Complex rocks above the Cayoosh Assemblage, and most likely occurred during extensive southwest-vergent contraction in the mid- to Late Cretaceous. D_2 resulted in the mylonitic fabric (S_2), peak metamorphism, and ductile extension that now characterizes the footwall of the Cayoosh Creek fault. S_2 fabrics were generated at temperatures around 500° C and depths of 7-11 kilometers. The Cayoosh Creek fault accommodated approximately 10-12 kilometers of top-down-to the northwest displacement. Extension and exhumation resulted in the ascent of penetrative footwall fabrics through the brittle-ductile transition. Extensional deformation on the Cayoosh Creek fault is in many respects similar to metamorphic core complexes documented in southeastern British Columbia and the southwestern United States.

The Cayoosh Creek fault is integrally related to the dextral strike-slip fault system that includes the Yalakom, Marshall Creek, and Mission Ridge faults. Extension partially pre-dates dextral translation on the Marshall Creek fault but is essentially synchronous with most Middle Eocene strike-slip faulting and plutonism. The Phair Creek fault terminates the Cayoosh Creek fault to the west, but some deformation may be coeval. A lack of conclusive kinematic evidence linking the Phair Creek and Cayoosh Creek faults prevents an association between the Phair Creek fault and the regional fault system, although its geometry and shear sense suggests that it may be related. Further isotopic analyses on lower plate metamorphic rocks are needed determine the absolute age of penetrative deformation on the Cayoosh Creek fault as well as an exhumation rate.

The Cayoosh Creek fault—as well as the Tatla Lake metamorphic complex, Mission Ridge area, and Ross Lake shear zone—lies within a belt of high metamorphic grade and low-angle ductile deformation that coincides with the axis of the Eocene magmatic arc. Orogen-parallel extension and translation were the dominant means of accommodation during Early to Middle Eocene oblique-convergence on the plate margin. The likely cause of regional extension was gravitational collapse of an overthickened and thermally weakened crust, as well as a slight change in the relative motions of the North American and Pacific plates. Significant deformation on the Cayoosh Creek fault had diminished by 47.0 Ma but regional strike-slip faulting in the arc-axial belt continued into the Oligocene.

REFERENCES

Armstrong, R.L., 1988, Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera, Geological Society of America Special Paper, 218, p. 55-91

Aydin, A. and Page, B.M., 1984, Diverse Pliocene-Quaternary tectonics in a transform environment, San Francisco Bay region, California, Geological Society of America Bulletin, v. 95, p. 1303-1317

Aydin, A. and Nur, A., 1985, The types and role of stepovers in strike-slip tectonics, *in* Strike-slip Deformation, Basin Formation and Sedimentation, K.T. Biddle and N. Christie-Blick *eds.*, Society of Economic Paleontologists and Mineralogists, Special Publication 37, p. 35-44

Bott, M.H.P., 1982, The Interior of the Earth: its structure, constitution, and evolution, Second edition, Elsevier, New York, 403 pages

Burkhard, M., 1993, Calcite twins, their geometry, appearance and significance as stress-strain markers and indicators of tectonic regime; a review, Journal of Structural Geology, v. 15, n. 3-5, p. 351-368

Calon, T.J., Malpas, J.G., and MacDonald, R., 1990, The anatomy of the Shulaps ophiolite, *in* Geological Fieldwork, British Columbia Ministry of Energy, Mines, and Petroleum Resources, Paper 1990-1, p. 375-386

Coleman, M.E., 1989, Geology of Mission Ridge, near Lillooet, British Columbia (92I, J), *in* Geological Fieldwork, British Columbia Ministry of Energy, Mines, and Petroleum Resources, Paper 1989-1, p. 99-104

Coleman, M.E., 1990, Eocene dextral strike-slip and extensional faulting in the Bridge River terrane, southwest British Columbia, M.Sc. thesis, Carleton University, 87 pages

Coleman, M.E. and Parrish, R.R., 1991, Eocene dextral strike-slip and extensional faulting in the Bridge River terrane, southwest British Columbia, Tectonics, v. 10, p. 1222-1238

Cowan, D.S., 1994, Alternative hypotheses for the mid-Cretaceous paleogeography of the Western Cordillera, G.S.A. Today, v. 14, p. 181, 184-186

Crittenden, M.D., Coney, P.J., and Davis, G.H. (*eds.*), 1980, Cordilleran metamorphic core complexes, Geological Society of America Memoir 153, 490 pages

