Nature of the basement to Quesnel Terrane near Christina Lake, southeastern British Columbia

S.L. Acton, P.S. Simony, and L.M. Heaman

Abstract: The character of the Paleozoic basement of Quesnel Terrane and the position of the terrane accretion surface that separates Quesnel and Kootenay terranes from rocks of the ancient North American margin are subjects of debate. To address these problems, detailed mapping and U–Pb geochronologic studies were carried out in the Christina Lake area to define the relationship of the Mollie Creek assemblage, Josh Creek diorite, and Fife diorite to similar lithologies in the Greenwood – Grand Forks and Rossland regions, and to place limits on the ages of regional deformation and local position of the terrane accretion surface. Deformed metasedimentary rocks of the Mollie Creek assemblage may correlate with sedimentary rocks of the Pennsylvanian to Early Triassic Mount Roberts Formation in the Rossland area. The Mollie Creek assemblage is intruded by the foliated Late Triassic Josh Creek diorite. The Josh Creek diorite and Mollie Creek assemblage have been deformed together as a result of phase two deformation, following the intrusion of the Josh Creek diorite in the Late Triassic and prior to the intrusion of the Fife diorite and deposition of the overlying Rossland Group in the Early Jurassic. Based on relative age, structural position, and lithological similarities to other units within Quesnel Terrane, the Mollie Creek assemblage, Josh Creek diorite, and Fife diorite are a part of Quesnel Terrane and lie above the terrane accretion surface in the Christina Lake area. Therefore, Quesnel Terrane does not unconformably overlie basement rocks of known North American affinity in this region.

Résumé : Le caractère du socle paléozoïque du terrane de Quesnel et la position de la surface d'accrétion du terrane qui sépare les terranes de Quesnel et de Kootenay des roches de l'ancienne marge nord-américaine sont sujets à discussion. Afin d'aborder ces problèmes, de la cartographie de détail et des études géochronologiques U–Pb ont été entreprises dans la région du lac Christina afin de définir la relation entre l'assemblage de Mollie Creek, la diorite de Josh Creek, la diorite de Fife et des lithologies similaires dans les régions de Greenwood–Grand Forks et de Rossland et de circonscrire les âges de la déformation régionale ainsi que la position locale de la surface d'accrétion du terrane. Des roches métasédimentaires déformées de l'assemblage de Mollie Creek correspondent peut-être à des roches sédimentaires de la Formation de Mount Roberts (Pennsylvanien à Trias précoce) dans la région de Rossland. La diorite foliée de Josh Creek (Trias tardif) pénètre dans l'assemblage de Mollie Creek. La diorite de Josh Creek et l'assemblage de Mollie Creek ont été déformés ensemble à la suite d'une déformation de phase deux, après l'intrusion de la diorite de Josh Creek au Trias tardif et avant l'intrusion de la diorite de Fife et la déposition du Groupe de Rossland sus-jacent, au Jurassique précoce. Selon les âges relatifs, la position structurale et les similitudes lithologiques aux autres unités à l'intérieur du terrane de Quesnel, l'assemblage de Mollie Creek, la diorite de Josh Creek et la diorite de Fife font partie du terrane de Quesnel et reposent au-dessus de la surface d'accrétion du terrane dans la région du lac Christina. Le terrane de Quesnel ne repose donc pas en discordance sur les roches du socle d'affinité nord-américaine connue dans cette région.

[Traduit par la Rédaction]

Introduction

The boundary between accreted terranes and rocks of pericratonic and North American affinity lies within the Omineca Belt in southeastern British Columbia. The boundary consists of an array of thrust faults of Middle Jurassic age that merge at depth into a major fault zone (Leclair 1983; Schiarizza and Preto 1987; Struik 1988; Einarsen 1995). This fault zone, the terrane accretion surface, is interpreted to have carried the inner accreted terranes over pericratonic assemblages included within Kootenay Terrane and rocks of the ancient western margin of North America, with an overlap

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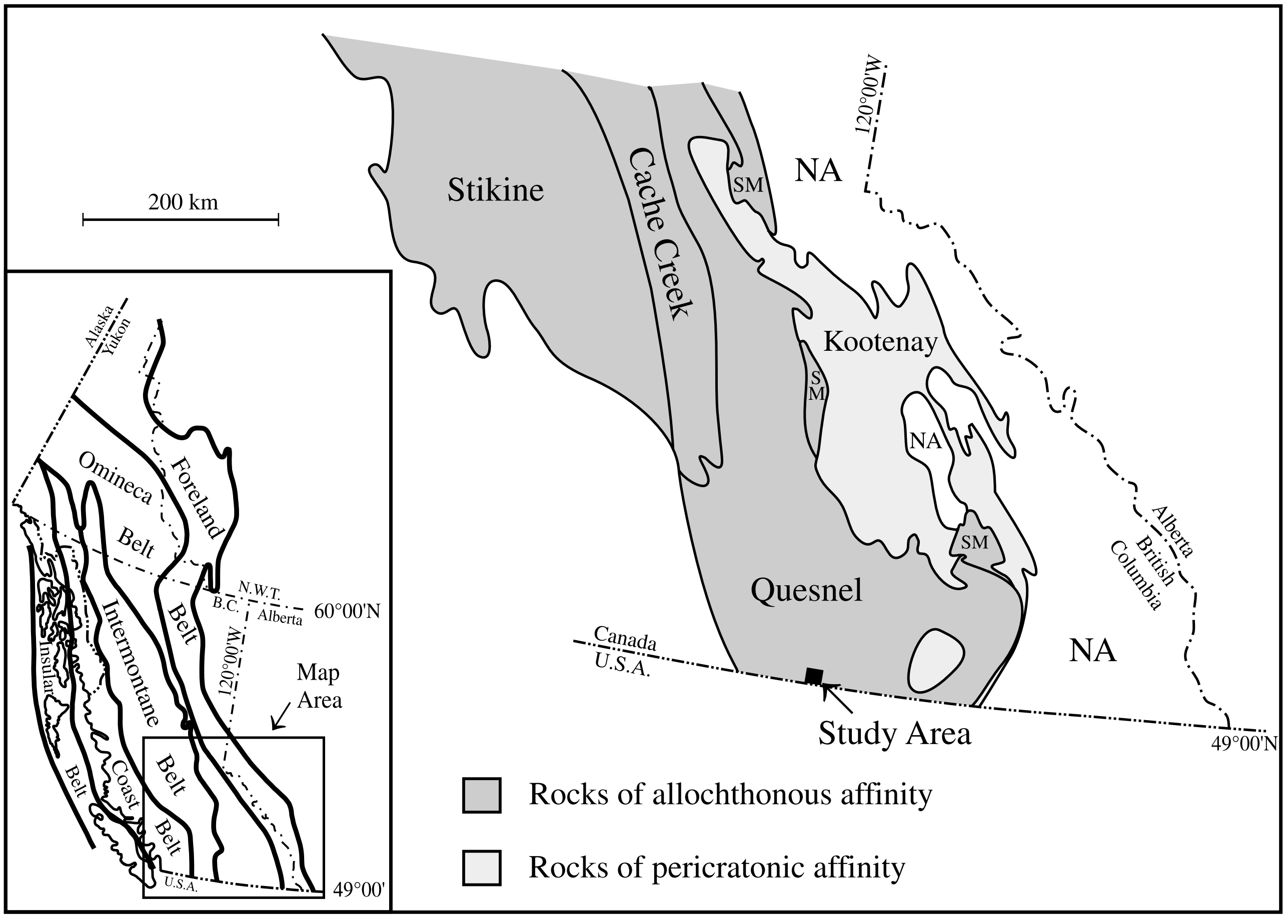
Fig. 1. Terranes of allochthonous and pericratonic affinity in southeastern British Columbia and the location of the Foreland, Omineca, and Intermontane Belts in the Canadian Cordillera. SM, Slide Mountain; NA, North America.



of 150–200 km (Cook et al. 1991; Varsek and Cook 1994; Cook 1995; Ghosh 1995). The inner accreted terranes, formerly “Composite Terrane I” of Monger et al. (1982) and the “Intermontane Superterrane” of Wheeler et al. (1991), include the Quesnel and Stikine terranes of island-arc affinity, the oceanic Slide Mountain, and the accretionary complex Cache Creek terranes (Fig. 1).

