The Wineglass assemblage, lower Chilcotin River, south-central British Columbia: Late Permian volcanic and plutonic rocks that correlate with the Kutcho assemblage of northern British Columbia

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Abstract

Late Permian volcanic and plutonic rocks that were identified along the lower Chilcotin River by Read (1993) were examined to evaluate a possible correlation with the Kutcho assemblage of northern British Columbia, host to the Kutcho Creek volcanogenic massive sulphide deposit. These rocks, herein named the Wineglass assemblage, include a lower volcanic unit of mainly basalt, an upper volcanic unit that includes rhyolite, basalt, and felsic volcaniclastic rocks, and an intrusive body of tonalite, quartz diorite, and granodiorite, referred to as the Wineglass pluton. The Wineglass assemblage is correlated with the Kutcho assemblage on the basis of its striking lithologic similarity, overlapping U-Pb zircon ages, similar unconformable relationship with an overlying Triassic-Jurassic sedimentary sequence, and similar relationship to structurally overlying Cache Creek Complex. Clastic sedimentary rocks that unconformably overlie the Wineglass assemblage are part of the predominantly Late Triassic-Middle Jurassic Cadwallader arc terrane. Expanding the definition of Cadwallader terrane to include the Wineglass assemblage and correlatives makes for a compelling correlation with Wallowa terrane, in the Blue Mountains region of northeastern Oregon and west-central Idaho.

Keywords: Late Permian Wineglass assemblage, rhyolite, basalt, tonalite, Kutcho assemblage, Sitlika assemblage, Cache Creek terrane, Cadwallader terrane, Tyaughton Formation, Ladner Group, Hurley Formation, Wallowa terrane

1. Introduction

Read (1992, 1993) identified Late Permian bimodal volcanic and intrusive rocks along the lower reaches of the Chilcotin River southwest of Williams Lake (Fig. 1). He mapped these, together with unconformably overlying Lower Jurassic clastic rocks, as a structural window, which he referred to as the Wineglass slice, beneath the Cache Creek Complex. Read et al. (1995) included rocks of the Wineglass slice in the Cadwallader terrane, which is also represented by Upper Triassic limestone and clastic sedimentary rocks, preserved in adjacent fault slices to the west and north.

The Kutcho assemblage of northern British Columbia, host to the Kutcho Creek volcanogenic massive sulphide deposit, comprises a heterogeneous package of schists derived from felsic and mafic volcanic and volcaniclastic rocks and associated felsic and mafic intrusions (Fig. 1; Schiarizza, 2012a). The Kutcho assemblage was thought to be Late Triassic at the time of Read's (1992, 1993) work near the Chilcotin River (Thorstad and Gabrielse, 1986), but subsequent studies have shown that it is Late Permian to Middle Triassic (Childe and Thompson, 1997; Schiarizza 2012a, b). Similar Late Permian to Middle Triassic ages have been obtained from the correlative Sitlika assemblage in central British Columbia (Fig. 1), also subsequent to Read's work in the Chilcotin River area (Childe and Schiarizza, 1997; M. Villeneuve, in Struik et al., 2007).

The lithologic descriptions of the Late Permian rocks of the Wineglass slice provided by Read (1992, 1993), together with their similar spatial relationship to Cache Creek terrane (Fig. 1), suggest possible correlation with Permo-Triassic rocks of the Kutcho and Sitlika assemblages. Field studies in 2012 support the hypothesis that the Late Permian rocks of the Wineglass slice, herein assigned to the Wineglass assemblage, correlate with the Kutcho and Sitlika assemblages, and that the overlying Mesozoic rocks correlate with the Tyaughton Formation and Ladner Group of Cadwallader terrane.

2. Geological setting of the Wineglass slice

The area studied is on the Fraser Plateau, just west of the Fraser River, within the traditional territories of the Northern Secwepemc te Qelmucw and Tsilhqot'in First Nations. A good gravel road that branches southward from Highway 20 at Riske Creek crosses the Chilcotin River at Farwell Canyon, and continues south to Gang Ranch. Secondary roads that branch southeast from this road, south of the Chilcotin River, provide easy access to the parts of the Wineglass slice that were examined.

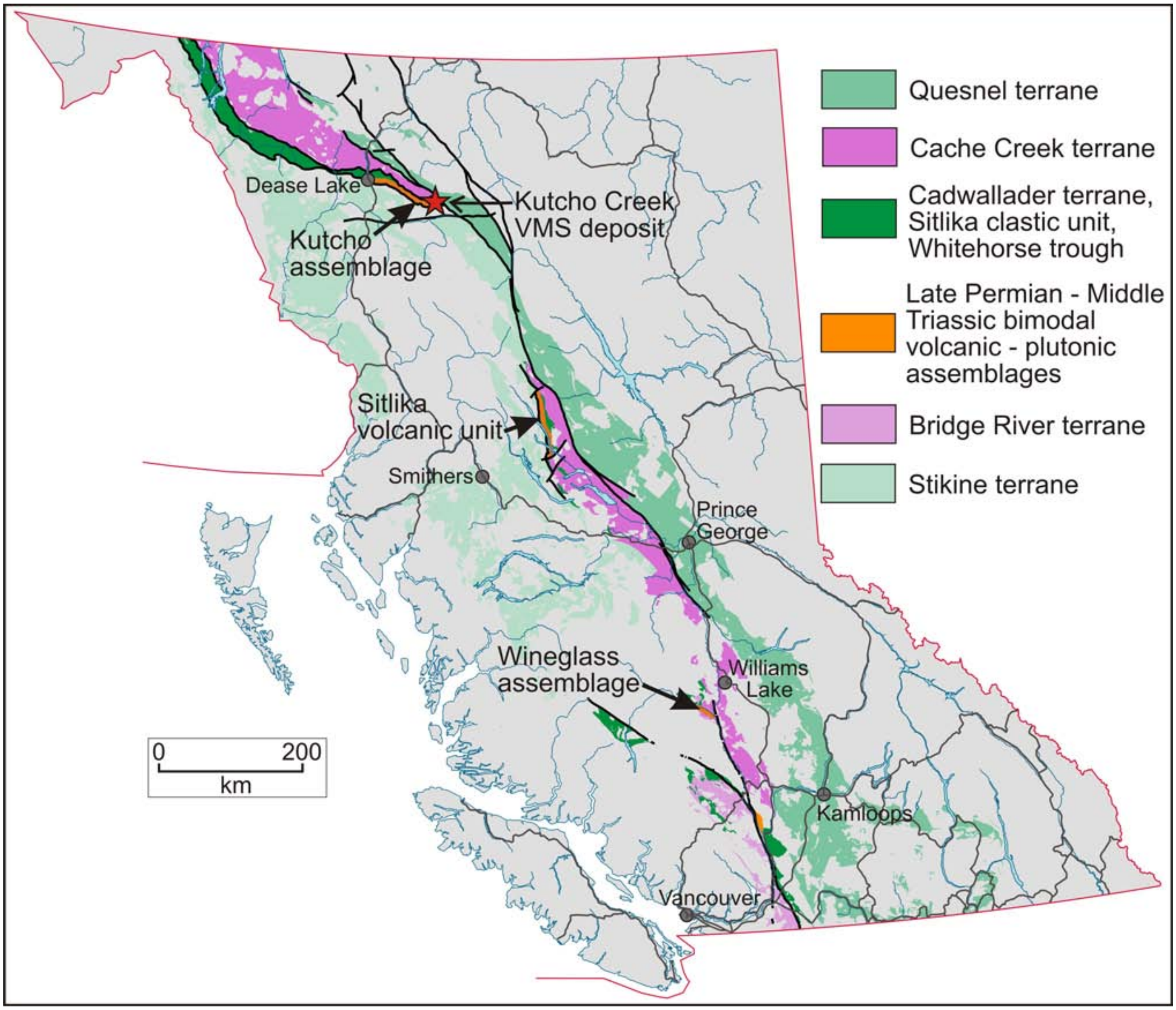

Fig. 1. Map of British Columbia showing the distribution of selected terranes and the Kutcho, Sitlika and Wineglass assemblages.

In the lower Chilcotin River area (Fig. 2), Late Paleozoic and Mesozoic rocks are assigned to three main packages, separated from one another by thrust faults that are commonly marked by units of serpentinite melange. These packages are: Cache Creek terrane, Cadwallader terrane, and Thaddeus assemblage. Younger rocks include plugs of Jura-Cretaceous diorite and quartz diorite that cut Cache Creek rocks in the southern part of the area, Eocene volcanic and sedimentary rocks that overlap thrust faults but are cut by younger north-trending faults, and flat-lying basalt and related sedimentary rocks of the Miocene-Pleistocene Chilcotin Group.

Cache Creek terrane, represented by rocks of the Cache Creek Complex, underlies much of the lower Chilcotin River area. The complex is subdivided into three composite units: one consisting of mainly chert, siliceous phyllite, and limestone; another of predominantly basalt (commonly structurally and/or stratigraphically interleaved with limestone); and a third siliciclastic sedimentary package of mainly siltstone and sandstone. A large diorite body is also included in the Cache Creek Complex because it locally shows intrusive contacts with mafic volcanic rocks of the complex (Read, 1992), but is apparently faulted against other units in the area. Temporal constraints come mainly from the chert-siliceous phyllite-limestone unit, which has yielded radiolarians of Early Permian, Middle Triassic and Late Triassic age (Cordey and Read, 1992).