Davis, G.A., Lister, G.S., and Reynolds, S.J., 1986, Structural evolution of the Whipple and South mountains shear zones, southwestern United States, Geology, v. 14, p. 7-10

Davis, G.A. and Lister, G.S., 1988, Detachment faulting in continental extension; perspectives from the southwestern U.S. Cordillera, Geological Society of America Special Paper 218, p. 133-159

Dewey, J.F., Holdsworth, R.E., and Strachan, R.A., 1998, Transpression and transtension zones, *in* Continental Transpressional and Transtensional Tectonics, R.E. Holdsworth, R.A. Strachan, and J.F. Dewey *eds.*, Geological Society, London, Special Publication 135, p. 1-14

Duffell, S. and McTaggart, K.C., 1952, Ashcroft map area, British Columbia, Geological Survey of Canada memoir 262, 122 pages

Engebretson, D.A., Cox, A., and Gordon, R.R., 1985, Relative motion between ocean and continental plates in the Pacific Basin, Geological Society of America Special Paper, 206, 55 pages

Fletcher, J.M. and Bartley, J.M., 1994, Constrictional strain in a non-coaxial shear zone: implications for fold and rock fabric development, central Mojave metamorphic core complex, California, Journal of Structural Geology, v. 16, n. 4, p. 555-570

Friedman, R.M. and Armstrong, R.L., 1988, Tatla Lake metamorphic complex: an Eocene metamorphic core complex on the southwestern edge of the Intermontane Belt of British Columbia, Tectonics, v. 7, n.6, p. 1141-1166

Gabrielse, H., 1985, Major dextral transcurrent displacements along the northern Rocky Mountain trench and related lineaments in north central British Columbia, Geological Society of America Bulletin, v. 96, p. 1-14

Garver, J.I., 1989, Basin evolution and source terranes of Albian-Cenomanian rocks in the Tyaughton Basin, southern British Columbia: implications for mid-Cretaceous tectonics in the Canadian Cordillera, Ph.D. thesis, University of Washington, 227 pages

Garver, J.I., 1991, Kinematic analysis and timing of structures in the Bridge River complex and overlying Cretaceous sedimentary rocks, Cinnabar Creek area, southwest British Columbia (92J/15), in Geologic Fieldwork 1990, British Columbia Ministry of Energy, Mines, and Petroleum Resources, paper 1991-1, p. 65-74

Garver, J.I., Archibald, D.A., and Van Order, W.F., 1994, Late Cretaceous to Paleogene cooling adjacent to strike-slip faults in the Bridge River area, southern British Columbia, based on fission-track and Ar-Ar analyses, *in* Current Research, 1994-A, Geological Survey of Canada, p. 177-183

Gehrels, G.E. and Saleeby, J.B., 1987, Geologic framework, tectonic evolution, and displacement history of the Alexander terrane, Tectonics, v. 6, p. 151-173

Glover, J.K. and Schiarizza, P., 1987, Geology and mineral potential of the Warner Pass map sheet (92O/3), British Columbia Ministry of Energy, Mines, and Petroleum Resources, paper 1987-1, p. 157-169

Hanmer, S. and Passchier, C., 1991, Shear-sense indicators: a review, Geological Survey of Canada, paper 90-17, 72 pages

Holdaway, M.J., 1971, Stability of andalusite and the aluminum silicate phase diagram, American Journal of Science, v. 271, summer, p. 97-131

Irving, E. and Wynne, P.J., 1991, Paleomagnetism: review and tectonic implications, Chapter 3 of Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C.J. Yorath *eds.*, Geological Survey of Canada, Geology of Canada, n. 4, p. 63-86

Jeletzky, J.A. and Tipper, H.W., 1968, Upper Jurassic and Cretaceous rocks of the Taseko Lakes map area and their bearing on the geological history of southwestern British Columbia, Geological Survey of Canada, Paper 67-54, 218 pages

Jiang, D. and White, J.C., 1995, Kinematics of rock flow and the interpretation of geological structures, with particular reference to shear zones, Journal of Structural Geology, v. 17, n. 9, p. 1249-1265

Journeay, J.M., 1990, A progress report on the structural and tectonic framework of the southern Coast Belt, British Columbia, *in* Current Research, Part E, Geological Survey of Canada, Paper 90-1E, p. 183-195

Journeay, J.M., 1993, Tectonic assemblages of the Eastern Coast Belt, southwestern British Columbia: implications for the history and mechanisms of terrane accretion, *in* Current Research, Part A, Geological Survey of Canada, Paper 93-1A, p. 221-233

