Detrital zircons from the Gun Lake unit, Gold Bridge area, southwestern British Columbia

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Abstract

Undated siliciclastic rocks that rest above the Bridge River complex (Mississippian-Jurassic) at several localities near Gold Bridge were previously assigned to the Gun Lake unit and thought to correlate with the basal Callovian-early Oxfordian unit of the Relay Mountain Group (lower Tyaughton basin). Detrital zircons analyzed from two of these localities show that the sampled rocks represent two different units, both younger than the basal unit of the Relay Mountain Group. The Gun Lake unit near Downton Lake contains detrital zircons ranging from 180 to 118 Ma. We now correlate these rocks with the Paradise Formation (Aptian-early Albian) of the Taylor Creek Group (upper part of the Tyaughton basin). Our results are consistent with previous interpretations of a western source in the southwest part of the Coast belt. The Gun Lake unit near Truax Creek contains detrital zircons that mostly fall within a restricted time span between 165 and 142 Ma, with a much smaller population of Late Triassic (214-208 Ma) grains. These rocks, and the adjacent Truax Creek conglomerate, are here correlated with the middle (upper Oxfordian-Valanginian) unit of the Relay Mountain Group. A likely source area to the northeast includes Cadwallader terrane and a Late Jurassic volcanic-plutonic belt that cuts across it.

Keywords: Gun Lake unit, Bridge River complex, Tyaughton basin, Relay Mountain Group, Taylor Creek Group, Paradise Formation, Cayoosh assemblage

1. Introduction

Bridge River terrane is a tract of oceanic rocks exposed in the eastern Coast Mountains of southwestern British Columbia (Fig. 1), where it forms the boundary between markedly different geologic domains. To the west are assemblages of the southwestern Coast belt (Monger and Journeay, 1994), including the Harrison arc terrane (Triassic-Jurassic), Early Cretaceous arc volcanic and sedimentary rocks of the Gambier Group, and voluminous Middle Jurassic to Late Cretaceous granitic intrusions. To the east are Cadwallader, Cache Creek and Quesnel terranes (late Paleozoic-Middle Jurassic), the Methow basin (Jurassic-Cretaceous), and belts of Late Jurassic and Early Cretaceous volcanic and plutonic rocks that cut across the older terrane boundaries (Monger, 1989; Monger and McMillan, 1989; Mahoney et al., 2013; Schiarizza, 2013).

Bridge River terrane consists mainly of Paleozoic-Mesozoic assemblages of predominantly chert and basalt that Monger and Journeay (1994) considered part of a subduction-related accretionary wedge. The Bridge River complex is the predominant component; correlative rocks of the Hozameen Group form the southeast part of the terrane, and rocks of the Cogburn Group, metamorphosed to amphibolite grade, form the southwestern part (Monger, 1989). Siliciclastic sedimentary and metasedimentary rocks are distributed along the full length

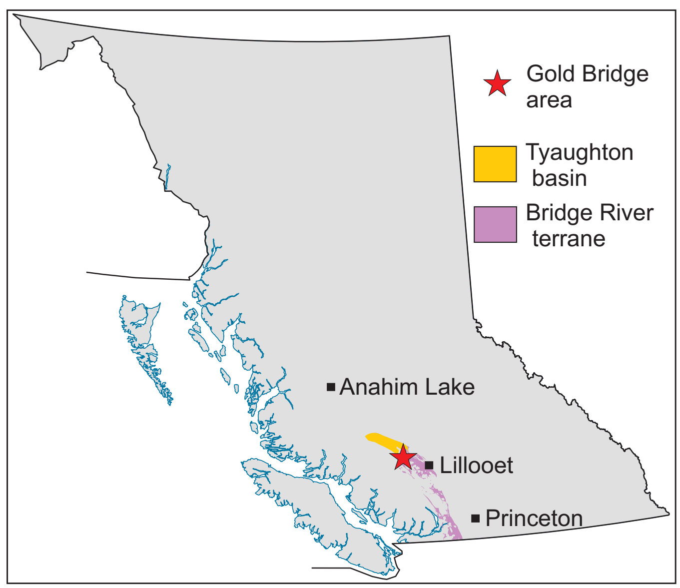

Fig. 1. Location of the Gold Bridge area and the main exposures of the Bridge River terrane and Tyaughton basin.