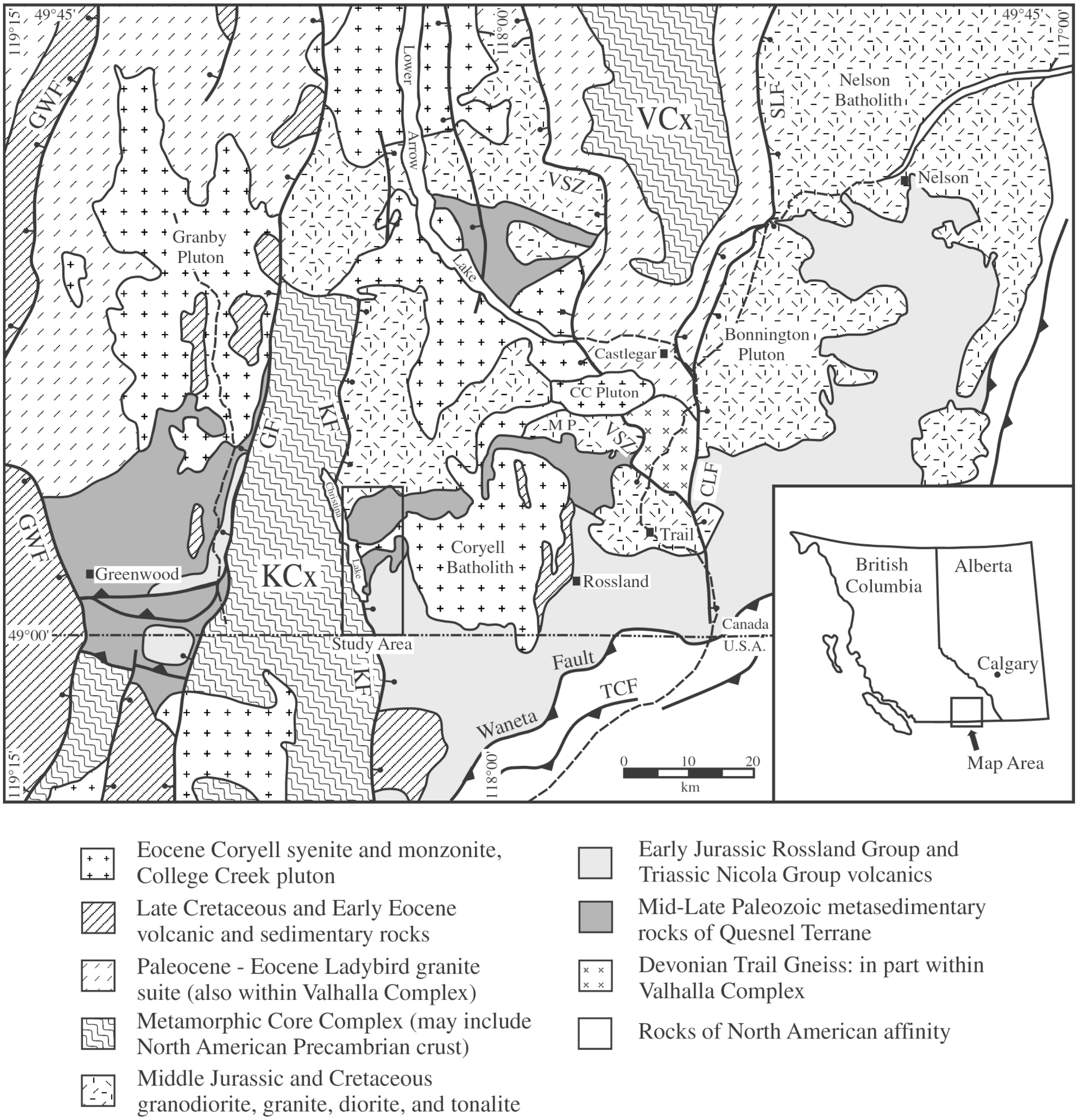
Extensive post-accretionary Eocene extension has thinned the crust in the Omineca Belt in southeastern British Columbia (Monger et al. 1972, 1982; Parrish et al. 1988; Wheeler and McFeely 1991). Crustal thinning has resulted in the exhumation of deep crustal rocks, providing the opportunity to map and study the exposed base of the Quesnel and Slide Mountain terranes, and the terrane accretion surface along which they are juxtaposed against the pericratonic Kootenay Terrane (Figs. 1, 2). Mapping of the basement of Quesnel Terrane would allow us to place limits on the position of the terrane accretion surface and would provide the opportunity to better constrain the relationship of this surface with thrust faults mapped to the east.

Study of the exhumed base of Quesnel Terrane is of particular interest in light of recent suggestions that the Quesnel magmatic arc developed on the ancient margin of western North America and is not allochthonous (Erdmer et al. 1999). However, there is little agreement regarding the stratigraphy and character of the rocks that constitute the Paleozoic basement of Quesnel Terrane, on which the Mesozoic arc was built. To address this problem, a study of the Quesnel terrane and adjacent pericratonic strata was undertaken in the Christina Lake area, southeastern British Columbia (Figs. 2, 3). Particularly, 1 : 20 000 scale geologic mapping and U–Pb geochronological studies focused on the following: (1) determining the stratigraphic and structural setting and terrane affinity of a complexly deformed assemblage of metasedimentary rocks and a highly deformed body of diorite; (2) defining the relationship of this supracrustal sequence with similar sequences to the west in the Greenwood – Grand Forks region, and to the east in the Rossland–Trail region; and (3) constraining the ages of regional deformation. Results of this study allow us to better understand the nature of the basement to Quesnel Terrane and to place limits on the position of the terrane accretion surface.

Regional geology

Quesnel Terrane is characterized by island-arc assemblages and associated mafic and intermediate intrusions of the Late Triassic Nicola and Early Jurassic Rossland Groups (Fig. 2; Little 1982; Coney et al. 1980; Roback et al. 1995). These assemblages unconformably overlie deformed late Paleozoic and older rocks of Quesnel Terrane that have poorly defined and highly variable stratigraphic and tectonic histories (Klepacki

Fig. 2. Generalized geological map of southeastern British Columbia, modified from Little (1982), Carr et al. (1987), Parrish et al. (1988), Wheeler and McFeely (1991), and Stinson (1995). CC, College Creek; CLF, Champion Lake Fault; GF, Granby Fault; GWF, Greenwood Fault System; KCx, Kettle River Complex; KF, Kettle River Fault; MP, Mackie Pluton; SLF, Slocan Lake Fault; TCF, Tillicum Creek Fault; VCx, Valhalla Complex; VSZ, Valkyr Shear Zone.



and Wheeler 1985; Schiarizza 1989). Rocks of the pericratonic Kootenay Terrane lie east of Quesnel Terrane and include Neoproterozoic and Early Cambrian strata that are stratigraphically continuous with units deposited on the North American craton (Fritz et al. 1991; Monger and Nokleberg 1996). These rocks are overlain by Paleozoic units of pericratonic affinity that contain a record of Devonian magmatic and late Paleozoic deformation events (Klepacki and Wheeler 1985). Pericratonic and North American margin rocks included within the Kootenay Terrane are juxtaposed against Mesozoic and Paleozoic rocks of Quesnel Terrane in the Greenwood – Grand Forks, Christina Lake, and Rossland–Trail regions in southeastern British Columbia (Fig. 2; Table 1).