Journeay, J.M. and Csontos, L., 1989, Preliminary report on the structural setting along the southeast flank of the Coast Belt, British Columbia, *in* Current Research, Part E, Geological Survey of Canada, Paper 89-1E, p. 177-187

Journeay, J.M. and Northcote, B.R., 1992, Tectonic assemblages of the Eastern Coast Belt, southwest British Columbia, *in* Current Research, Part A, Geological Survey of Canada, Paper 92-1A, p. 215-224

Journeay, J.M. and Friedman, R.M., 1993, The Coast Belt thrust system: Evidence of late Cretaceous shortening in southwestern British Columbia, Tectonics, v. 12, p. 756-775

Journeay, J.M. and Mahoney, J.B., 1994, Cayoosh Assemblage: regional correlations and implications for terrane linkages in the southern Coast Belt, British Columbia, *in* Current Research, 1994-A, Geological Survey of Canada, p. 165-175

Journeay, J.M., Sanders, C., Van-Konijnenburg, J.H., and Jaasma, M., 1992, Fault systems of the Eastern Coast Belt, southwest British Columbia, *in* Current Research, Part A, Geological Survey of Canada, Paper 92-1A, p. 225-235

Kelley, K.P. and Engebretson, D.C., 1994, Updated relative motions and terrane trajectories for North American and oceanic plates: Cretaceous to present, Abstracts with Programs, Geological Society of America Annual Meeting, p. A-459

Krantz, R.W., 1995, The transpressional strain model applied to strike-slip, oblique-convergent and oblique-divergent deformation, Journal of Structural Geology, v. 17, n. 8, p. 1125-1137

Leech, G.B., 1953, Geology and mineral deposits of the Shulaps Range, British Columbia Ministry of Energy, Mines, and Petroleum Resources, Bulletin 32, 54 pages

Mahoney, J.B. and Journeay, J.M., 1993, The Cayoosh Assemblage, southwestern British Columbia, *in* Current Research, Part A, Geological Survey of Canada, Paper 93-1A, p. 235-244

McDonough, M.R. and Simony, P.S., 1989, Valemount strain zone: a dextral oblique-slip thrust system linking the Rocky Mountain and Omineca belts of the southeastern Canadian Cordillera, Geology, v. 17, p. 237-240

McGroder, M.F., 1991, Reconciliation of two-sided thrusting, burial metamorphism, and diachronous uplift in the Cascades of Washington and British Columbia, Geological Society of America Bulletin, v. 103, p. 189-209

Miller, M.G., 1988, Possible pre-Cenozoic left-lateral slip on the Yalakom fault, southwestern British Columbia, Geology, v. 16, p. 584-587

Miller, R.B. and Bowring, S.A., 1990, Structure and chronology of the Oval Peak batholith and adjacent rocks: implications for the Ross Lake fault zone, North Cascades, Washington, Geological Society of America Bulletin, v. 102, p. 1361-1377

Miller, R.B., 1994, A mid-crustal contractional stepover zone in a major strike-slip system, North Cascades, Washington, Journal of Structural Geology, v. 16, p. 47-60

Monger, J.W.H., 1985, Structural evolution of the southwestern Intermontane Belt, Ashcroft and Hope map areas, British Columbia, *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 349-358

Monger, J.W.H., 1986, Geology between Harrison lake and Fraser River, Hope map area, southwestern British Columbia, *in* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, p. 699-706

Monger, J.W.H., 1989, Geology, Hope, British Columbia (92H), G.S.C. Map 41-1989

Monger, 1991, Correlation of the Settler Schist with the Darrington phyllite and Shuksan greenschist and its tectonic implications, Coast and Cascade Mountains, British Columbia and Washington, Canadian Journal of Earth Sciences, v. 28, p. 447-458

Monger, J.W.H. and McMillan, W.J., 1989, Geology, Ashcroft, British Columbia (92I), Geological Survey of Canada Map 42-1989

Monger, J.W.H. and Journeay, J.M., 1994, Guide to the geology and tectonic evolution of the southern Coast Mountains, Geological Survey of Canada Open File 2490, 77 pages

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera, Geology, v. 10, p. 70-75

Monger, J.W.H., van der Heyden, P., Journeay, J.M., Evenchick, C.A., and Mahoney, J.B., 1994, Jurassic-Cretaceous basins along the Canadian Coast Belt: their bearing on pre-mid-Cretaceous sinistral displacements, Geology, v. 22, p. 175-178