of the terrane and include the Cayoosh assemblage (above the Bridge River complex), and the correlative(?) Settler schist, which is spatially associated with the Cogburn Group in the southwest part of the terrane (Monger, 1989, 1991; Journeay and Mahoney, 1994). These siliciclastic rocks are commonly included in Bridge River terrane, but it is generally unclear if they are an integral part or represent an overlying overlap assemblage (Monger and Journeay, 1994).

The Bridge River complex is best understood near the northern limit of Bridge River terrane, near Gold Bridge, where Cordey and Schiarizza (1993) interpreted it as an accretionary complex because of its lithologic components (radiolarian chert, basalt, glaucophane schist), wide age range (Mississippian to late Middle Jurassic), and lack of a coherent stratigraphy. Siliciclastic rocks inferred to rest depositionally above the Bridge River complex at several localities in this area were mapped as the Gun Lake unit by Schiarizza et al. (1997). Undated, these rocks were thought to correlate with the Relay Mountain Group (lower part of Tyaughton basin) exposed to the north and/or to parts of the Cayoosh assemblage overlying the Bridge River complex to the south. In this study we analyzed detrital zircons from two samples of the Gun Lake unit, to establish maximum depositional ages, provenance, and possible correlations with strata of the Tyaughton basin.

2. Geology of the Gold Bridge area

The community of Gold Bridge, 180 km north of Vancouver, is in the valley of the Bridge River, now occupied by Downton and Carpenter lakes, which cuts through rugged terrain of the southeastern Coast Mountains (Fig. 2). The area around Gold Bridge is underlain predominantly by chert, basalt and related rocks of the Bridge River complex (Mississippian to Jurassic). It is also underlain by Jura-Cretaceous siliciclastic rocks of the Tyaughton basin, undated siliciclastic rocks that rest stratigraphically above the Bridge River complex south of the Tyaughton basin (Gun Lake unit and Cayoosh assemblage), fault panels containing late Paleozoic and Mesozoic rocks of the Cadwallader arc terrane, and Late Cretaceous and Tertiary granitoid intrusions (Fig. 2). Structures in the area include several generations of southwest-directed thrusts (mid- to Late Cretaceous), slightly younger northeast-vergent thrusts and folds, and an array of northwest-trending dextral strike-slip faults and related structures that are part of the latest Cretaceous and early Tertiary Yalakom fault system (Umhoefer and Schiarizza, 1996; Schiarizza et al., 1997). Within the Bridge River complex these map-scale structures are superimposed on older structures attributed to deformation in an accretionary complex.

The Bridge River complex comprises rocks previously referred to as Bridge River Series (McCann, 1922), Fergusson Series (Cairnes, 1937, 1943) and Bridge River Group (Woodsworth, 1977). It is a heterogeneous assemblage of rocks lacking a coherent map-scale stratigraphy and with many outcrop-scale faults and folds (Schiarizza et al., 1997). Radiolarian chert and basalt are the predominant components, but it also includes argillite, limestone, gabbro, diabase, serpentinite, sandstone, siltstone, and conglomerate. Cherts dated with radiolarians range from Mississippian to late Middle Jurassic (Cordey and Schiarizza, 1993), limestones dated with conodonts are mainly Late Triassic, and a belt of blueschist-facies rocks, traced for 14 km near Tyaughton Lake (Fig. 2) has yielded Late Triassic Ar-Ar ages on white mica (Schiarizza et al., 1997).