Rocks of the Rossland Group unconformably overlie breccia, conglomerate, limestone, and volcanic rocks of the Middle Triassic Brooklyn Formation in the Greenwood – Grand Forks region west of Christina Lake (Fig. 2; Table 1). The Brooklyn Formation in turn unconformably overlies greenstone, banded chert, siltstone, limestone, and serpentinite bodies of the late Paleozoic Knob Hill and Attwood Groups (Little 1983; Fyles 1990; Roback et al. 1995). These lithologies are

Fig. 3. (*a*) Cross-section C–C′ and (*b*) simplified geologic map of the Christina Lake area showing the location of structural domains 1, 2, and 3 of the Mollie Creek assemblage. ASL, above sea level; KR, Kettle River.

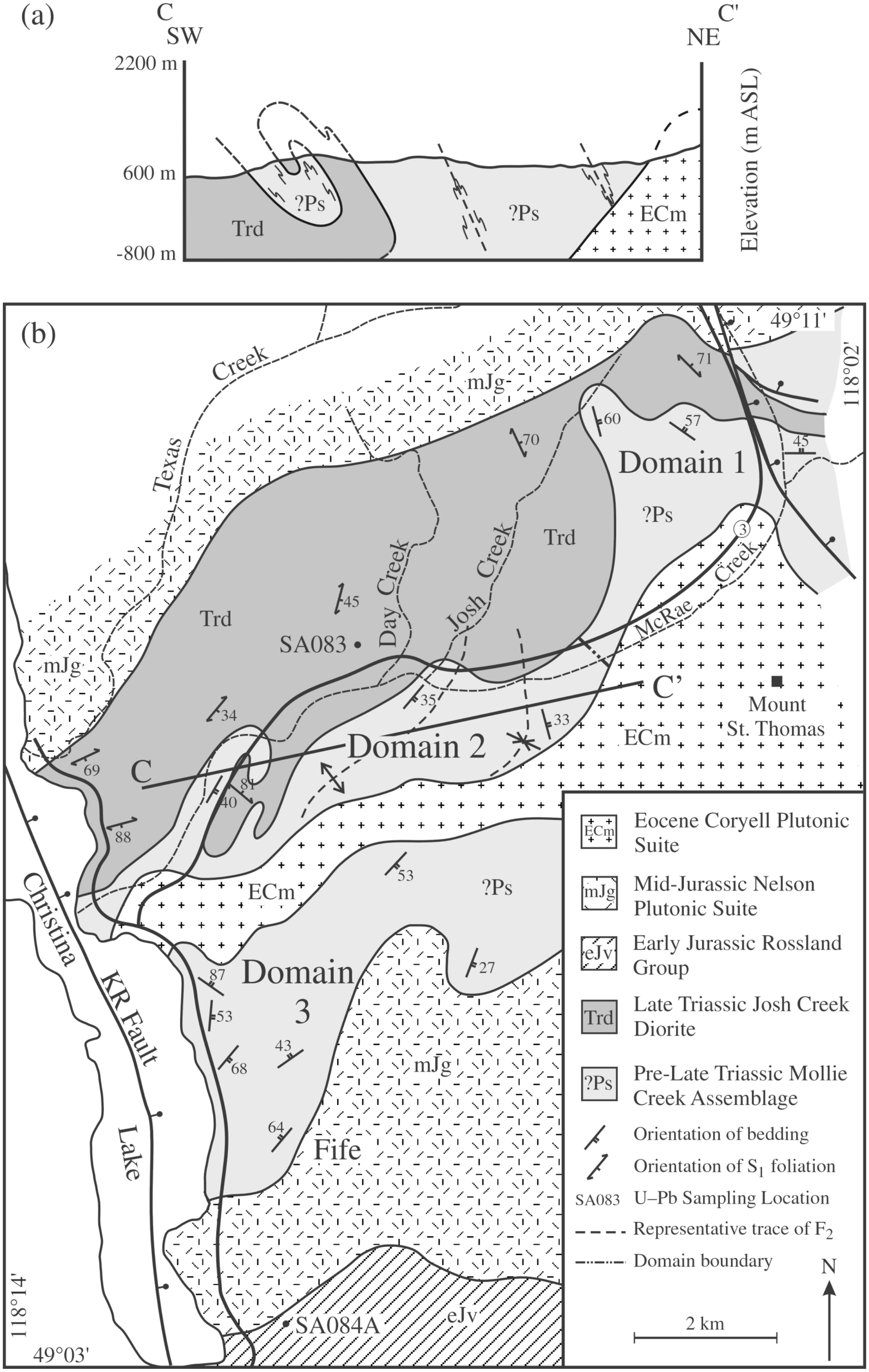


Table 1. Geological units in the Christina Lake, Greenwood – Grand Forks, Rossland–Trail, and Nelson–Castlegar regions.

Age		Greenwood - Grand Forks	Christina Lake	Rossland - Trail	Nelson - Castlegar
EOCENE		Coryell Suite Marron, Kettle Formations Ladybird Suite?	Coryell Suite Ladybird Suite?	Coryell Suite Marron Formation (OK Volcanics) Ladybird Suite	Coryell Suite College Creek Pluton Ladybird Suite
CRET.				Sophie Mountain Formation	Kinnaird Pluton
JURASSIC	Middle	Nelson Suite	Nelson Suite Hornblende Diorite (Nelson S.)	Nelson Suite Rossland Monzonite	Nelson Suite, Bonnington, Mackie Plutons
	Early		Rossland Group Elise Fm.? (Sinemurian) Archibald Fm.? Fife diorite	Rossland Group Hall Fm. (Toarcian) Elise Fm.? (Sinemurian) Archibald Fm. (Sinemurian)	Rossland Group Hall Fm. (Toarcian) Elise Fm.? (Sinemurian) Archibald Fm. (Sinemurian)
TRIASSIC		Brooklyn Formation	Josh Creek diorite (foliated calcic amphibole microdiorite)		Slocan Group
PERMIAN		Attwood Group Knob Hill Group Old Diorite (Carb. to Permian)		Mount Roberts Formation (Pennsylvanian to Early Triassic)	Mount Roberts Formation Kaslo Group
AGE?		Grand Forks-Kettle Complex (Precambrian)	Mollie Creek assemblage (metasiltstone, marble, and metasedimentary schist)	Trail Gneiss	Gneiss - Gwillim Creek and Castlegar areas
Reference		Little 1982, Fyles 1990	This Contribution	Simony 1979, Little 1982, Höy and Andrew 1991, Höy and Dunne 1997, Stinson 1995, Roback and Walker 1995	Simony 1979, Little 1982, Carr et al. 1987, Parrish et al. 1988, Brown and Logan 1989, Roback and Walker 1995, Simony and Carr 1997

Note: Carb., Carboniferous; Cret., Cretaceous; Fm., Formation; S., Suite.

similar to metabasalt, mafic intrusive rocks, serpentinite, argillite, and chert of the Permian Kaslo Group included within the oceanic Slide Mountain Terrane in the Kootenay Arc region (Table 1; Klepacki 1983; Klepacki and Wheeler 1985; Roback et al. 1994, 1995). This suggests that Mesozoic rocks of Quesnel Terrane depositionally overlie Paleozoic rocks of both Quesnel and Slide Mountain terrane and are an overlap sequence that links Slide Mountain Terrane to Paleozoic Quesnel Terrane by the Late Triassic. However, pre-Late Triassic stratigraphic correlations between the Quesnel and Slide Mountain terranes have not been recognized (Roback et al. 1994, 1995).

The Greenwood – Grand Forks region is separated from the Christina Lake area by the Eocene Grand Forks – Kettle River metamorphic core complex. The Grand Forks – Kettle River complex is bounded by the north–south-trending, east-dipping Kettle River normal fault to the east and the west-dipping Granby normal fault to the west. The complex contains orthoquartzites that may correlate to typical North American Lower Cambrian quartzite successions and Proterozoic orthogneisses (Armstrong 1988; Fyles 1990; Ross 1991). These gneisses may be autochthonous North American basement, or slices of North American basement transported in thrust sheets beneath the terrane accretion surface.