Cadwallader terrane is exposed in two fault panels in the northwestern part of the area (Fig. 2). These panels include Upper Triassic limestone and associated conglomerate and sandstone of the Hurley Formation (Cadwallader Group; Rusmore and Woodsworth, 1991), and Jurassic sandstone and conglomerate included in the Ladner Group (Read, 1992; Read et al., 1995). It is also represented by rocks of the Wineglass slice, which are exposed in a structural window, 22 km long and up to 6.5 km wide, beneath Cache Creek terrane on the southwest side of the Chilcotin River. The youngest rocks in this window comprise Upper Triassic(?) and Lower Jurassic

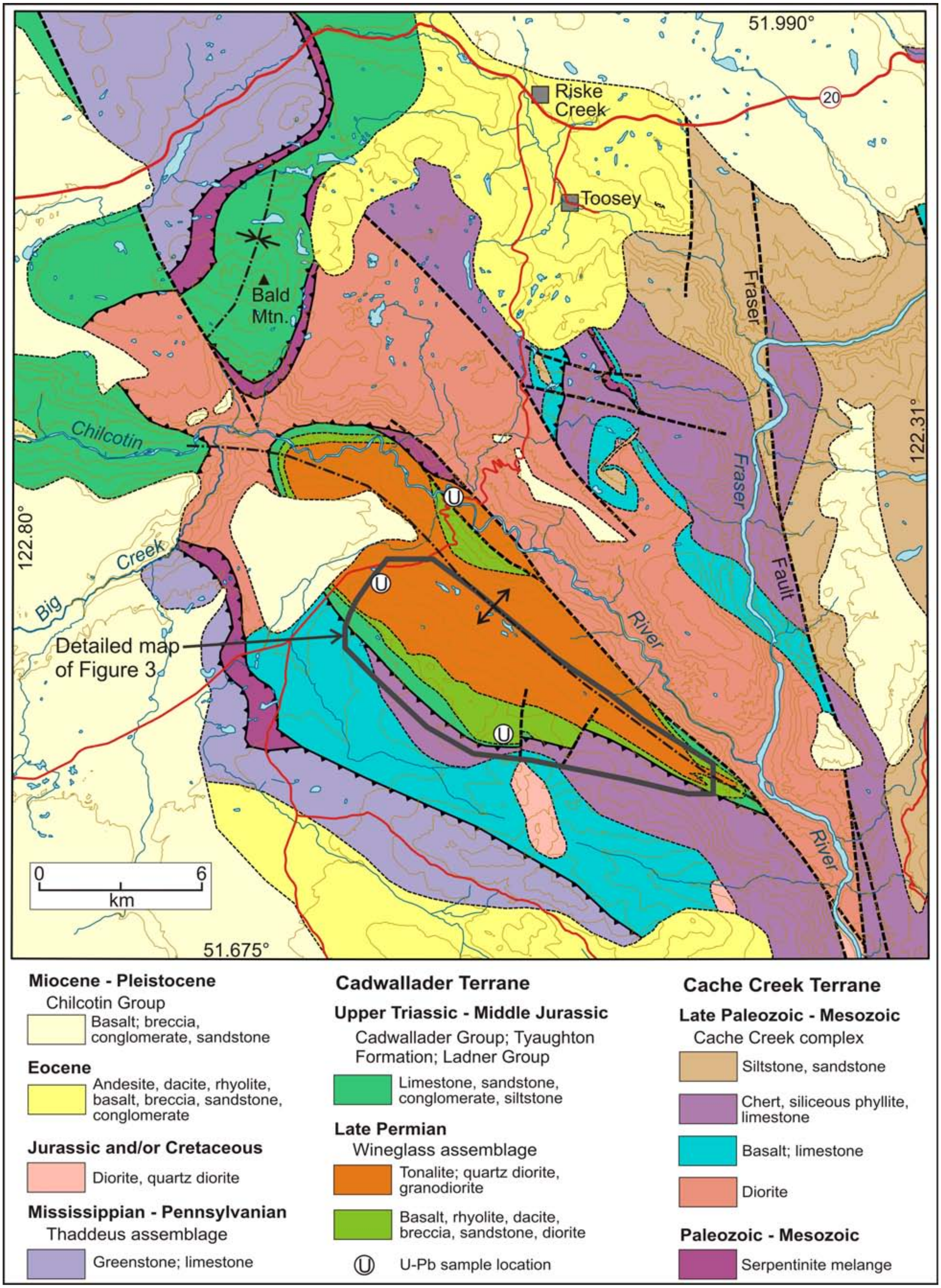

Fig. 2. Geological map of the lower Chilcotin River area, after Tipper (1978), Read (1993), and Mihalynuk and Harker (2007).

siliciclastic rocks correlated with the Tyaughton Formation and Ladner Group, prominent components of Cadwallader terrane elsewhere in the region. The predominant rocks within the window, however, are Late Permian volcanic and plutonic rocks of the Wineglass assemblage, which are unconformably overlain by the Mesozoic rocks. Following Read et al. (1995), this volcano-plutonic suite is included in Cadwallader terrane because of its position beneath the sub-Mesozoic unconformity.

The Thaddeus assemblage comprises massive greenstone that encloses limestone lenses with Mississippian and Pennsylvanian conodonts (Read, 1993). These rocks are thrust above Cache Creek terrane in the southern part of the lower Chilcotin River area, and above Cadwallader terrane in the northwestern part of the area (Fig. 2). Read (1993) noted that Thaddeus rocks are older than any known components of southern Cache Creek terrane, but are similar in age to the oldest known cherts from Bridge River terrane (Cordey and Schiarizza, 1993). However, Read et al. (1995) included the Thaddeus assemblage (Thaddeus slice) in the Pioneer Formation of Cadwallader terrane rather than correlating with either of these terranes. The Thaddeus assemblage was not examined during the present study, and no correlation is attempted herein.

Prominent structures in the lower Chilcotin River area include post-Early Jurassic thrust faults, folds that deform some thrust faults, and north- to northwest-striking faults related to the Eocene and younger Fraser fault system (Read, 1992, 1993). The thrust faults, typically defining the contacts between Cache Creek terrane, Cadwallader terrane, and Thaddeus assemblage, are commonly marked by zones of serpentinite melange. Read (1992, 1993) inferred that thrust movement was to the northeast, based in part on asymmetric folds in serpentinite melange at the south end of the Bald Mountain slice. However, the folded thrust that separates Cache Creek terrane from the Wineglass slice might be westerly directed, because Cache Creek terrane typically occurs to the east of Cadwallader terrane, and to the east of Wineglass correlatives in central and northern British Columbia. Thrust systems that might correlate with those in the lower Chilcotin River area include Jurassic imbrications of Cache Creek terrane and Sitlika assemblage in central British Columbia (Struik et al., 2001), and Cretaceous structures that imbricate Cadwallader terrane and associated rocks in southern British Columbia (Schiarizza et al., 1997). These systems include an older, predominant set of westerly-directed structures and a younger set of easterly-directed structures.

3. Geology of the southern part of the Wineglass slice

The southern part of the Wineglass slice was mapped to evaluate the possible correlation between the Kutcho and Wineglass assemblages (Figs. 3, 4). The area encompasses a large part of the Late Permian Wineglass pluton, as well as the thickest section of Late Permian volcanic rocks exposed within the slice, including locations where the pluton and volcanic rocks were dated. The map area also includes a substantial section of the overlying Mesozoic rocks, including the fossil locality that yielded an Early Jurassic ammonite.

3.1. Wineglass assemblage

The Wineglass assemblage comprises two major components: a volcanic succession and a tonalitic intrusive body referred to here as the Wineglass pluton. The volcanic succession is divided into two main units (Wv1 and Wv2). Unit Wv1 consists mainly of basalt, whereas unit Wv2 comprises a more heterogeneous package that includes rhyolite, basalt, and fine- to coarse-grained volcaniclastic rocks. Unit Wv2 is inferred to overlie unit Wv1 because the former is unconformably overlain by younger rocks of the Tyaughton Formation, although no independent younging indicators were observed in the volcanic succession. A third unit, Wva, comprises volcanic(?) rocks in the eastern part of the area which, because of poor exposure and intense alteration, could not be confidently assigned to either Wv1 or Wv2.

The Wineglass assemblage is assigned a Late Permian age on the basis of U-Pb zircon ages reported by Friedman and van der Heyden (1992) and Read (1993). Two ages reported by Read (1993) are from the current study area: 259 ±2 Ma on dacite of unit Wv2, and 254 ±1.2 Ma on leuco-quartz monzonite of the Wineglass pluton. Friedman and van der Heyden (1992) obtained a date of 258 ±5 Ma on quartz monzodiorite of the Wineglass pluton to the north of the current study area, at the bridge over the Chilcotin River (Fig. 2). A sample of rhyolite that was collected from unit Wv2 during the 2012 field season has been submitted to the geochronology laboratory at the University of British Columbia for U-Pb zircon geochronology.

3.1.1. Unit Wv1

Unit Wv1 consists mainly of basalt and weakly foliated chloritic schist, but also includes narrow units of felsic volcanic rock, as well as small bodies of diorite and tonalite. It is cut by tonalitic intrusive rocks of the Wineglass pluton to the north, and is in contact with (apparently overlain by) volcanic and volcaniclastic rocks of unit Wv2 to the south. The latter unit pinches out to the west, apparently due to erosion beneath the unconformity at the base of the Tyaughton Formation, such that unit Wv1 is directly overlain by the Tyaughton formation near the western boundary of the map area.