The Tyaughton basin, exposed mainly north and northwest of the Gold Bridge area, includes a lower component (late Middle Jurassic to Early Cretaceous) represented by sandstone, siltstone, shale, and conglomerate of the Relay Mountain Group (Umhoefer et al., 2002), and an upper component (mid-Cretaceous) represented by the Taylor Creek Group and Silverquick Formation (Garver, 1989, 1992). The Relay Mountain Group is subdivided into lower (Callovian-lower Oxfordian), middle (upper Oxfordian-Valanginian), and upper (Hauterivian) units. The base of the group is not exposed, but it is inferred to have been deposited, at least in part, on the Bridge River complex (Schiarizza et al., 1997; Umhoefer et al., 2002). The Taylor Creek Group comprises synorogenic conglomerates, sandstones, and shales that were deposited unconformably above the Relay Mountain Group and, locally, the Bridge River complex. It includes three main compositionally distinct units (Garver, 1989, 1992): one derived from volcanic rocks to the west (Paradise Formation); one derived mainly from the Bridge River complex (Dash Formation); and one consisting of arkoses derived from the east (Lizard Formation).

The Relay Mountain Group crops out only in the northwest corner of the Gold Bridge area, where it is structurally overlain to the east by fault panels of Cadwallader terrane and is truncated to the south by Late Cretaceous granodiorite (Fig. 2). However, a narrow fault-bounded lens in the Bridge River complex on the south side of Carpenter Lake, 11 km NE of Gold Bridge, may be correlative. This lens (Truax Creek conglomerate on Fig. 2) comprises unstratified pebble to cobble conglomerate containing mainly felsic to intermediate volcanic clasts, with a smaller but significant number of clasts derived from mafic volcanic rocks, granitic to gabbroic plutonic rocks, shale, and siltstone. Church and MacLean (1987) reported that fossils collected from a small siltstone lens in the conglomerate were identified as *Buchia* sp. (latest Jurassic?), making it the same age as the middle part of the Relay Mountain Group.

The upper part of the Tyaughton basin is represented by a well-exposed section of mid-Cretaceous (Albian-Cenomanian) rocks that crosses Tyaughton Lake in the north-central part of the Gold Bridge area (Fig. 2; Garver, 1989, 1992). This section, from bottom to top, consists of chert-rich conglomerates of the Dash Formation, mica-bearing quartzofeldspathic sandstones of the Lizard Formation, and polymictic conglomerates of the Silverquick Formation. The latter unit is locally overlain by volcanic and volcaniclastic rocks included in the Powell Creek Formation, a unit of subaerial arc volcanic rocks that makes extensive exposures northwest of the Gold Bridge area. The Dash Formation is the oldest unit of the Taylor Creek Group exposed in the Tyaughton Lake area, where it rests unconformably above the Bridge River complex, including blueschist facies metamorphic rocks (Fig. 2). However, Taylor Creek Group exposures to the northwest include an older unit

(Paradise Formation) that rests stratigraphically beneath the Dash Formation.

Cadwallader terrane, represented mainly by exposures east, northeast, and northwest of Bridge River terrane (Schiarizza, 2013) forms a number of composite fault panels across the full width of the Gold Bridge area (Fig. 2). The Cadwallader Group, including Late Triassic arc basalts of the Pioneer Formation and overlying Late Triassic arc-derived sandstone and conglomerate of the Hurley Formation (Rusmore, 1987) is the predominant component in all these fault panels. The panels invariably contain slices of the Bralorne-East Liza complex (Early Permian), which includes diorite, gabbro, metabasalt and serpentinized ultramafic rocks. These plutonic and volcanic rocks are correlated with crustal components of the Shulaps ophiolite complex, which is exposed east and northeast of the Gold Bridge area and is juxtaposed above the Cadwallader Group across west-directed thrusts (Calon et al., 1990; Schiarizza et al., 1997). Fault panels of Cadwallader Group and Bralorne-East Liza complex in the Gold Bridge area are interpreted as remnants of mid-Cretaceous sheets that were thrust westward over the Bridge River complex and Tyaughton basin then cut and segmented by younger structures (Schiarizza et al., 1997).