Volcanic and volcaniclastic rocks, and associated porphyries and diorite of the Early Jurassic Rossland Group lie above Pennsylvanian to Early Triassic sedimentary rocks of the Mount Roberts Formation in the Rossland–Trail region east of Christina Lake and above complexly folded metasedimentary rocks in the Christina Lake area (Fig. 2; Table 1). In the

Rossland–Trail region, rocks of the Rossland Group unconformably overlie metamorphosed siltstone, argillaceous quartzite, slate, fine- to coarse-grained sandstone, conglomerate, and limestone of the Mount Roberts Formation (Little 1982; Fyles 1984; Roback and Walker 1995). Detrital zircon populations isolated from the Mount Roberts Formation and the composition of sedimentary clasts are consistent with derivation predominantly from rocks within Kootenay Terrane. A component of Early Paleozoic zircons may indicate an additional source region within Quesnel Terrane (Roback and Walker 1995).

The Mount Roberts Formation unconformably overlies the Trail Gneiss in the region north of Trail (Fig. 2; Table 1). The Trail gneiss consists predominantly of highly strained and foliated biotite and hornblende schist and gneiss that is intruded by sheets of Middle Devonian (~380 Ma) tonalite and trondhjemite. The Devonian and older Trail Gneiss constitutes the basement to late Paleozoic to Early Jurassic rocks included within Quesnel Terrane (Simony 1979; Simony et al. 1990). This interpretation is supported by geochronological and ε_{Nd} analyses of igneous rocks within the Trail Gneiss, which indicate that its protolith evolved from primitive magmas with no Proterozoic inheritance within an island-arc setting (R. Armstrong, personal communication, 1990; Simony et al. 1990; Roback et al. 1995). However, tonalite and trondhjemite within the Trail Gneiss are lithologically similar to Devonian tonalite and granodiorite orthogneiss characteristic of Kootenay Terrane (Okulitch et al. 1975; Mortensen et al. 1987; Monger and Nokleberg 1996). This implies that the Trail Gneiss could have formed on the western margin of pericratonic Kootenay Terrane and may have been involved in its Devonian magmatic history.

In the Christina Lake area, highly deformed sheets of diorite extensively intrude an assemblage of deformed metasedimentary rocks, here referred to as the Josh Creek diorite and the Mollie Creek assemblage, respectively (Table 1). Metasedimentary rocks of the Mollie Creek assemblage have been interpreted as the westernmost continuation of the Mount Roberts Formation (Little 1957). Alternatively, these supracrustal rocks may be the western equivalents of Ordovician to Devonian rocks of the pericratonic Kootenay Terrane (Tempelman-Kluit 1989; D. Tempelman-Kluit, personal communication, 1997).

Supracrustal rocks within the Greenwood – Grand Forks, Christina Lake, and Rossland–Trail–Nelson regions have been extensively intruded by granitic and syenitic bodies that range in age from Middle Jurassic to Eocene and show varying amounts of inheritance (Fig. 2; Table 1; Armstrong 1988; Wheeler and McFeely 1991). Granitic rocks of the Middle Jurassic Nelson Plutonic Suite occur as large laccoliths and stocks throughout the southern portion of the Omineca Belt, particularly in the region around Nelson, Rossland–Trail, and Christina Lake. Paleocene to Eocene granites and pegmatites of the Ladybird Suite and Eocene syenites and monzonites of the Coryell Suite are present throughout southeastern British Columbia (Carr et al. 1987; Parrish et al. 1988; Stinson 1995).

Mollie Creek assemblage

The Mollie Creek assemblage can be subdivided into three lithological associations that include compositionally banded metamorphosed siltstone, coarse-crystalline marble, and lithologically variable metasedimentary schist (Table 1). Compositional banding within metamorphosed siltstones may be original bedding where sedimentary structures, such as cross-beds and truncations, are locally apparent. However, in most examples banding appears to be transposed bedding that formed in response to multiple phases of deformation as indicated by small, tight folds outlined by the light and dark layers.

Layers of coarse-crystalline marble from 1 cm to 40 m in thickness are interbedded within the banded metasiltstone. In some examples, metamorphosed coarse-crystalline marble grades from highly strained to relatively undeformed marble proximal to the metasiltstone contact(s). Layers of lithologically variable metasedimentary schist are associated with the compositionally banded metasiltstone and marble bands. These include very fine- to fine-grained garnet actinolite schist, almandine garnet schist, and pelitic cordierite biotite schist. The marble and schist units may be important stratigraphic markers within the Mollie Creek assemblage. However, the significance of these units cannot be determined because the stratigraphic top of the assemblage is unknown.

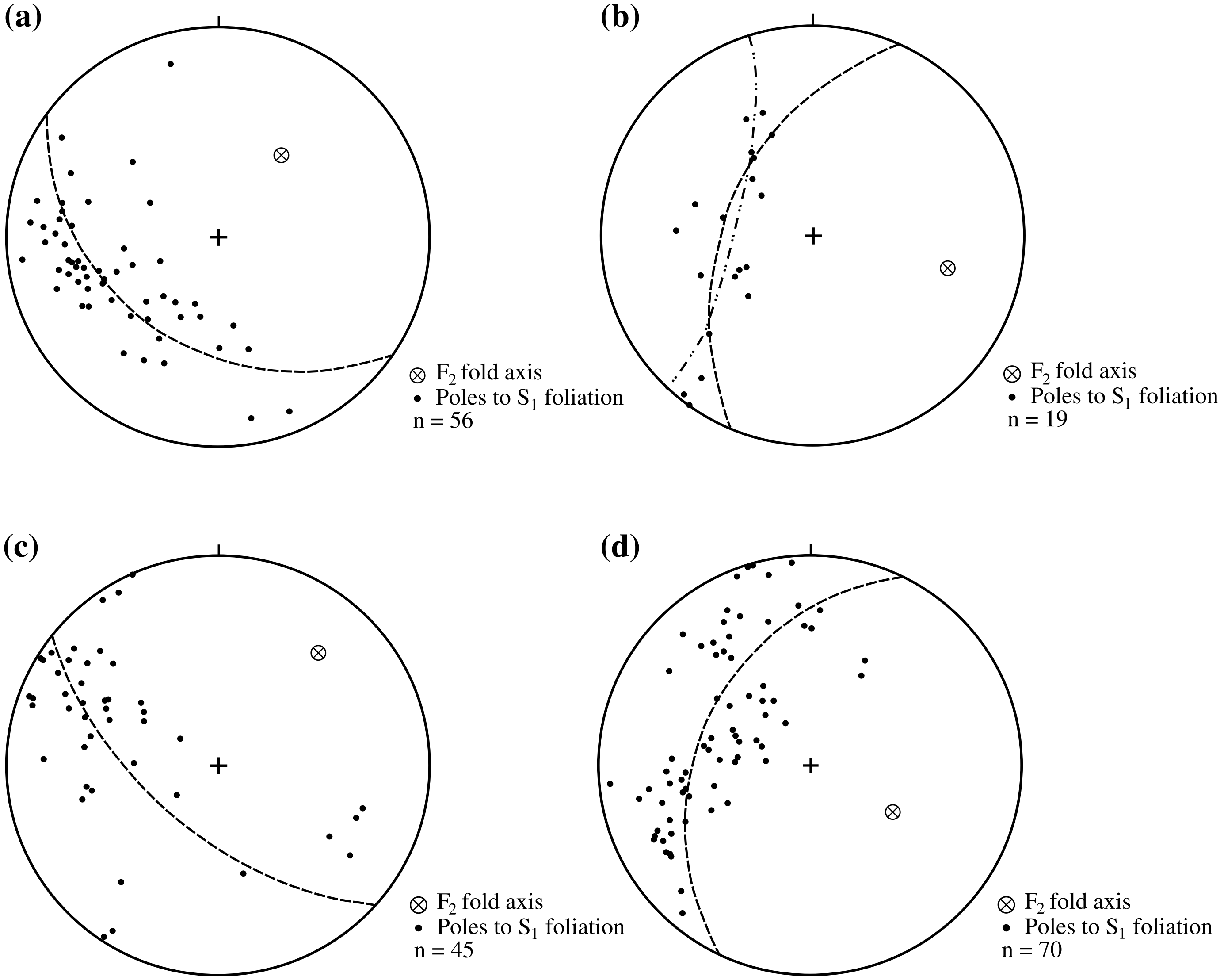
Rocks of the Mollie Creek assemblage have been regionally metamorphosed from greenschist to lower amphibolite facies. The presence of cordierite-bearing lower amphibolite facies mineral assemblages indicates metamorphism under low-pressure conditions. Compositionally banded metasiltstones regionally metamorphosed in the greenschist facies exhibit a distinct banding defined by the occurrence of biotite, plagioclase, quartz, and epidote in dark coloured layers and white mica, plagioclase, quartz, and epidote in light coloured layers. Rocks of the Mollie Creek assemblage have also undergone contact metamorphism to transitional greenschist–amphibolite facies adjacent to granitic bodies of the Middle Jurassic Nelson Suite. Almandine garnet schist occurs adjacent to cordierite biotite schist in the area north of Fife (Fig. 3). Marble, skarn, and hornfels are well developed in the Mollie Creek assemblage as a result of recrystallization and hydrothermal alteration within the contact aureole(s) of Middle Jurassic plutons of the Nelson Suite.