The predominant rock type of unit Wv1 is medium to dark green, greenish brown-weathered, fine-grained basalt that commonly contains 5-15% clinopyroxene and/or plagioclase phenocrysts, 1-2 mm in size. Patches, veins, and fracture-coatings of epidote ±calcite are ubiquitous, but vary from a minor to a very major component of any given exposure (Fig. 5). Secondary chlorite is also a highly variable component, and where abundant it typically displays a preferred orientation that

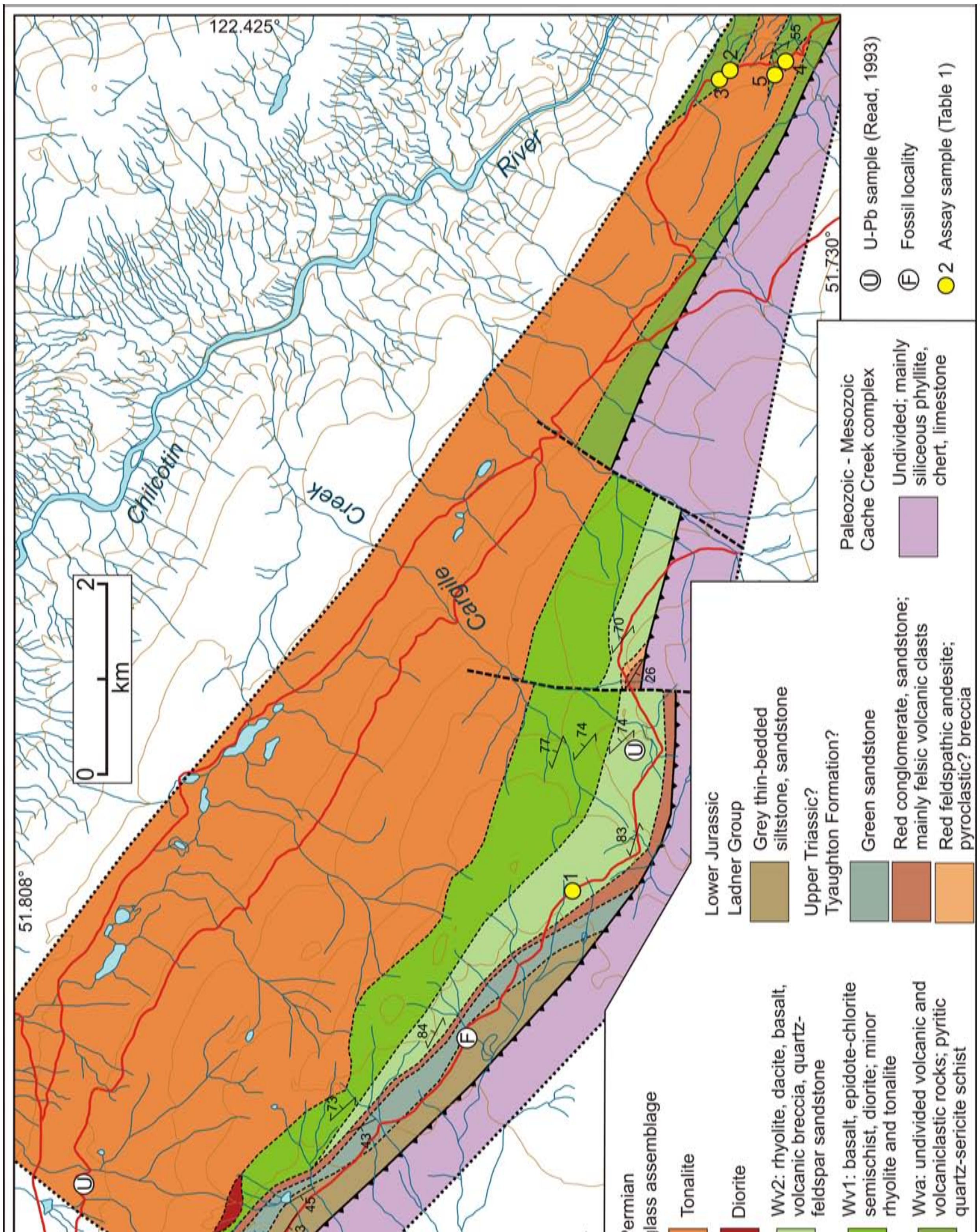

Fig. 3. Geology of the southern part of the Wineglass slice, based on 2012 fieldwork.

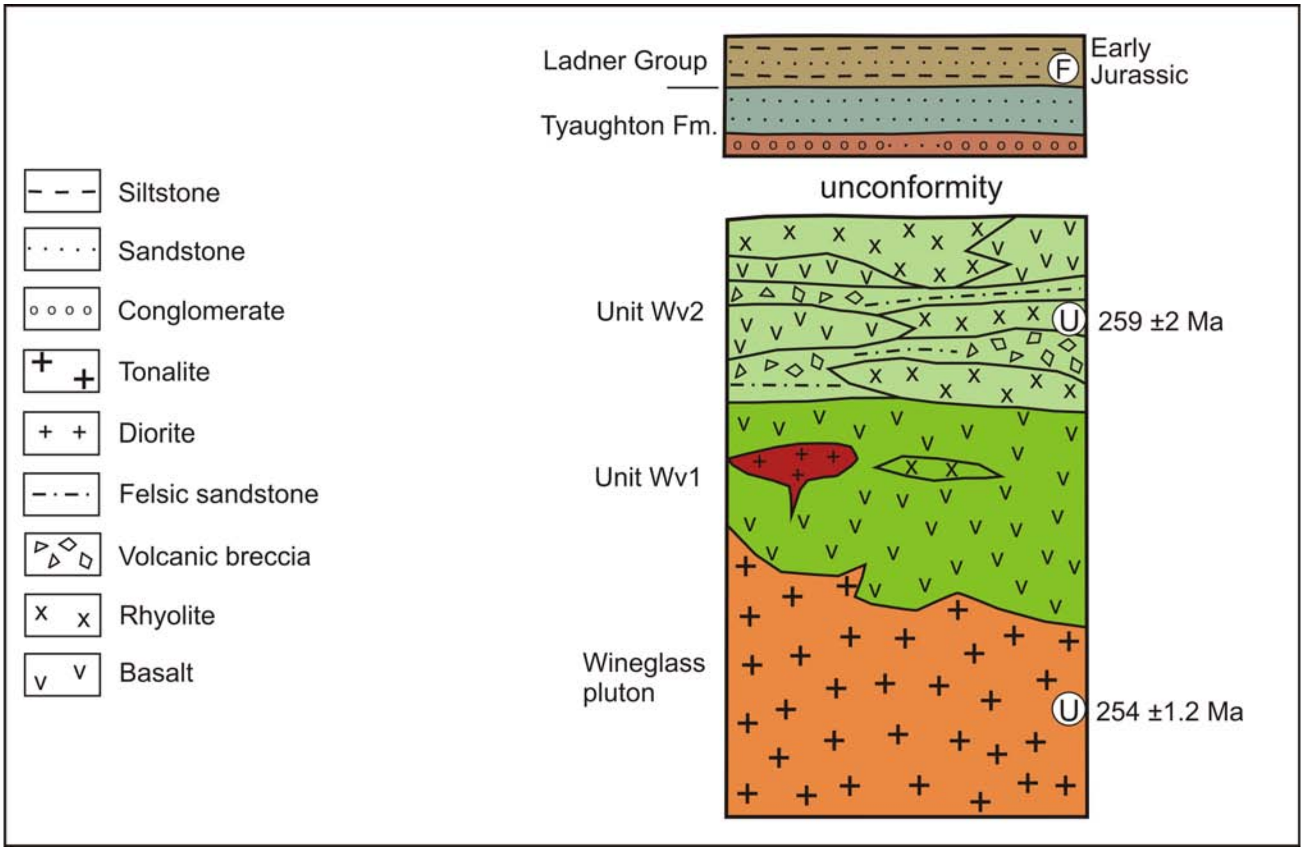

Fig. 4. Schematic stratigraphy of the Wineglass assemblage and overlying sedimentary rocks of the Tyaughton Formation and Ladner Group in the southern part of the Wineglass slice. Early Jurassic fossil determination reported in Hickson (1990); U-Pb zircon ages from Read (1993).

Fig. 5. Epidote-altered chloritic basalt, Wineglass assemblage, unit Wv1.

imparts a weak foliation to the rock. Thin sections show relatively fresh clinopyroxene and/or plagioclase phenocrysts set in a groundmass of variably saussuritized plagioclase, locally aligned in a trachytic texture, that is intergrown with secondary epidote-chlorite±actinolite.

Felsic volcanic rocks are uncommon in unit Wv1. They form 1-10 m wide tabular bodies within basalt, that may constitute dikes, sills, and flows. The felsic rocks are typically pale to medium grey or green, and display a very fine-grained to aphanitic quartzose groundmass, locally with faint flow laminae, containing small phenocrysts of plagioclase and/or quartz.

Diorite was noted at several localities within unit Wv1, and forms a small mappable body near the western boundary of the map area. Diorite exposures typically display strong epidote alteration, and are characterized by a fine- to medium-grained, equigranular, isotropic intergrowth of plagioclase and altered mafic grains. Small intrusive bodies of fine- to medium-grained, equigranular tonalite and quartz diorite, compositionally similar to the Wineglass pluton, are also present at scattered localities within unit Wv1.