Monger, J.W.H. and Nokleberg, W.J., 1996, Evolution of the northern North American Cordillera: generation, fragmentation, displacement and accretion of successive North American plate-margin arcs, *in* Coyner, A.R. and Fahey, P.L. eds., Geology and Ore deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 1133-1152

Mortensen, J.K., Ghosh, D., and Ferri, F., 1995, U-Pb geochronology of intrusive rocks associated with copper-gold porphyry deposits in the Canadian Cordillera, *in* Porphyry deposits of the northwestern Cordillera of North America, T.G. Schroeter, *ed.*, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, p. 142-160

Mulligan, G., 1998, Fluid flow across the Cayoosh Creek fault, near Lillooet, British Columbia: constraints from structural data and $^{18}O/^{16}O$, $^{13}C/^{12}C$ stable isotope analysis, B.Sc. thesis, University of British Columbia, 68 pages

Mustard, J.F., 1983, The geology of the Mount Brew area, Lillooet, British Columbia, B.Sc. thesis, University of British Columbia, 74 pages

Nitsch, K.H., 1971, Stabilitätsbeziehungen von prehnit-und pumpellyit-haltiger paragenesen, Contributions to Mineralogy and Petrology, v. 30, p. 240-260

Parrish, R.R., Carr, S.D., and Parkinson, D.L., 1988, Eocene extensional tectonics and geochronology of the southern Omineca Belt, British Columbia and Washington, Tectonics, v. 7, p. 181-212

Passchier, C.W. and Trouw, R.A.J., 1996, Microtectonics, Springer-Verlag, Berlin, 289 pages

Passchier, C.W. and Simpson, C., 1986, Porphyroclast systems as kinematic indicators, Journal of Structural Geology, v. 8, n. 8, p. 831-843

Platt, J.P. and Vissers, R.L.M., 1989, Extensional collapse of thickened continental lithosphere, Geology, v. 17, p. 540-543

Potter, C.J., 1983, Geology of the Bridge River Complex, southern Shulaps range, British Columbia: a record of Mesozoic convergent tectonics, Ph.D. thesis, University of Washington, 192 pages

Potter, C.J., 1986, Origin, accretion, and postaccretionary evolution of the Bridge River Terrane, southwest British Columbia, Tectonics, v. 5, p. 1027-1041

Ramsay, J.G., 1980, Shear zone geometry: a review, Journal of Structural Geology, v. 2, p. 83-99

Ratschbacher, W.F., Neubauer, F., Schmid, S.M., and Neugebauer, J., 1989, Extension in compressional orogenic belts: the eastern Alps, Geology, v. 17, p. 404-407

Richard, P. and Cobbold, P., 1989, Structures en fleur positives et décrochements crustaux: modélisation analogique et interprétation méchanique, Comptes Rendus de l'Academie des Sciences, Serie 2, Méchanique, Physique, Chimie, Sciences de l'Univers, Sciences de la Terre, v. 308, n. 6, p. 553-560

Richard, P. and Cobbold, P., 1990, Experimental insights into partitioning of fault motions in continental convergent wrench zones, Annales Tectonicae, v. 4, n. 2, p. 35-44

Richardson, S.W., 1968, Staurolite stability in a part of the system Fe-Al-Si-O-H, Journal of Petrology, v. 9, part 3, p. 467-488

Roddick, J.A., 1987, Coast Plutonic Complex, *in* Cordilleran cross-section: Calgary to Vancouver, R.A. Price *ed.*, IUGG XIX General Assembly Guidebook for excursion A1

Roddick, J.A. and Hutchison, W.W., 1973, Pemberton (east half) map area, British Columbia, Geological Survey of Canada, Paper 73-17, 21 pages

Roddick, J.A. and Woodsworth, G.J., 1975, Coast Mountains project, Pemberton (92J west half) map area, British Columbia, in Report of Activities, Geological Survey of Canada, Paper 75-1, p. 37-40

Rusmore, M.E., 1985, Geology and tectonic significance of the Upper Triassic Cadwallader Group and its bounding faults, southwestern British Columbia, Ph.D. thesis, University of Washington, Seattle, 174 pages

Rusmore M.E. and Woodsworth, G.J., 1988, Eastern margin of the Coast Plutonic Complex, Mount Waddington map area (92N), British Columbia, Geological Survey of Canada, Paper 88-1E, p. 185-190

Rusmore, M.E. and Woodsworth, G.J., 1991, Coast Plutonic Complex: a mid-Cretaceous contractional orogen, Geology, v. 19, p. 941-944