Structural geology — Mollie Creek assemblage

At least two phases of folding are superimposed on rocks of the Mollie Creek assemblage. Phase one and two fold axial surfaces (S_1, S_2) and fold axes (F_1, F_2) are subparallel to parallel throughout the study area. This geometric relationship and the lack of reliable stratigraphic markers in the Mollie Creek assemblage make the delineation of map-scale phase one folds difficult. However, phase one folds can be recognized and distinguished from phase two folds at the outcrop scale. Both phase one and two folds may deform poorly defined pre-S_1 foliations and folds present locally in the Mollie Creek assemblage.

Phase one folds (F_1) are inclined with tight interlimb angles and subhorizontal fold axes, whereas phase two folds (F_2) are upright to inclined with close to open interlimb angles and moderately plunging fold axes. A bedding-parallel, axial planar foliation (S_1) is refolded and in some locations destroyed by a pervasive, axial planar foliation (S_2) that

Fig. 4. Equal area plots of poles to S_1 foliation. Dashed lines indicate statistically calculated great circles for each plot. (*a*) Domain 1 of the Mollie Creek assemblage. (*b*) Domain 2 of the Mollie Creek assemblage. Poles to bedding-parallel S_1 foliation may be scattered about a small circle (dash–dot line) or a statistically calculated great circle (dashed line). A small circle pattern would indicate a conical antiform within domain 2. However, more data points are needed to resolve this distribution and the orientation of F_2. (*c*) Domain 3 of the Mollie Creek assemblage. (*d*) Josh Creek diorite.



developed in response to phase two and possible later deformation. S_2 is subparallel to parallel to S_1 in most examples. However, in some locations S_2 is at an angle of 30° to 60° to bedding (S_0) and S_1, and is a discontinuous and nonpenetrative foliation that deforms and crenulates S_0 and S_1.

The orientation of bedding (S_0), axial planar foliation (S_1), axial surfaces, and phase two fold axes varies from the northern to southern portions of the study area. As a result, the area was subdivided into three domains containing folds with relatively constant foliation and phase two axial plane orientations (Figs. 3, 4). In domain 1, phase two axial planes strike approximately north–south and dip to the east with mean F_2 axes plunging 44° toward 036° (Fig. 4*a*). Within domain 2, southeast-dipping phase two axial planes strike approximately northeast–southwest, with mean F_2 axes plunging 34° towards 112° (Fig. 4*b*). However, poles to bedding in domain 2 may fit a small circle distribution (Fig. 4*b*). More data points are needed to define the distribution of poles to bedding and the orientation of F_2 within domain 2. In domain 3, axial planes strike north-northeast to south-southwest and dip to the southeast with mean F_2 axes plunging 40° toward 028° (Fig. 4*c*).

Variations in the orientation of phase two fold axial surfaces (S_2) and fold axes (F_2) between domains may be a result of a later phase of folding, warping or tilting related to the intrusion of Middle Jurassic to Eocene plutonic rocks. Variations in the orientation of phase two folds may also be a result of the superimposition of F_2 folds on individual nonparallel limbs of close to tight F_1 folds.

Josh Creek diorite

The Josh Creek diorite is a large, deformed intrusive body previously unrecognized in the Christina Lake area. The

Josh Creek diorite consists of foliated calcic amphibole- and calcic amphibole biotite microdiorite (Table 1). Microdiorite is evident only in zones of low strain where the original igneous texture of interlocking and radiating crystals of fine-grained (<1 mm in diameter) acicular calcic amphibole and feldspar laths is preserved. Randomly oriented patches of nonfoliated diorite (15–20 cm in diameter) with phenocrysts of acicular calcic amphibole (2–4 mm in diameter) are present in some locations. In zones of intense deformation and ductile strain, the Josh Creek diorite occurs as calcic amphibole biotite microdiorite and biotite plagioclase schist. The microdiorite is strongly foliated and consists of very fine-grained (<1 mm in diameter) and partly altered oligoclase, calcic amphibole, biotite, zircon, titanite, epidote, and pyrite.

Calcic amphibole microdiorite and biotite plagioclase schist of the Josh Creek diorite have been regionally metamorphosed in the greenschist facies. In samples of metamorphosed microdiorite, igneous hornblende and plagioclase have been almost completely replaced and overprinted by calcic amphibole and albite respectively. Although the original igneous texture is destroyed in most samples, highly altered laths of igneous plagioclase are preserved within the groundmass of metamorphosed microdiorite in some locations. Where biotite plagioclase schist and metasiltstone of the Mollie Creek assemblage are complexly interfingered and sheared, secondary biotite occurs as clusters of fine-grained crystals (<1–2 mm in diameter) and as intergrowths with calcic amphibole.

The Josh Creek diorite is extensively intruded by plutons of the Nelson, Coryell, and Ladybird suites (Fig. 3). As a result, the original geometry of the Josh Creek diorite is obscured in most locations. The map pattern and style of deformation of the Josh Creek diorite in the McRae Creek – Josh Creek area suggests that the diorite was injected as a series of large sheets that were later folded with the Mollie Creek assemblage (Fig. 3). This relationship is also evident at the outcrop scale, where small individual inclusions and rows of inclusions of siltstone are observed within the diorite. This pattern may represent disintegrated screens that separated individual diorite sheets at an earlier stage in the intrusion process.

Structural geology — Josh Creek diorite

Phase two folds (F_2) within the Josh Creek diorite deform large, individual diorite sheets that were injected into metasedimentary rocks of the Mollie Creek assemblage. S_2 foliation within the Josh Creek diorite is subparallel to parallel to S_1 and S_2 surfaces in the Mollie Creek assemblage. S_2 surfaces within the diorite are defined by the parallel alignment of fine-grained calcic amphibole, metamorphic biotite, and by light coloured layers containing plagioclase.

The Josh Creek diorite and Mollie Creek assemblage have been deformed together into complex, macroscopic-scale folds as a result of phase two (D_2) deformation (Fig. 3). Phase two folds (F_2) are west-southwest verging and moderately inclined to upright with wavelengths of 1–2 km. F_2 folds within the Josh Creek diorite plunge 44° toward 116°, which is approximately the same orientation as F_2 folds within domain 2 of the Mollie Creek assemblage (Figs. 4*b*, 4*d*). However, an 80° difference between the trend of F_2 folds within the Josh Creek diorite and Domain 1 of the Mollie Creek assemblage is apparent (Figs. 4*a*, 4*d*). Variation in the orientation of F_2 folds may reflect differences in the original orientation of diorite sheets and bedding (S_0) within the Mollie Creek assemblage. The folding of original interdigitations of the Josh Creek diorite with the Mollie Creek assemblage may account for complex map patterns throughout the study area (Fig. 3).