3.1.2. Unit Wv2

Unit Wv2 is a heterogeneous succession that includes rhyolite, basalt, fragmental volcaniclastic rocks containing felsic and/or mafic volcanic clasts, and finer volcaniclastic rocks containing granules and sand-size grains of feldspar and quartz. It forms a panel that crops out south of, presumably stratigraphically above, unit Wv1. It is unconformably overlain by the Tyaughton Formation along most of its length, but locally may be in direct contact, across an inferred thrust fault, with siliceous phyllite and chert of the Cache Creek Complex (Fig. 3).

Coherent rhyolite units are typically pale grey to green, locally with a purplish to medium green mottle. They commonly include 10-25% phenocrysts of glassy quartz and white feldspar (1-4 mm) within an aphanitic to very fine-grained quartzofeldspathic groundmass (Fig. 6). Secondary sericite is common locally, and contributes to a weak foliation. Vague fragmental textures observed within some units may reflect autobrecciation.

Basalt units are typically medium to dark green, fine-grained, variably epidote-calcite-chlorite-altered schists, locally with small plagioclase and/or pyroxene phenocrysts, that resemble basalts from unit Wv1. However, pillow structures, not recognized in unit Wv1, occur locally in the upper part of unit Wv2 in the central part of the map area. Pillows typically display amygdaloidal cores (amygdules of chlorite and calcite), pervasive epidote alteration, and purplish hematite-altered rinds (Fig. 7).

Volcaniclastic rocks in unit Wv2 include both mafic and felsic varieties. Mafic varieties include medium to dark green, weakly to moderately foliated chloritic schists that contain fragments (<1-3 cm) of pale grey to green felsic volcanic rock and dark green mafic volcanic rock, locally accompanied by smaller mineral grains of plagioclase ±pyroxene (Fig. 8). Felsic varieties are pale grey to green, weakly foliated chlorite-sericite semischists that contain only felsic volcanic fragments, accompanied by grains of feldspar ±quartz. Finer grained felsic volcaniclastic rocks contain quartz, feldspar, and small lithic fragments in a matrix of weakly foliated chlorite, sericite, and fine quartzofeldspathic material (Fig. 9). Most of the volcaniclastic rocks of unit Wv2, are thought to have been deposited by epiclastic processes (e.g., Fig. 9).

Fig. 6. Quartz-plagioclase-phyric rhyolite, Wineglass assemblage, unit Wv2.

Fig. 7. Pillow from a pillowed basalt unit, Wineglass assemblage, unit Wv2.

Fig. 8. Fragmental rock with felsic and mafic volcanic clasts, Wineglass assemblage, unit Wv2.

Fig. 9. Well sorted, framework-intact volcaniclastic granulestone with subrounded fragments, Wineglass assemblage, unit Wv2.

3.1.3. Unit Wva

Rocks assigned to unit Wva are exposed only near the eastern edge of the map area, where they comprise highly-altered gossanous rocks that interfinger with less-altered tonalite of the Wineglass pluton. Most of the rocks included in unit Wva are pyrite-sericite-quartz semischists, locally with scattered relict grains of quartz and feldspar, which were probably derived from felsic volcanic or intrusive rocks. One exposure on the north side of the belt is a weakly pyritic, fine-grained chlorite-altered rock, with faint ghosts of relict feldspar, which may have been derived from a mafic volcanic rock.

3.1.4. Wineglass pluton

The Wineglass pluton forms most of the northern half of the study area. It is commonly represented by relatively resistant, light grey-weathered, blocky outcrops. The predominant rock type is a light greenish grey, medium- to coarse-grained, equigranular hornblende-biotite tonalite, locally grading to granodiorite or quartz diorite (Fig. 10). Mafic minerals commonly form 10-20% of the rock, with chloritized hornblende predominating over biotite. At one locality, the tonalite contains screens of an older phase, comprising fine grained, chlorite-epidote-altered hornblende diorite. Dikes of aplite and medium-grained leucotonalite cut the tonalite in several places. Contacts between tonalite and basalt were locally observed in the western part of the map area, confirming that the Wineglass pluton intrudes unit Wv1.

3.2. Sedimentary rocks overlying the Wineglass assemblage

A succession of southwest-dipping Mesozoic sedimentary rocks occurs above the Wineglass assemblage in the southwestern part of the map area (Fig. 3). These rocks were first discussed by Hickson (1990) who collected Early Jurassic (Toarcian) fossils from black shale, and suggested that they might belong to Cadwallader terrane. Read (1993) recognized felsic clasts in the basal part of the succession and suggested that it rested unconformably above the Permian rocks of the Wineglass assemblage. Here, the succession is subdivided into several mappable units, which are correlated with stratigraphic units of Cadwallader terrane, consistent with the interpretations of Hickson (1990) and Read et al. (1995). Lower units are tentatively assigned to the Upper Triassic Tyaughton Formation, based on similarities to Tyaughton exposures northwest of Bralorne (Umhoefer, 1990; Schiarizza et al., 1997) and east of Tatlayoko Lake (Schiarizza and Riddell, 1997; Schiarizza et al., 2002). The upper unit, which includes the Early Jurassic fossil locality, is included in the Lower to Middle Jurassic Ladner Group, following Read et al. (1995), as this group can reasonably be used to encompasses the various formal and informal Lower to Middle Jurassic clastic units that have been included in Cadwallader terrane (Umhoefer, 1990; Schiarizza et al., 1997; Schiarizza et al., 2002).

Fig. 10. Tonalite, south margin of the Wineglass pluton.

3.2.1. Tyaughton Formation

Rocks tentatively assigned to the Tyaughton Formation include two main components: a basal red conglomerate unit and an overlying unit of massive green sandstone. A third unit comprises red volcanic rocks, which occur within or below the red conglomerate unit in a set of small, poor exposures at one locality in the south-central part of the map area (Fig. 3).

The basal unit of the Tyaughton Formation consists mainly of red, locally green or mottled red/green, pebble conglomerate. Angular to subrounded clasts (generally 0.5-3 cm but up to 8 cm) are enclosed by a sand matrix of quartz, feldspar, and lithic grains (Fig. 11). The predominant clast types are pale grey, greenish-grey, beige or purple aphanitic felsic volcanic rocks, locally with small quartz and/or feldspar phenocrysts. Other clast types include light grey, fine- to medium-grained tonalite, medium to dark green mafic volcanic rock, grey or green chert, and grey-green microdiorite. The conglomerate defines poorly stratified layers up to several metres thick and thin to medium beds intercalated with gritty sandstone (Fig. 12). Local thinly bedded intervals of finer-grained rock include: red or green, medium- to fine-grained sandstone; red siltstone; and dark red mudstone.

The upper unit of the Tyaughton Formation consists of massive, blue-green to olive-green sandstone, which

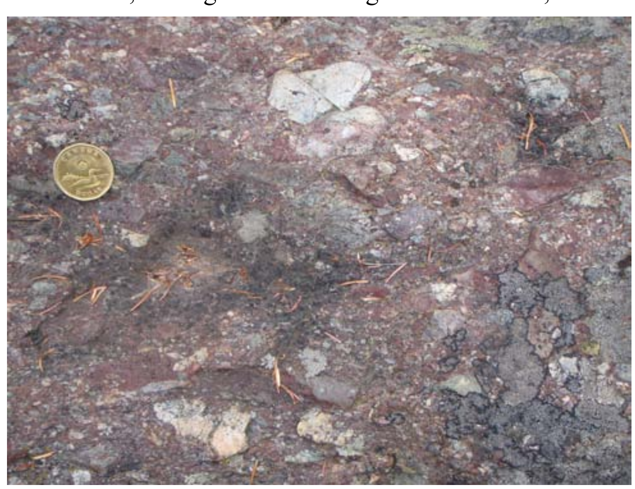

Fig. 11. Conglomerate, basal Tyaughton Formation.

Fig. 12. Interlayered conglomerate and parallel-stratified sandstone, lower Tyaughton Formation.

typically weathers to a greenish brown or rusty-brown colour. The sandstone is well indurated, medium to coarse grained, and composed mainly of feldspar, grey and green lithic grains, and quartz.

Red-coloured volcanic rocks tentatively included in the Tyaughton Formation occur as a single set of poor outcrops that underlie red conglomerate in the south-central part of the map area (Fig. 3). Volcanic rocks are absent in the type area of the Tyaughton Formation north of Bralorne (Umhoefer, 1990), but rare feldspathic tuffs are in the formation near Tatlayoko Lake (Schiarizza and Riddell, 1997). The volcanic rocks in the current map area include a fragmental unit directly beneath the conglomerate, and amygdaloidal andesite exposed a short distance to the northeast. The fragmental unit contains flattened intermediate volcanic clasts, up to 1.5 cm in longest dimension, in a weakly foliated matrix of similar composition. The andesite consists of small plagioclase phenocrysts and amygdules of chalcedonic quartz, in a very fine-grained groundmass with predominantly plagioclase laths, in part aligned in a trachytic texture.

3.2.2. Ladner Group

The Ladner Group, represented by only a few scattered exposures, consists of rusty-weathered, medium to dark grey, thinly bedded, variably calcareous, siltstone and fine- to medium-grained sandstone (Fig. 13). A fossil ammonite was collected from one exposure (Fig. 3), presumably the same location that yielded the Early Jurassic (Toarcian) fossil collection reported by Hickson (1990).

3.3. Cache Creek Complex

The Cache Creek Complex crops out at a few scattered localities near the southern margin of the map area (Fig. 3). Exposures in the southeast consist mainly of green to grey siliceous argillite containing thin contorted lenses of chert. A single exposure near the western margin of the map area comprises light grey-weathered, weakly foliated limestone. Contact relationships between the Cache Creek rocks and those of the adjacent Wineglass slice were not observed; the south-dipping thrust contact shown on Figure 3 is based on the interpretation of Read (1992, 1993).