Rusmore, M.E., Potter, C.J., and Umhoefer, P.J., 1988, Middle Jurassic terrane accretion along the western edge of the Intermontane superterrane, southwestern British Columbia, Geology, v. 16, p. 891-894

Sanderson, D.J. and Marchini, W.R.D., 1984, Transpression, Journal of Structural Geology, v. 6, p. 449-458

Schiarizza, P., Gaba, R.G., Glover, J.K., and Garver, J.I., 1989, Geology and mineral occurrences of the Tyaughton Creek area (92O/2, 92J/15, 16), British Columbia Ministry of Energy, Mines, and Petroleum Resources, paper 1989-1, p. 115-130

Schiarizza, P., Gaba, R.G., Coleman, M., Garver, J.I., and Glover, J.K., 1990, Geology and mineral occurrences of the Yalakom River area (92O/1, 2, 92J/15, 16), British Columbia Ministry of Energy, Mines, and Petroleum Resources, paper 1990-1, p. 53-72

Schiarizza, P., Melville, D.M., Riddell, J., Jennings, B.K., Umhoefer, P.J., and Robinson, M.J., 1995, Geology and mineral occurrences of the Tatlayoko Lake map area (92N/8, 9, 10), British Columbia Ministry of Energy, Mines, and Petroleum Resources, paper 1995-1, p. 297-320

Schiarizza, P., Gaba, R.G., Glover, J.K., Garver, J.I., and Umhoefer, P.J., 1997, Geology and mineral occurrences of the Taseko-Bridge River area, B.C. Ministry of Employment and Investment, Energy and Minerals Division, Geological Survey Branch, Bulletin 100, 292 pages

Skjernaa, L., 1980, Rotation and deformation of randomly oriented planar and linear structures in progressive simple shear, Journal of Structural Geology, v. 2, n. 1-2, p. 101-109

Sosson, M., Morillon, A.C., Bourgois, J., Féraud, G., Poupeau, G., and Saint-Marc, P., 1998, Late exhumation stages of the Alpujarride Complex (western Betic Cordilleras, Spain): new thermochronological and structural data on Los Reales and Ojen nappes, Tectonophysics, v. 285, p. 253-273

Spear, F.S., 1993, Metamorphic phase equilibria and pressure-temperature-time paths, Mineralogical Society of America Monograph, 799 pages

Sylvester, A.G., 1988, Strike-slip faults, Geological Society of America Bulletin, v. 100, p. 1666-1703

Tabor, R.W., Frizzell Jr., V.A., Vance, J.A., and Naeser, C.W., 1984, Ages and stratigraphy of Lower and Middle Tertiary sedimentary and volcanic rocks of the Central Cascades, Washington: application to the tectonic history of the Straight Creek fault, Geological Society of America Bulletin, v. 95, p. 26-44

Tikoff, B. and Teyssier, C., 1994, Strain modeling of displacement-field partitioning in transpressional orogens, Journal of Structural Geology, v. 16, n. 11, p. 1575-1588

Tikoff, B. and Greene, D., 1997, Stretching lineations in transpressional shear zones: an example from the Sierra Nevada Batholith, California, Journal of Structural Geology, v. 19, n. 1, p. 29-39

Tikoff, B. and Peterson, K., 1998, Physical experiments of transpressional folding, Journal of Structural Geology, v. 20, p. 661-672

Tullis, J. and Yund, R.A., 1987, Transition from cataclastic flow to dislocation creep of feldspar; mechanisms and microstructures, Geology, v. 15, p. 606-609

Twiss, R.J. and Moores, E.M., 1992, Structural Geology, W.H. Freeman and Company, New York, 532 pages

Umhoefer, P.J. and Miller, R.B., 1996, Mid-Cretaceous thrusting in the southern Coast Belt, British Columbia and Washington, after strike-slip fault reconstruction, Tectonics, v. 15, n. 2, p. 545-564

Umhoefer, P.J. and Schiarizza, P., 1996, Latest Cretaceous to early Tertiary dextral strike-slip faulting on the southeastern Yalakom fault system, southeastern Coast Belt, British Columbia, Geological Society of America Bulletin, v. 108, p. 768-785

van den Driessche, J. and Brun, J.P., 1987, Rolling structures at large shear strain, Journal of Structural Geology, v. 9, n. 5-6, p. 691-704 van der Heyden, P., 1982, Tectonic and stratigraphic relations between the Coast Plutonic Complex and Intermontane Belt, west-central British Columbia, M.Sc. thesis, University of British Columbia, Vancouver, 172 pages

van der Heyden, P.,1992, A middle Jurassic to Early Tertiary Andean-Sierran arc model for the Coast Belt of British Columbia, Tectonics, v. 11, p. 82-97