U–Pb Geochronology

The age of the Josh Creek diorite and the Mollie Creek assemblage are poorly constrained by field relationships. The Josh Creek diorite intrudes the Mollie Creek assemblage and is cut by granitic rocks of the Middle Jurassic Nelson Suite. Based on this relationship, the diorite and the Mollie Creek assemblage are older than Middle Jurassic (169–171 Ma; Armstrong 1988). To provide a minimum estimate for the age of the Mollie Creek assemblage, three 30–45 kg samples of the Josh Creek diorite were collected for U–Pb geochronology (SA083, SA095, SA096). Of the three samples, only one (SA083) yielded zircon for U–Pb analysis. The lack of zircons recovered within the Josh Creek diorite is attributed to the high degree of deformation of the diorite, and the poor quality of the zircons as a result of this deformation.

A body of undeformed diorite intrudes rocks of the Rossland Group proximal to rocks of the Mollie Creek assemblage near Fife (Fig. 3). This diorite was initially interpreted as an undeformed part of the Josh Creek diorite. To clarify its relationship to the units in the Christina Lake area, a sample of the Fife diorite (SA084A) was analyzed. The results of U–Pb analyses of samples SA083 (Josh Creek diorite) and SA084A (Fife diorite) are given in Table 2 and in the following sections. Analytical methods are described in Appendix 1.

Josh Creek diorite (sample SA083)

Sample SA083 yielded 300–400 zircon grains for U–Pb analysis. The zircons are small, cloudy, fractured prisms with some dark inclusions oriented parallel to the *c*-axis. Two fractions were analyzed, consisting of 136 and 145 unabraded cloudy and fractured prisms and fragments of prisms (Table 2). The two fractions are slightly discordant and plot below the concordia curve (Fig. 5). Both fractions have high uranium contents (1700–2155 ppm) and Th/U ratios (1.3–1.4). Th/U ratios greater than 1 are typical of primary zircon crystallizing from a mafic magma (Heaman and LeCheminant 1993). These two zircon analyses define a reference line with a lower intercept age of 215.9 ± 1.4 Ma and an upper intercept age of ca. 1100 Ma. The lower intercept is interpreted as the time of emplacement of the diorite and constrains its crystallization age to Late Triassic. The discordance pattern indicates a component of probable Proterozoic age inheritance. A more precise age cannot be assigned due to a lack of data points.

Fife diorite (sample SA084A)

Sample SA084A yielded abundant high quality zircon. The zircon grains are transparent, colourless to light yellow, euhedral prisms and fragments of prisms. A small proportion of the zircon grains are turbid or contain inclusions and were avoided during grain selection. The zircons isolated from sample SA084A are less altered and more transparent than

Table 2. U–Pb analytical data.

	Weight (µg)	U (ppm)	TH (ppm)	Pb (ppm)	Th/U	TCPB (pg)	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	Model Ages (Ma)[b] $\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	% disc
SA083 (Josh Creek diorite)[a]														
1	46	2155	2939	97.4	1.36	30.7	7030	0.03475 ± 13	0.2446 ± 10	0.05106 ± 4	220.2 ± 0.8	222.2 ± 0.8	243.5 ± 1.7	9.7
2	33	1734	2290	76.4	1.32	13.9	8982	0.03441 ± 11	0.2409 ± 8	0.05077 ± 5	218.1 ± 0.7	219.2 ± 0.7	230.6 ± 2.1	5.5
Sa084A (hornblende diorite, Rossland Group[a]														
1	448	356	235	10.8	0.66	46.8	5928	0.02766 ± 8	0.1904 ± 6	0.04992 ± 4	175.9 ± 0.5	177.0 ± 0.5	191.5 ± 1.6	8.3
2	103	318	215	9.6	0.68	19.4	2890	0.02727 ± 6	0.1876 ± 5	0.04991 ± 6	173.4 ± 0.4	174.6 ± 0.4	190.8 ± 2.8	9.3
3	47	221	176	7.0	0.80	14.5	1264	0.02766 ± 6	0.1896 ± 9	0.04970 ± 20	175.9 ± 0.3	176.3 ± 0.8	181.2 ± 9.6	3.0

[a] Location of sample SA083 (Josh Creek diorite): 413950E 5443600N. Location of sample SA084A (hornblende diorite, Rossland Group): 412140E 5433600N. Errors are quoted at 1 sigma for ratios. TCPb, Total common lead. ^{206}Pb/^{204}Pb corrected for fractionation (0.088%/amu for Pb, 0.155%/amu for U) and spike. Amu, atomic mass unit.

[b] Corrected for fractionation, blank (3–8 pg for Pb and 0.5–2 pg for U), initaial common Pb (Stacey and Kramers 1975, Pb composition model) and and spike. Errors are quoted at 1 sigma. Decay constants used in age calculation: $^{238}U = 1.55125 \times 10^{-10} a^{-1}$, $^{235}U = 9.8458 \times 10^{-10} a^{-1}$ (Jaffey et al. 1971).

the zircons extracted from sample SA083 (Josh Creek diorite).

A total of three fractions were analyzed from SA084A and include a fraction of 500 light yellow euhedral prisms, 190 light yellow euhedral prisms, and 132 abraded, light yellow to colourless euhedral to subhedral fragments of prisms (Table 2). The two unabraded fractions are slightly discordant (8–9%) and yield similar ^{207}Pb/^{206}Pb ages of 191 Ma. Together these two fractions yield an upper intercept age of 197 ± 5 Ma (Fig. 6). The abraded fraction (fraction 3) is slightly discordant (3%) and the ^{207}Pb/^{206}Pb age of 181 ± 9.6 Ma provides a minimum estimate for the emplacement age of the diorite (Fig. 6). The slightly older ages obtained for zircon analyses 1 and 2 could be interpreted to reflect the presence of a slight amount of inheritance. However, it is unlikely that two multigrain zircon fractions would contain exactly the same proportion of new and inherited zircon. Therefore, the age of crystallization of the Fife diorite is interpreted as 197–181 Ma.

Discussion and conclusions

Detailed mapping and U–Pb geochronology have resulted in several important observations pertaining to the Christina Lake area. Particularly, the stratigraphic and structural setting of supracrustal rocks in the Christina Lake region and their relationship to rocks of the Quesnel and Kootenay terranes was addressed. The relationship of the Mollie Creek assemblage, Josh Creek diorite, and Fife diorite to similar lithologies in the Greenwood – Grand Forks and Rossland regions, ages of regional deformation, and the local position of the terrane accretion surface are summarized in the following discussion.

Mollie Creek assemblage

Supracrustal rocks between the Greenwood – Grand Forks, Christina Lake, and Rossland–Trail regions are cut by numerous faults and intrusions. As a result, the correlation of the metamorphosed and deformed Mollie Creek assemblage to other metasedimentary packages is difficult. In spite of this, the following correlations of the Mollie Creek assemblage are possible: (1) The Mollie Creek assemblage may correlate with the Carboniferous to Permian Attwood and Knob Hill Groups in the Greenwood area (Little 1983; Fyles 1990; Tempelman-Kluit 1989). The Attwood and Knob Hill groups are similar to oceanic assemblages of the Permian Kaslo Group, included within the oceanic Slide Mountain Terrane in the Kootenay Arc region (Klepacki and Wheeler 1985; Roback et al. 1994, 1995). Although these assemblages could be the same age, they are lithologically distinct from rocks of the Mollie Creek assemblage, making this correlation improbable.