Fig. 13. Thinly bedded siltstone and sandstone, Ladner Group.

3.4. Structure

Mesozoic sedimentary rocks of the Tyaughton Formation and Ladner Group form a right-way-up panel that dips at moderate angles to the southwest. Underlying volcanic rocks of the Wineglass assemblage are thought to young southwest also, but the orientation of layering is unknown; the few internal contacts observed, typically rhyolite against basalt, generally strike northwest and dip steeply, but might represent dikes rather than bedding orientations. A poor to moderately developed cleavage occurs sporadically within both the Wineglass assemblage and the overlying Mesozoic sedimentary rocks, and displays a fairly uniform orientation, with steep dips to the northeast. The only mesoscopic folds observed comprise a set of complex southwest-plunging folds with gently dipping axial surfaces that deform thin-bedded sedimentary rocks of the Ladner Group. These folds seem to predate the poorly developed cleavage, and it is suspected that they are soft-sediment structures.

According to the interpretation of Read (1992, 1993), the 2012 map area comprises the southwest limb of an anticline that is cored by the Wineglass slice, resulting in its exposure as a window beneath the Cache Creek Complex. The sparse structural observations outlined above are consistent with this interpretation.

3.5. Alteration and mineralization

An extensive zone of predominantly pyrite-sericite-quartz alteration, at least 600 m wide, encompasses the Farwell pluton and adjacent rocks assigned to unit Wva near the eastern boundary of the map area (Fig. 14). This zone has received some attention from exploration geologists (Morton, 1984; Benvenuto and Bailey, 1990) who have thus far failed to locate any base or precious metal occurrences. The alteration zone was mentioned by Read (1992), who noted that similar alteration occurs in the northwestern part of the Wineglass assemblage, along the Chilcotin River, 4.8 km downstream from the mouth of Big Creek (Fig. 2).

Fig. 14. Pyrite-sericite-quartz-altered rocks of the Wineglass assemblage, east end of 2012 map area.

The alteration zone at the east end of the map area consists of variably schistose pyrite-sericite-quartz-altered rocks interspersed with bodies of variably silicified ±sericite ±chlorite ±pyrite-altered tonalite. The schistosity dips at moderate angles to the southwest, as do a set of green microdiorite dikes that postdate the alteration. The altered rocks locally contain relict grains of feldspar and quartz, indicating a felsic volcanic or plutonic protolith, although one exposure at the north end of the belt consists of weakly pyritic chlorite-altered rock that may have been derived from basalt. Four grab samples collected from altered rocks within this zone yielded only background base and precious metal values (locations 2-5, Fig. 3, Table 1).

Weak to moderate pyrite alteration occurs in both rhyolite and basalt of unit Wv2 in and around the upper reaches of Cargile Creek, where old pits and trenches attest to past exploration. A sample of rusty pyritic rock, apparently in basalt, collected from one of these pits contained anomalous concentrations of zinc and lead (location 1, Fig. 3, Table 1).

4. Discussion

4.1. Correlation of the Wineglass, Sitlika and Kutcho assemblages

The Wineglass assemblage is correlated with the Kutcho assemblage and the volcanic unit of the Sitlika assemblage on the basis of a remarkable similarity in lithologic components, overlapping ages, similar structural relationships to Cache Creek terrane, and similar unconformable relationships with overlying Upper Triassic-Jurassic sedimentary rocks.

The Wineglass assemblage includes three major units, all of which have lithologic counterparts in the Kutcho and Sitlika assemblages. Mafic volcanic rocks of unit Wv1 are very similar to unit KS3 of the Kutcho assemblage (Schiarizza, 2012a) and to mafic volcanic rocks of the Sitlika volcanic unit exposed near Diver Lake (Schiarizza and Payie, 1997; Schiarizza and Massey, 2010). In all cases, basalt is predominant, but is intercalated with narrow units of felsic volcanic or volcaniclastic rock, and includes small bodies of diorite. Unit Wv2 resembles unit KC of the Kutcho assemblage (Schiarizza, 2011, 2012a), which overlies mafic volcanics of unit KS3, and includes coherent rhyolite, metabasalt, and volcaniclastic rocks containing felsic volcanic clasts and granules of quartz and feldspar. A similar heterogeneous package of mafic and felsic volcanic and volcaniclastic rocks forms the upper part of the Sitlika volcanic unit in the area between Mt. Olson and Mt. Bodine (Schiarizza and Payie, 1997; Schiarizza and Massey, 2010). Tonalitic intrusive rocks, similar to the Wineglass pluton, form two mappable stocks in the Sitlika volcanic unit (Schiarizza and Massey, 2010), and several mappable bodies within the Kutcho assemblage, including one sill-like pluton more than 12 km long (Schiarizza, 2012a, b).

U-Pb zircon crystallization ages for the Kutcho, Sitlika and Wineglass assemblages are summarized in Figure 15. The few ages for the Wineglass assemblage are older than many Kutcho and Sitlika determinations, but overlap with the oldest ages from both assemblages.

Correlation of the Kutcho assemblage, the volcanic unit of the Sitlika assemblage and the Wineglass assemblage is corroborated by a virtually identical stratigraphic and structural context. All three are unconformably overlain by Mesozoic sedimentary successions that include a lower conglomerate unit containing felsic volcanic and plutonic clasts probably derived from underlying rocks, and upper stratigraphic levels with predominantly siltstone and sandstone of known or suspected Lower-Middle Jurassic age

Table 1. Selected elements from analyses of altered rock. See Fig. 3 for locations. UTM coordinates are zone 10, North American Datum 1983.

Map Ref.	Sample	Easting	Northing	Rock Type	Mo PPM 0.1	Cu PPM 0.1	Pb PPM 0.1	Zn PPM 1	Ag PPM 0.1	As PPM 0.5	Au PPB 0.5	Sb PPM 0.1	Ba PPM 1	W PPM 0.1	Hg PPM 0.01
1	12PSC-28	530473	5733911	altered pyritic rock	0.5	47.1	29.1	237	<0.1	10	<0.5	0.2	22	<0.1	0.06
2	12PSC-84	539121	5732330	quartz-pyrite-sericite-altered rock	0.1	53.1	10.9	106	0.2	1.7	0.7	0.4	11	<0.1	<0.01
3	12PSC-85	539018	5732427	fractured green gossanous rock	0.5	3.8	7.4	130	<0.1	0.7	1.2	<0.1	8	<0.1	<0.01
4	12PSC-87	539205	5731724	pale green pyritic siliceous rock	0.2	65.9	2.3	61	<0.1	<0.5	<0.5	<0.1	4	<0.1	<0.01
5	12PSC-89	539090	5731847	pale green pyrite-altered rock	0.4	35.5	8	66	0.1	1.4	2.2	<0.1	21	<0.1	<0.01

Samples analysed at ACME Analytical Laboratories Ltd. , Vancouver BC, by ICP-MS following digestion of a 15 g sample split in hot Aqua Regia

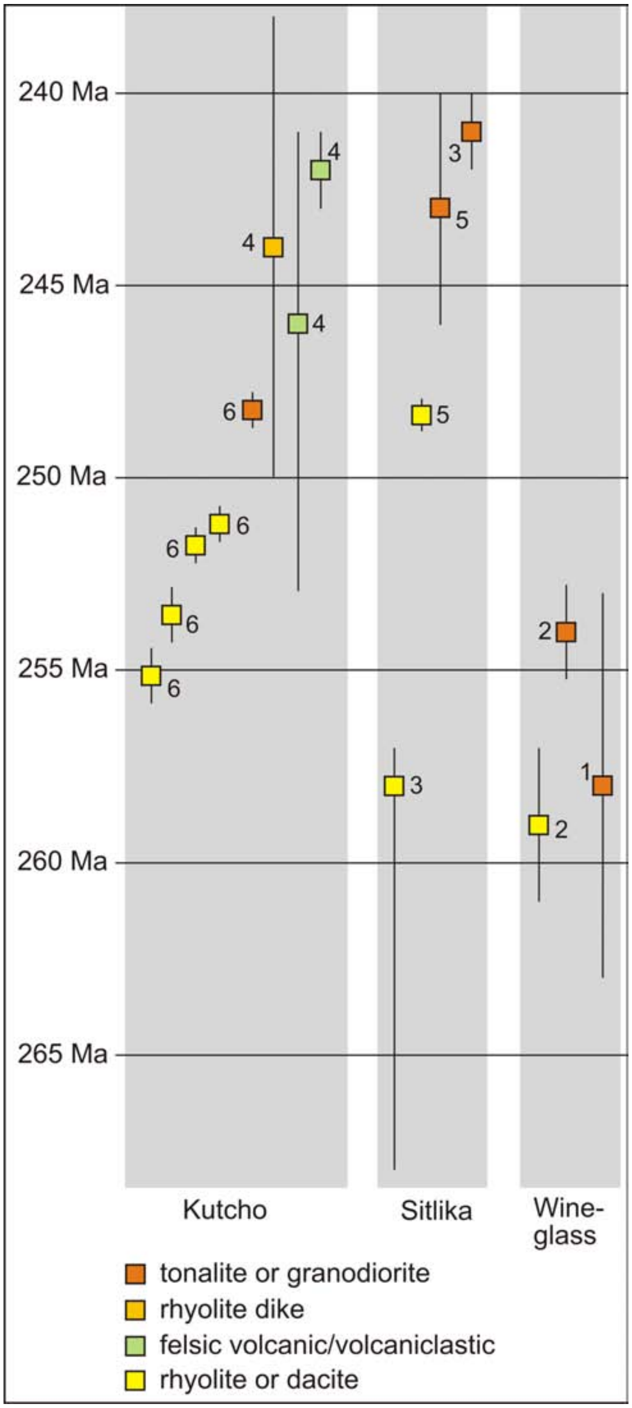

Fig. 15. Summary of U-Pb zircon ages for the Kutcho, Sitlika and Wineglass assemblages. Sources of information: 1) Friedman and van der Heyden, 1992; 2) Read, 1993; 3) Childe and Schiarizza, 1997; 4) Childe and Thompson, 1997; 5) M. Villeneuve in Struik et al., 2007; 6) R. Friedman in Schiarizza, 2012b.