Wernicke, B., 1981, Low-angle faults in the Basin and Range province—Nappe tectonics in an extending orogen, Nature, v. 291, p. 646-648

White, S.H., Burrows, S.E., Carreras, J., Shaw, N.D., and Humphreys, F.J., 1980, On mylonites in ductile shear zones, Journal of Structural Geology, v. 2, n. 1-2, p. 175-187

Wilcox, R.E., Harding, T.P., and Seely, D.R., 1973, Basic wrench tectonics, American Association of Petroleum Geologists Bulletin, v. 57, p. 74-96

APPENDIX 1: U/PB GEOCHRONOLOGY

Analytical techniques

U-Pb geochronological work for this study was undertaken in the Geochronology Laboratory at the University of British Columbia. Samples weighing approximately 10 kilograms each were collected for U-Pb zircon dating. Zircons were separated using conventional crushing, grinding, Wilfley table and heavy liquid methods. The zircons were subsequently separated into various magnetic fractions using a Frantz isodynamic magnetic separator and sieved into several size fractions. Grains were selected for analysis from the coarsest, least magnetic, most fracture- and inclusion-free material available. The selected grains were then strongly air abraded prior to dissolution to remove outer portions of the grains that might be susceptible to post-crytallization Pb-loss. Sample dissolution, separation and purification of U and Pb, mass spectrometry and error analysis was as described by Mortensen et al. (1995). All errors are quoted at the 2 σ level. Analytical data are reported in Table 1.

Table 1: U-Pb analytical data

Sample Description[1]	Wt (mg)	U (ppm)	Pb (ppm)[2]	$^{206}Pb/^{204}Pb$ (meas.)[3]	total common Pb (pg)	% ^{208}Pb[4]	$^{206}Pb/^{238}U$* (± % 1σ)	$^{207}Pb/^{235}U$* (± % 1σ)	$^{207}Pb/^{206}Pb$* (± % 1σ)	$^{206}Pb/^{238}U$ age (Ma; ± % 2 σ)	$^{207}Pb/^{206}Pb$ age (Ma; ± % 2σ)
Sample MS-Aplite											
A: N2,+134,a	0.086	646	4.92	2104	12	11.9	0..00744(0.09)	0.04821(0.24)	0.04697(0.19)	47.8(0.1)	47.7(9.0)
B: N2,+134,a	0.116	776	5.96	2472	17	11.7	0.00753(0.11)	0.04913(0.21)	0.04735(0.16)	48.3(0.1)	66.9(7.4)
C: N2,+134,a	0.101	797	6.01	2990	13	11.9	0.00738(0.09)	0.04783(0.19)	0.04700(0.12)	47.4(0.1)	49.1(5.7)
Sample MS-Porphyry											
A: N2,+134,a	0.115	252	1.92	910	15	13.6	0.00731(0.18)	0.04735(0.37)	0.04695(0.28)	47.0(0.2)	46.9(13.2)
B: N2,+134,a	0.041	219	1.65	390	11	10.9	0.00743(0.18)	0.04847(0.95)	0.04731(0.88)	47.7(0.2)	64.9(41.6)
C: N2,+134,a	0.098	335	2.48	698	22	11.6	0.00728(0.14)	0.04711(0.54)	0.04695(0.48)	46.7(0.1)	46.8(22.8)
Sample MS-Granite											
A: N2,+134,a	0.145	679	5.19	2048	23	10.5	0.00760(0.12)	0.04921(0.23)	0.04699(0.16)	48.8(0.1)	48.8(7.4)
B: N2,+134,a	0.091	669	5.11	2071	14	10.4	0.00759(0.09)	0.04917(0.23)	0.04698(0.17)	48.7(0.1)	48.4(7.9)
C: N2,+134,a	0.085	712	5.43	1780	16	11.1	0.00753(0.09)	0.04878(0.27)	0.04698(0.22)	48.4(0.1)	48.2(10.4)

[1] N1, N2 = non-magnetic at n degrees side slope on Frantz magnetic separator; grain size given in microns; a = abraded
[2] radiogenic Pb; corrected for blank, initial common Pb, and spike
[3] corrected for spike and fractionation as determined from replicate analyses of NBS common Pb standards
[4] corrected for 2-7 pg blank Pb and 1 pg blank U, and initial common Pb.

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