(2) Rocks of the Mollie Creek assemblage may be the westernmost continuation of the Pennsylvanian to Early Triassic Mount Roberts Formation in the Rossland area (Little 1957). Rocks of the Mount Roberts Formation have been mapped to within 6 km of the Mollie Creek assemblage immediately east of the study area (Little 1957, 1982). Also, the lithological characteristics, stratigraphic position, style of deformation, and metamorphism of metasedimentary rocks of the Mollie Creek assemblage are similar to those of the Mount Roberts Formation (Little 1957, 1982; Fyles 1984; Roback and

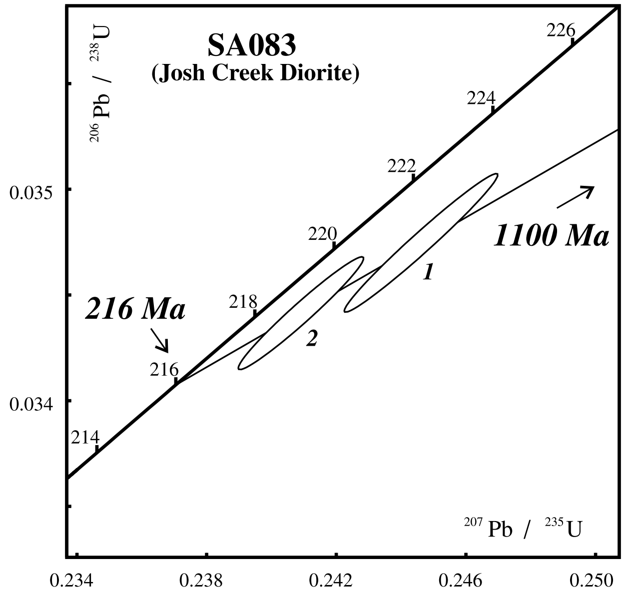


Fig. 5. Concordia plot for sample SA083 (Josh Creek diorite).

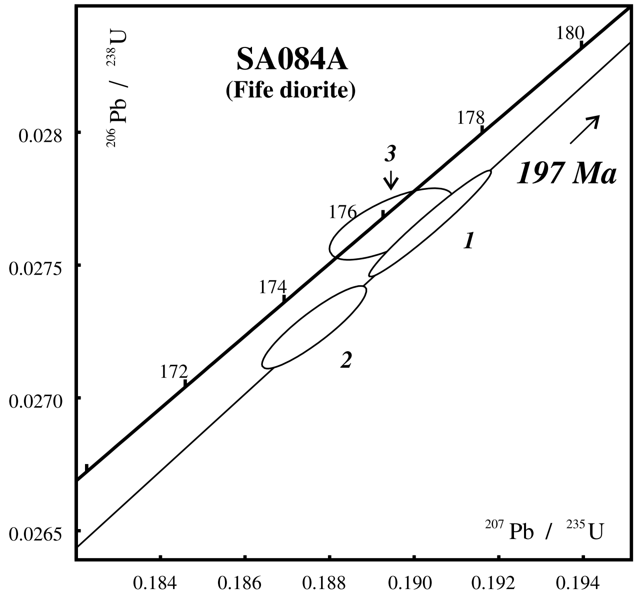


Fig. 6. Concordia plot for sample SA084A (Fife diorite).

Walker 1995). This suggests that the Mollie Creek assemblage correlates with the Mount Roberts Formation or that it belongs to the same late Paleozoic-Early Triassic package.

(3) The Mollie Creek assemblage may be the western equivalent of Ordovician to Devonian rocks included within the pericratonic Kootenay Terrane (Tempelman-Kluit 1989; D. Tempelman-Kluit, personal communication, 1997). The Late Triassic Josh Creek diorite intrudes rocks of the Mollie Creek assemblage, constraining the age of the Mollie Creek assemblage to Late Triassic or older. Further limits on the age of the Mollie Creek assemblage cannot be made since greenschist-facies metamorphism and multiple phases of deformation have destroyed fossils, sedimentary structures, and stratigraphic contacts. Consequently, this correlation cannot be made with any certainty.

Based on lithological similarities, style of deformation, and stratigraphic position, the interpretation that the Mollie Creek assemblage correlates with the Pennsylvanian to Early Triassic Mount Roberts Formation in the Rossland area is the most plausible (Little 1957, 1982; Fyles 1984; Roback and Walker 1995). Since the age of the Mollie Creek assemblage is constrained only by the Late Triassic age of the Josh Creek diorite, the assemblage may correlate with Ordovician to Devonian strata included within Kootenay Terrane (D. Tempelman-Kluit, personal communication, 1997). However, the affinity of the Mollie Creek assemblage before the Late Triassic is uncertain, and this interpretation is not conclusive.

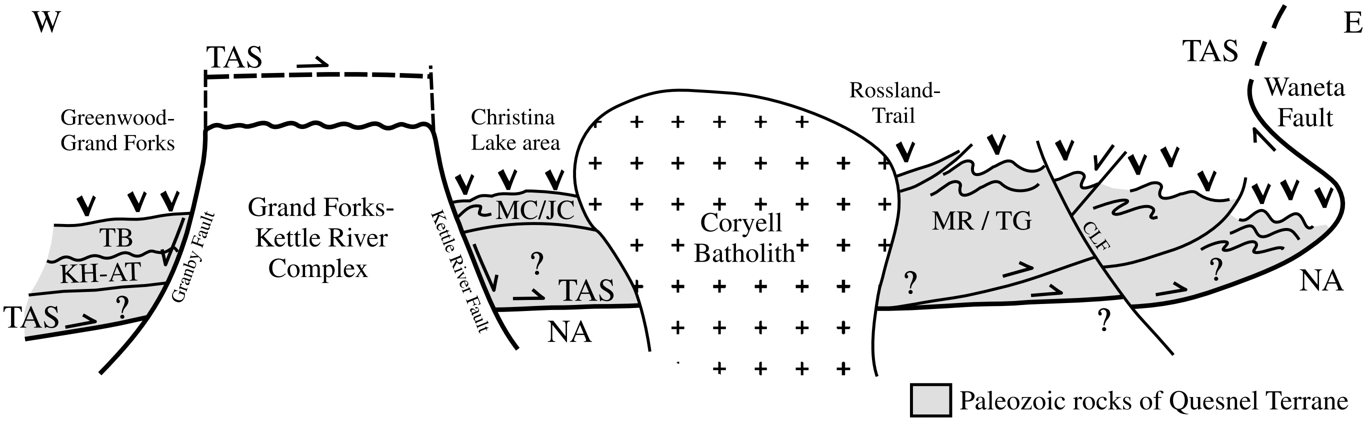
Josh Creek and Fife diorite

U–Pb geochronology constrains the crystallization age of the Fife diorite to 197–181 Ma. This Early Jurassic date is similar to the ages of a suite of bodies of diorite in southeastern British Columbia inferred to be related to volcanic rocks of the Rossland Group. Brown and Logan (1989) tentatively correlate 195 Ma hornblende diorite with the Rossland Group in the Nelson area. In the Rossland region, Fyles (1984) and earlier workers have also identified diorite and hornblende- and augite porphyries related to the Rossland Group. Based on its age and similarity to other diorite bodies in southeastern British Columbia, the Fife diorite is interpreted to represent igneous activity associated with the deposition of the early Sinemurian to early Toarcian (197–178 Ma) Rossland Group (Fyles 1984; Tipper 1984; Stinson 1995; Okulitch 1999). As well, the Fife diorite is undeformed and structurally overlies the highly foliated Josh Creek diorite. This suggests that the Josh Creek diorite is older than the Fife diorite and was deformed before the Early Jurassic, supporting the Late Triassic age obtained for the Josh Creek diorite.

The Late Triassic Josh Creek diorite is similar to other Triassic diorite intrusions that are interpreted to represent part of the plutonic root of the Nicola volcanic arc in the western part of Quesnel Terrane (Monger et al. 1972; Mortimer 1987; Mortimer et al. 1989; Ghosh 1995; Moore et al. 2000). In eastern Quesnel Terrane, the accumulation of the Rossland Group is interpreted to have taken place within the later stages of the evolution of a back-arc extensional environment (Beddoe-Stephens and Lambert 1981; Höy and Andrew 1991; Ghosh 1995). Hence, the Josh Creek diorite represents the early stages of island-arc tectonism and magmatism within eastern Quesnel Terrane prior to the accumulation of the Rossland Group in the Early Jurassic.