(Schiarizza, 2012a; Schiarizza and Payie, 1997; Read, 1993; this study). In addition, all three Permo-Triassic packages, together with the unconformably overlying Mesozoic sedimentary rocks, are structurally beneath rocks of the Cache Creek Complex, along or near the western margin of Cache Creek terrane (Fig. 1).

The Mesozoic sedimentary rocks that overlie the Kutcho assemblage include discontinuous conglomerate and limestone units of suspected Upper Triassic age, and an extensive package of Lower to Middle Jurassic sandstones and siltstones assigned to the Inklin Formation (Schiarizza, 2012a). The Inklin Formation is the main component of the Whitehorse trough, a sedimentary basin that received detritus mainly from Stikine terrane (Fig. 1; Johannson et al., 1997; English et al., 2005). Similar sedimentary units that overlie the Sitlika volcanic unit are assigned to the clastic sedimentary unit of the Sitlika assemblage (Schiarizza and Payie, 1997; Schiarizza and Massey, 2010) and are probably an offset counterpart of the Whitehorse trough (Fig. 1). In contrast, the very similar Mesozoic rocks that overlie the Wineglass assemblage are included in Cadwallader terrane (Read et al., 1995; this study). This suggests that Cadwallader terrane has paleogeographic links to the Whitehorse trough and Stikine terrane, although addressing these connections is beyond the scope of this paper.

4.2. An expanded definition of Cadwallader terrane

Rusmore et al. (1988) interpreted Cadwallader terrane as a Late Triassic volcanic arc with a Late Triassic to Middle Jurassic fringing sedimentary apron (represented by the Cadwallader Group and the Tyaughton and Last Creek formations in the southern Chilcotin Ranges near Bralorne). Subsequent studies, the results of which are summarized in Figures 16 and 17, have expanded the known distribution of Cadwallader rocks, identified a major plutonic component to the Triassic arc system, included Lower and Middle Jurassic rocks formerly assigned to Methow terrane, and demonstrated that the Mesozoic rocks of Cadwallader terrane are underlain by an older, Late Permian arc system.

The type areas of the Cadwallader Group, the Tyaughton Formation, and the Last Creek Formation are in a large fault-bounded panel north-northwest of Bralorne (Fig. 16). The Cadwallader Group comprises Upper Triassic clastic sedimentary rocks and local limestone of the Hurley Formation and underlying arc basalt of the Pioneer Formation (Rusmore, 1987). The Tyaughton Formation consists of Upper Triassic shallow-marine and nonmarine clastic rocks and limestone that are in fault contact with the Cadwallader Group, and the Last Creek Formation is a transgressive sequence of Lower to Middle Jurassic siliciclastic rocks that overlies the Tyaughton Group disconformably (Umhoefer, 1990). The Cadwallader Group also crops out in numerous fault-bounded slivers southeast of its type area, where it is structurally interleaved with chert, basalt and related rocks of the oceanic Bridge River terrane along complex systems of thrust and strike-slip faults of Cretaceous and Tertiary age (Schiarizza et al., 1997). The Cadwallader rocks within these fault slices are almost invariably accompanied by fault panels of Early Permian diorite, basalt, and serpentinized ultramafite, including the Bralorne diorite which hosts mesothermal gold-quartz

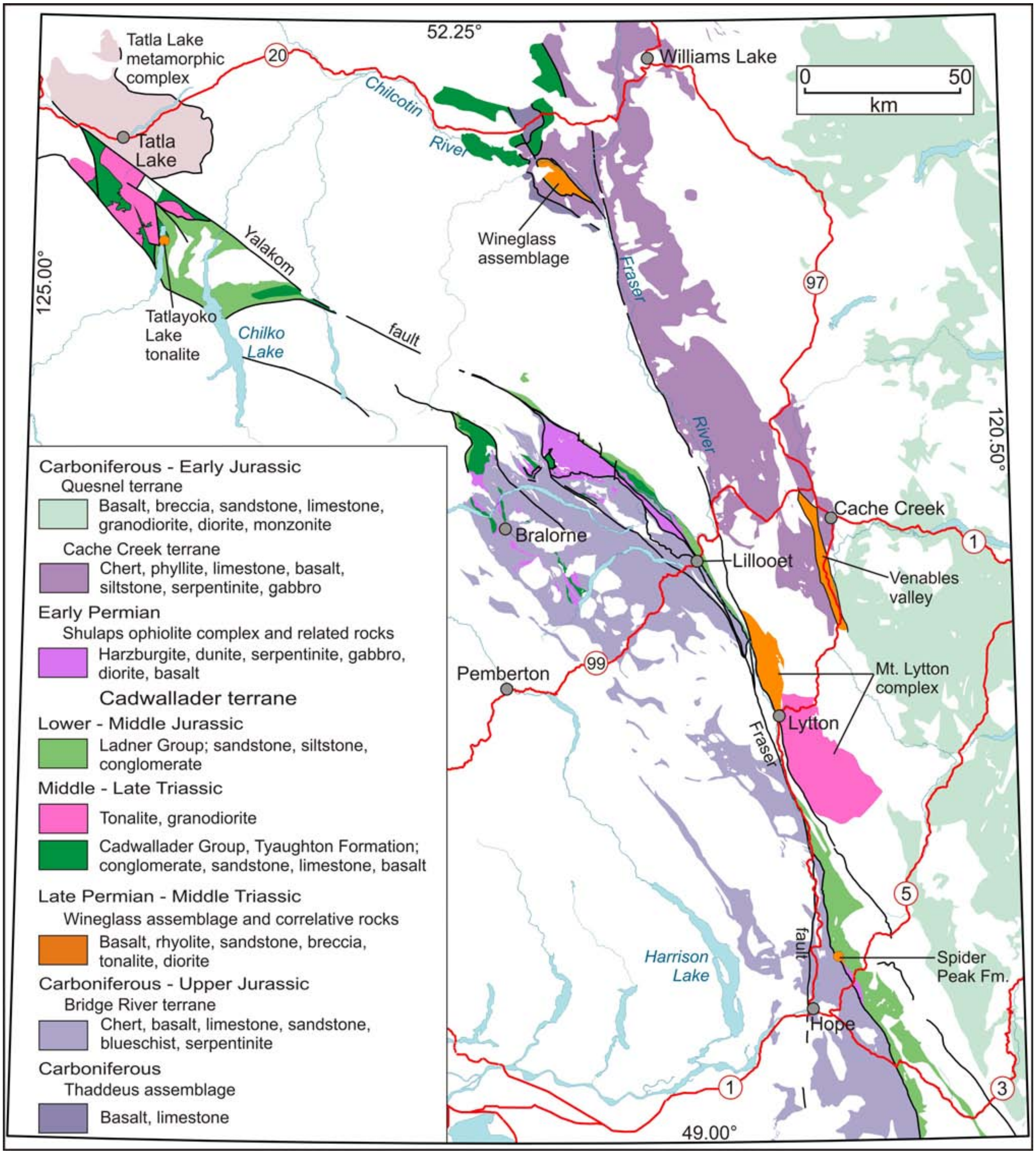

Fig. 16. Map of part of southern British Columbia highlighting Cadwallader terrane and adjacent Paleozoic to mid-Mesozoic terranes. Modified from Massey et al. (2005). Uncoloured areas are mainly younger rocks, including Upper Jurassic and Cretaceous siliciclastic rocks of the Tyaughton-Methow basin, which overlap Cadwallader and Bridge River terranes (see Fig. 17).

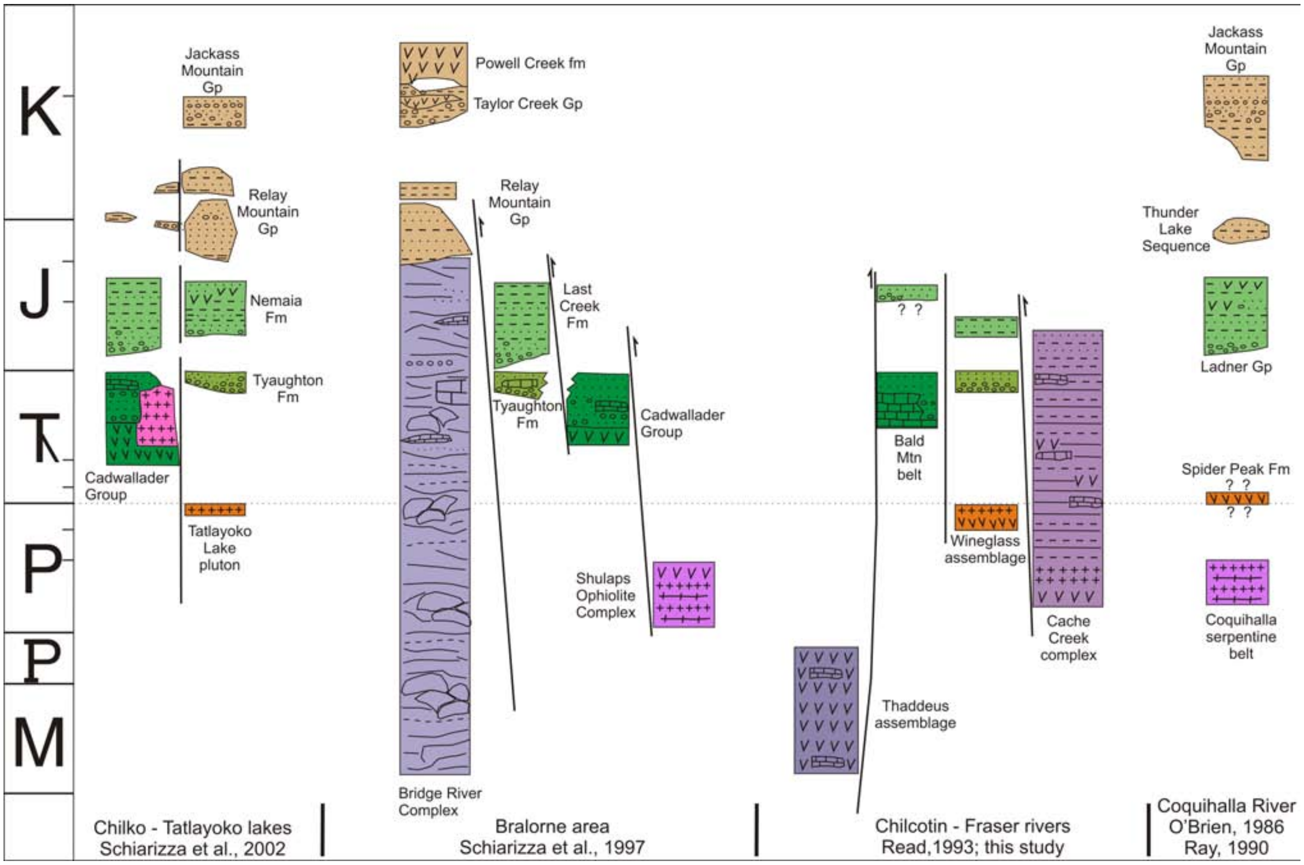

Fig. 17. Schematic stratigraphic sections for Cadwallader terrane and associated units. Upper Triassic and Lower to Middle Jurassic rocks of Cadwallader terrane shown in shades of green; Late Triassic plutons of Cadwallader terrane are magenta; Permo-Triassic rocks of Cadwallader terrane are orange. Pale brown colour denotes Upper Jurassic and Cretaceous rocks of the Tyaughton-Methow basin.

veins at the Bralorne and Pioneer mines. These panels of ultramafic-mafic rock may be related to the Shulaps ophiolite complex, which lies structurally above the Cadwallader Group northeast of Bralorne (Fig. 16).

The Cadwallader Group, Tyaughton Formation, and overlying Lower to Middle Jurassic rocks (Nemaia Formation of Schiarizza et al., 2002) are also exposed over a broad area near Chilko and Tatlayoko lakes (Fig. 16). These exposures are bounded to the northeast by the Yalakom fault, along which they were translated about 115 km to the northwest in early Tertiary time (Riddell et al., 1993; Umhoefer and Schiarizza, 1996). Cadwallader terrane in this area also includes several large plutons consisting of Late Triassic tonalite, granodiorite, and diorite, with crystallization ages ranging from 231 to 207 Ma (Friedman and Schiarizza, 1999; Schiarizza et al., 2002).

The Lower and Middle Jurassic rocks of Cadwallader terrane in the Chilko Lake – Tatlayoko Lake area were referred to as the Huckleberry formation by Schiarizza and Riddell (1997) and the Nemaia Formation by Schiarizza et al. (2002). These rocks are generally similar to the Last Creek Formation, but include some intermediate to mafic volcanic and volcaniclastic rocks in the Middle Jurassic part of the section (Schiarizza and Riddell, 1997). The Nemaia Formation, together with overlying Jura-Cretaceous sedimentary rocks of the Tyaughton-Methow basin (Relay Mountain and Jackass Mountain groups), can be traced southeastward, with significant dextral offsets along the Yalakom and Fraser faults, into identical rocks of the Lower to Middle Jurassic Ladner Group, which forms a linear belt extending from south of Lytton to the international boundary (Fig. 16; O'Brien, 1986; Mahoney, 1992, 1993; Schiarizza and Riddell, 1997; Schiarizza et al., 1997). The Ladner Group was previously assigned to the basal part of the Methow trough (O'Brien, 1986) or Methow terrane (Wheeler et al., 1991), but is here included in Cadwallader terrane, as suggested by Schiarizza and Riddell (1997), based on its correlation with the Nemaia Formation. Overlying Upper Jurassic and Cretaceous siliciclastic sedimentary rocks are included in the Tyaughton-Methow basin, which overlaps Cadwallader and Bridge River terranes (Umhoefer et al., 2002).

The Wineglass assemblage, first included in Cadwallader terrane by Read et al. (1995), is a Late Permian component of the terrane that has not been widely recognized. It is included in Cadwallader terrane because it rests stratigraphically beneath Mesozoic rocks that are correlated with the Tyaughton Formation and Ladner Group. Corroboration of a stratigraphic relationship between Triassic rocks of Cadwallader terrane and an older, Late Permian arc assemblage comes from the large belt of Cadwallader terrane rocks in the Chilko Lake – Tatla Lake area. Within this belt, an altered tonalite pluton exposed on the east shore of Tatlayoko Lake is nonconformably overlain (contact exposed and described by Schiarizza et al., 1995) by fossiliferous Upper Triassic rocks of the Tyaughton Formation, which in turn are apparently overlain (contact not exposed) by Lower Jurassic rocks of the Nemaia Formation (Tipper, 1969; Schiarizza et al., 2002). The tonalite body beneath the unconformity has yielded a U-Pb zircon age of 253.8 ±1.4 Ma (Friedman and Schiarizza, 1999; Schiarizza et al., 2002), virtually identical to the age for the Wineglass pluton reported by Read (1993).

In summary, Cadwallader terrane, as used in this report, includes a Late Permian volcanic-plutonic arc complex, and an overlying Late Triassic to Middle Jurassic arc complex and related arc-derived sedimentary sequence. The Late Permian component is best represented by the Wineglass assemblage. The Mesozoic component includes the traditional units of Cadwallader terrane (Cadwallader Group, Tyaughton Formation, Last Creek Formation), Late Triassic plutons mapped around Tatlayoko Lake, and Lower to Middle Jurassic rocks previously included in Methow terrane (Ladner Group).

4.3. Other possible Kutcho-Sitlika-Wineglass correlatives in southern British Columbia

The Wineglass assemblage, and the Late Permian tonalite body that underlies the Tyaughton Formation along Tatlayoko Lake, show that Kutcho-correlative rocks are basement to Triassic-Jurassic rocks of Cadwallader terrane. Three additional occurrences of Late Permian or Early-Middle Triassic rocks that might correlate with the Kutcho-Wineglass assemblage are briefly described here. At least two of these are reasonably included in Cadwallader terrane.

4.3.1. Mount Lytton complex

The Mount Lytton complex is a belt of mainly plutonic rocks, 70 km long and up to 20 km wide, that is exposed on the east side of the Fraser River near the town of Lytton (Fig. 16). It includes granodioritic to dioritic plutonic rocks, as well as screens of layered quartzofeldspathic rock and amphibolite and, in the southern part of the complex, screens of carbonate (Monger and McMillan, 1989; Monger, 1989). External contacts are mainly faults, but locally the complex is unconformably overlain by mid-Cretaceous volcanic rocks of the Spences Bridge Group, or intruded by Jura-Cretaceous rocks of the Eagle Plutonic complex. Tonalite from the northern part of the complex yielded a U-Pb zircon age of 250 ±5 Ma (Friedman and van der Heyden, 1992), quartzofeldspathic gneiss farther south was assigned a U-Pb zircon age of 225 ±5 Ma (Parrish and Monger, 1992), and granodiorite from the east-central margin of the complex yielded a U-Pb zircon age of 212 ±1 Ma (Parrish and Monger, 1992). The Late Permian age from the northern part of the Mount Lytton complex prompted Friedman and van der Heyden (1992) to speculate that it correlated with the Wineglass pluton. The Late Triassic ages presented by Parrish and Monger (1992) are within the range (231-207 Ma) obtained from plutonic rocks of Cadwallader terrane near Tatlayoko Lake (Friedman and Schiarizza, 1999; Schiarizza et al., 2002). It may be that the Mount Lytton complex is an uplifted belt exposing relatively deep levels of Cadwallader terrane, including plutonic rocks related to both the Late Permian and Late Triassic arc systems.