Inheritance of material of probable Proterozoic age within zircons from the Josh Creek diorite is of uncertain significance. Proterozoic ages that have been interpreted to represent incorporation of Precambrian crustal material into Quesnel Terrane have been found from other rocks in Quesnel Terrane and the adjacent pericratonic Kootenay Terrane (Ross 1991; Roback and Walker 1995; Patchett and Gehrels 1998). This implies that Quesnel Terrane formed near the ancient margin of North America. Other investigations along the eastern margin of Quesnel Terrane have found that the volcanic-island arcs of Quesnel Terrane were in part built on fragments of crust of North American affinity (Klepacki and Wheeler 1985; Schiarizza 1989; Höy and Dunne 1997). However, since a more precise age of inheritance cannot be

Fig. 7. Simplified cross-section from the Greenwood – Grand Forks area to the Waneta Fault, immediately north of the 49th parallel, showing the relationship of Quesnel Terrane rocks in the Christina Lake area to adjacent regions. Refer to Fig. 2, generalized geologic map of southeastern British Columbia. CLF, Champion Lake Fault; KH-AT, Knob Hill and Attwood Groups; MC/JC, Mollie Creek assemblage and Josh Creek diorite; MR, Mount Roberts Formation; NA, North American margin and cratonic basement rocks; TAS, terrane accretion surface; TB, Brooklyn Formation; TG, Trail Gneiss; V, Rossland Group.



assigned due to a lack of data points, these implications are tentative.

Ages of regional deformation

The Josh Creek diorite and Mollie Creek assemblage have been deformed together into complex folds as a result of phase two deformation (Fig. 3). Phase two folds (F_2) deform an older foliation (S_1) that developed in response to phase one deformation. Phase two deformation postdates the intrusion of the Late Triassic Josh Creek diorite, and predates the intrusion of the Early Jurassic Fife diorite and granitic rocks of the Middle Jurassic Nelson Suite.

There is evidence for Paleozoic deformation to the east and west of the Christina Lake area, suggesting that pre-Late Triassic deformation of the Mollie Creek assemblage may have occurred. For example, the Mount Roberts Formation unconformably overlies the Trail Gneiss and Late Devonian intrusions in the Rossland–Trail area, implying Devonian to Mississippian deformation (Simony et al. 1990). Also, there is an angular unconformity between the Middle Triassic Brooklyn Formation and late Paleozoic Knob Hill and Attwood Groups in the Greenwood area, suggesting pre-Middle Triassic and older deformation (Read and Okulitch 1977; Fyles 1990). Therefore, highly deformed and poorly defined pre-S_1 foliations and folds present locally in the Mollie Creek assemblage may be pre-Late Triassic.

Position of the terrane accretion surface

The pre-Late Triassic age of the Mollie Creek assemblage and its similarity to the Mount Roberts Formation indicate that supracrustal rocks in the Christina Lake area are a part of Paleozoic Quesnel Terrane and lie above the terrane accretion surface (Fig. 7). The terrane accretion surface then lies below the Mount Roberts Formation and Trail Gneiss in the Rossland area to the east and above North American basement rocks in the Grand Forks – Kettle River metamorphic core complex to the west of Christina Lake. The surface is interrupted by Middle Jurassic, Cretaceous, and Eocene intrusions to the north of the metamorphic complex, obscuring its position (Fig. 7; Tempelman-Kluit 1989). West of the Grand Forks – Kettle River complex, the terrane accretion surface lies at depth below the Knob Hill and Attwood Groups in the Greenwood region (Fig. 7). Prior to the exhumation of the Grand Forks – Kettle River complex in the Eocene, the lithologically contrasting Mollie Creek assemblage and Knob Hill and Attwood groups may have been juxtaposed along a zone of thrust faults related to faults mapped in the Greenwood area (Little 1983; Fyles 1990). These thrust faults may merge at depth with the terrane accretion surface.

Alternatively, if rocks of the Mollie Creek assemblage were to be included within Kootenay Terrane, the terrane accretion surface would lie above the Mollie Creek assemblage and the overlying Rossland Group in the Christina Lake area (Tempelman-Kluit 1989; D. Tempelman-Kluit, personal communication, 1997). This would imply that Mesozoic arc rocks of Quesnel Terrane were formed on the ancient western margin of North America, as suggested by Erdmer et al. (1999) for the Vernon area, approximately 100 km northwest of Christina Lake. The terrane accretion surface would have to rise westward through rock assemblages in its hanging wall, from below the Trail Gneiss in the Rossland area to above the Rossland Group near Christina Lake, and drop westward below the rocks in the Greenwood region. This geometry is unlikely because the terrane accretion surface would have to cut down eastward in the direction of transport. Therefore, the terrane accretion surface most likely lies below the Mollie Creek assemblage, Josh Creek diorite, and Rossland Group in the Christina Lake area (Fig. 7).

The Mollie Creek assemblage and Josh Creek diorite have undergone low-pressure regional metamorphism in the greenschist to lower amphibolite facies, supporting the interpretation that these rocks lie above the terrane accretion surface. Low-pressure metamorphism suggests that these rocks were not buried to significant depths beneath an overriding thrust sheet. Typically, North American strata that have been metamorphosed below the terrane accretion surface record higher pressure (500–800 Mpa) Jurassic and (or) Cretaceous metamorphism within the kyanite zone of the amphibolite facies (Colpron et al. 1996; Ghent et al. 1982). Hence, it is concluded that the Christina Lake area is situated within a thrust sheet containing rocks of Quesnel Terrane that overrode pericratonic and North American margin strata and that Quesnel Terrane does not unconformably overlie basement rocks of known North American affinity in this region.

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Appendix 1. Analytical methods

Three 30–45 kg samples of the Josh Creek diorite were collected for U–Pb geochronology (samples SA083, SA095, SA096). Of the three samples, only one (SA083) yielded zircon for U–Pb analysis. Approximately 35 kg of relatively unfoliated Josh Creek diorite (sample SA083) and 5 kg of unaltered and undeformed Fife diorite (sample SA084A) were analyzed at the University of Alberta Radiogenic Isotope Facility (Edmonton, Alberta).

Zircon-containing, heavy-mineral fractions were recovered after the crushed and ground samples were passed over a wet shaking Wilfley Table. Zircon and pyrite were isolated from the heavy mineral fractions using standard magnetic and heavy liquid separation techniques. Zircons were then hand picked and separated into several fractions based on the colour, clarity, shape and degree of deformation of individual grains. To reduce discordance, abrasion of fraction 3 from sample SA084A was conducted following the procedures outlined by Krogh (1982). The number of zircon grains in each fraction was then counted, weighed using an UTM2 ultra-microbalance, and then dissolved for up to five days using a mixture of HF–HNO_3 (220°C) in TFE Teflon bombs. A calibrated amount of ^{205}Pb–^{235}U tracer solution was added to each fraction prior to dissolution. Uranium and lead were purified using anion exchange chromatography following a slightly modified procedure originally developed by Krogh (1973) (Heaman and Machado 1990). The combined U and Pb aliquots were then loaded together with Si gel onto outgassed Re filaments. Their isotopic compositions were determined using a VG354 thermal ionization mass spectrometer in single collector Faraday or Daly photomultiplier peak-hopping mode. Data obtained with the Daly detector were corrected for detector bias using an empirically derived factor of +0.13%/amu (Pb) and +0.15%/amu (U). All isotopic ratios were corrected for mass discrimination (0.088%/amu Pb; 0.155%/amu U) based on replicate analyses of the NBS 981 and U500 standards. Ages were calculated using the linear regression routine of Davis (1982) and associated age uncertainties are reported at 2 sigma.