4.3.2. Spider Peak Formation

The Spider Peak Formation is a basalt unit that crops out locally in the Coquihalla River area, northeast of Hope (Figs. 16, 17). The base of the unit is a system of faults, related to the Hozameen fault system, and the upper contact is an unconformity with overlying Lower to Middle Jurassic rocks of the Ladner Group (O'Brien, 1986; Monger, 1989; Ray, 1990). The Spider Peak Formation consists of mainly low-potassium tholeiitic basalts, but also includes gabbro and minor amounts of tuff, argillite, volcanic sandstone, and tuffaceous conglomerate that contains quartz grains and felsic volcanic fragments (Ray, 1990). The formation is undated, but Ray (1990) noted that angular chert fragments in conglomerate directly above the unconformity, with conodonts of probable Early Triassic age, might have been derived from interpillow chert breccias of the Spider Peak Formation. Although an Early Triassic age is unproven, the presence of quartz and felsic volcanic-bearing clastic rocks within the basalt, and the unconformable relationship with overlying Ladner Group, invite speculation that the Spider Peak Formation might be related to the Kutcho-Wineglass assemblage.

4.3.3. Venables Valley belt

The Venables Valley belt is a narrow fault-bounded panel of felsic to mafic volcanic and volcaniclastic rocks and associated tonalitic and dioritic intrusions, that is exposed west and south of the town of Cache Creek (Fig. 16). These rocks were assigned mainly to the western belt of the Upper Triassic Nicola Group (Quesnel terrane) by Grette (1978), Ladd (1978) and Monger and McMillan (1989). However, the belt was later correlated with the Kutcho and Sitlika assemblages on the basis of comparable low-potassium tholeiitic geochemistry, primitive Nd isotopic signatures, and an Early to Middle Triassic U-Pb zircon age of 242 ±2 Ma on a tonalite intrusion (Childe et al., 1997, 1998). This correlation is compelling, but the structural position of the belt, near the eastern edge of Cache Creek terrane, is difficult to reconcile with the structural position of the Kutcho, Sitlika and Wineglass assemblages, which are structurally beneath the western edge of Cache Creek terrane.

4.4. Correlation of Cadwallader and Wallowa terranes

Paleozoic-Mesozoic rocks in the Blue Mountains region of northeastern Oregon and west-central Idaho comprise an inlier that is isolated from terranes to the north and southwest by younger cover, including the Columbia River basalts. These rocks are assigned to three major terranes: Olds Ferry, Baker and Wallowa (Fig. 18). There seems to be general agreement that Olds Ferry and Baker terranes correlate with Quesnel and Cache Creek terranes, respectively, of the Canadian Cordillera (Mortimer, 1986; Monger and Nokleberg, 1996). Correlations for Wallowa terrane are more controversial. It is most commonly correlated with either Wrangellia (Jones et al., 1977; Wernicke and Klepacki, 1988; Kurz et al., 2012) or Stikine terrane (Mortimer, 1986), but has also been correlated with Cadwallader terrane (Umhoefer, 1990; Monger and Nokleberg, 1996).

Wallowa terrane consists of two main components: a Permian submarine intra-oceanic arc complex, and a younger Late Triassic-Middle Jurassic assemblage of arc volcanic and plutonic rocks and arc-related sedimentary rocks (Follo, 1992, 1994; Kays et al., 2006; Kurz et al., 2012). The older component of the terrane has yielded U-Pb crystallization ages on plutonic rocks that overlap those of the Kutcho-Sitlika-Wineglass assemblages (Walker, 1995; Kurz et al., 2012), and hosts Cu-Zn-Ag massive sulphide prospects that resemble the Kutcho Creek deposit of northern British Columbia (Fifarek, 1994).

Previous correlations between Cadwallader and Wallowa terranes (Umhoefer, 1990; Monger and Nokleberg, 1996) have been based on a marked similarity of the Mesozoic rocks in the two terranes, including Middle to Upper Triassic predominantly mafic arc volcanic rocks, Late Triassic arc plutonic rocks, Upper Triassic limestone and arc-derived siliciclastic sedimentary rocks, and Lower to Middle Jurassic siliciclastic sedimentary rocks (Rusmore, 1987; Umhoefer, 1990; Schiarizza et al., 2002; Follo, 1992, 1994; Kays et al., 2006; Kurz et al., 2012). The expanded definition of Cadwallader terrane presented herein strengthens this correlation by including a Late Permian-Early Triassic intra-oceanic arc assemblage, which is markedly similar to the Permian rocks of Wallowa terrane. This correlation is consistent with the spatial relationship of Cadwallader and Wallowa terranes to Cache Creek-Baker and Quesnel-Olds Ferry terranes (Fig. 18), particularly when it is noted that terranes of the Blue Mountains region attain a more north-south orientation when 65º or more post-Early Cretaceous clockwise rotation is restored (Kay et al., 2006; Wilson and Cox, 1980).

5. Conclusions

In the lower Chilcotin River area, the Wineglass assemblage (new name) and unconformably overlying sedimentary rocks are exposed in a structural window enclosed by overthrust rocks of Cache Creek terrane. The

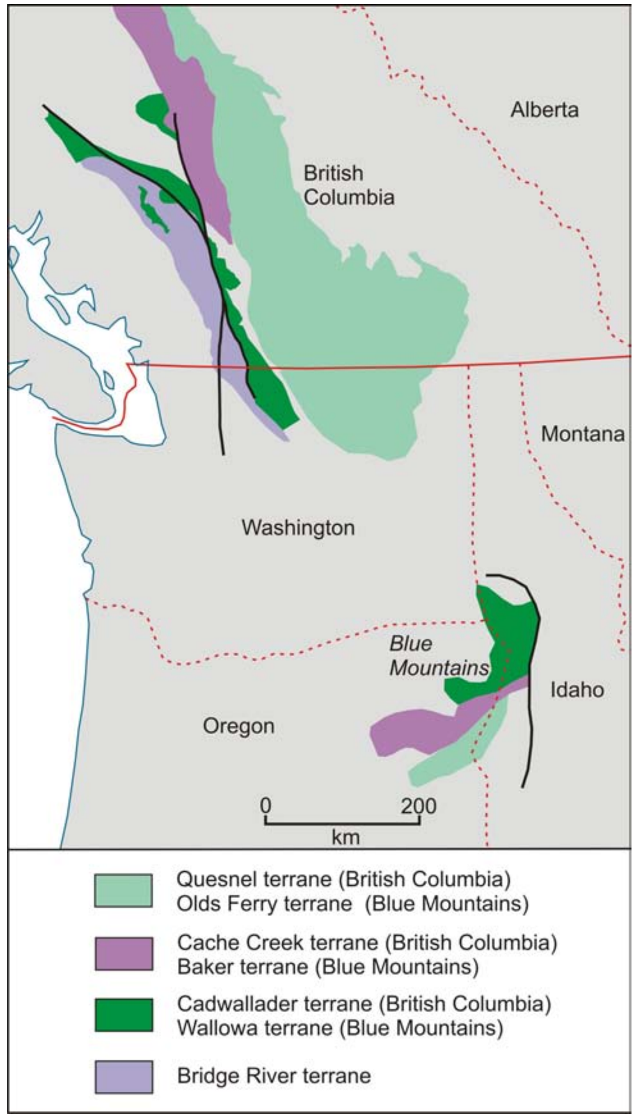

Fig. 18. Map of southern British Columbia and the adjacent United States, showing the distribution of Cadwallader, Wallowa and associated terranes.

Wineglass assemblage comprises Late Permian volcanic rocks cut by a Late Permian tonalitic pluton. The volcanic rocks are subdivided into a lower unit of predominantly basalt, and an upper unit of rhyolite, basalt, and volcaniclastic rocks. The Wineglass assemblage is unconformably overlain by Upper Triassic(?) and Lower Jurassic siliciclastic rocks that are correlated with the Tyaughton Formation and Ladner Group of Cadwallader terrane.

The Wineglass assemblage is correlated with the Kutcho assemblage of northern British Columbia, and its offset counterpart, the Sitlika volcanic unit, of central British Columbia. The correlation is based on a striking similarity of all lithologic components, overlapping U-Pb zircon ages, similar unconformable relationships with overlying Triassic-Jurassic sedimentary successions, and similar structural relationships to overthrust Cache Creek terrane.

The unconformable stratigraphic relationship between the Wineglass assemblage and Mesozoic clastic sedimentary rocks of Cadwallader terrane indicates that the Late Permian rocks of the Wineglass assemblage are part of Cadwallader terrane, as suggested by Read et al. (1995). Late Permian tonalite that nonconformably underlies Upper Triassic and Lower Jurassic rocks of Cadwallader terrane along Tatlayoko Lake (Schiarizza et al., 2002) confirms this relationship, and suggests that this older component of Cadwallader terrane may be widespread. Late Permian granitic rocks documented within the northern part of the Mt. Lytton complex may also correlate with plutonic rocks of the Wineglass assemblage, as suggested by Friedman and van der Heyden (1992), and Late Triassic granodiorite that forms part of the Mt. Lytton complex may correlate with Late Triassic plutons that form a prominent component of Cadwallader terrane near Tatlayoko Lake.

Upper Triassic and Jurassic rocks of Cadwallader terrane are similar to age-equivalent rocks of Wallowa terrane, exposed in the Blue Mountains area of eastern Oregon and adjacent Idaho and Washington states (Umhoefer, 1990; Monger and Nokleberg, 1996), although Wallowa terrane has more commonly been correlated with either Wrangellia or Stikine terranes. Wallowa terrane includes both a Late Triassic – Early Jurassic arc sequence, and a Permian arc sequence of bimodal volcanic and associated plutonic rocks. The Wineglass assemblage shows a strong resemblance to the Permian component of Wallowa terrane, and expanding the definition of Cadwallader terrane to include the Wineglass assemblage and correlatives strengthens the case for a Cadwallader – Wallowa correlation.

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