2.1. Gun Lake unit

Schiarizza et al. (1997) introduced the term Gun Lake unit for undated siliciclastic rocks they mapped at five different localities near Gold Bridge (Fig. 2) in the southern part of the Taseko-Bridge River map area. At each locality, the rocks are known or inferred to be in depositional contact with underlying rocks of the Bridge River complex and consist mainly of argillite, siltstone, and feldspathic volcanic-lithic sandstone. Two northwest-trending belts near Downton and Gun lakes had previously been mapped as Noel Formation by Cairnes (1937, 1943), who recognized that they were in depositional contact above the Bridge River complex (his Fergusson Series). The three small belts assigned to the Gun Lake unit farther east had previously been included in undifferentiated Bridge River Group (Woodsworth, 1977). Schiarizza et al. (1997) correlated the Gun Lake unit with the lower part of the Cayoosh assemblage to the south (Mahoney and Journeay, 1993; Journeay and Mahoney, 1994) and with the lower unit of the Relay Mountain Group to the north, but also noted that the Gun Lake sandstones are lithologically similar to narrow lenses of volcanic-rich sandstone, none of mappable extent, that are included in the Bridge River complex.

2.2. Cayoosh assemblage

The Cayoosh assemblage comprises undated siliciclastic rocks, mainly phyllitic argillite, siltstone and sandstone, that overlie the Bridge River complex over large areas mainly to the south of the Gold Bridge area (Mahoney and Journeay, 1993; Journeay and Mahoney, 1994). The assemblage was traced into the southern part of the Gold Bridge area (Fig. 2) by Journeay and Mahoney (1994) and Monger and Journeay (1994). These Cayoosh exposures were inferred to correlate with the Gun Lake unit (Monger and Journeay, 1994; Schiarizza et al., 1997) and, like the Gun Lake unit, included rocks that had been mapped as Noel Formation by Cairnes (1937, 1943).

3. Detrital zircon geochronology

Here we present the results from isotopic analyses of detrital zircons extracted from two samples from the Gun Lake unit. The samples were collected in September 2015, from outcrops that had previously been mapped by Schiarizza et al. (1997). Sample preparation and analytical work (LA-ICP-MS) was conducted at the Pacific Centre for Isotopic and Geochemical Research (PCIGR), the Department of Earth, Ocean and Atmospheric Sciences, the University of British Columbia. Sample 15PSC-185 was processed in 2016, using a New Wave UP-213 laser ablation system, and techniques summarized by Mihalynuk et al. (2016). Sample 15PSC-183 was processed in 2017 using a Resonetics RESOlution M-50-LR, with procedures summarized here.

Following mineral separation by standard procedures, zircons were handpicked in alcohol and mounted in epoxy, along with reference materials. Grain mounts were then wet ground with carbide abrasive paper and polished with diamond paste. Next, cathodoluminescence (CL) imaging was carried out on a Philips XL-30 scanning electron microscope (SEM) equipped with a Bruker Quanta 200 energy-dispersion X-ray microanalysis system at the Electron Microbeam/X-Ray Diffraction Facility (EMXDF). An operating voltage of 15 kV was used, with a spot diameter of 6 µm and peak count time of 30 seconds. After removal of the carbon coat, the grain mount surface was washed with mild soap and rinsed with high-purity water. Before analysis, the grain mount surface was cleaned with 3 N HNO_3 acid and again rinsed with high-purity water to remove any surficial Pb contamination that could interfere with the early portions of the spot analyses.

Analyses were conducted using a Resonetics RESOlution M-50-LR, which contains a Class I laser device equipped with a UV excimer laser source (Coherent COMPex Pro 110, 193 nm, pulse width of 4 ns) and a two-volume cell designed and developed by Laurin Technic Pty. Ltd. (Australia). This sample chamber allowed us to investigate several grain mounts in one analytical session. The laser path was fluxed by N_2 to ensure better stability. Ablation was carried out in a cell with a volume of approximately 20 cm^3 and a He gas stream that ensured better signal stability and lower U-Pb fractionation (Eggins et al., 1998). The laser cell was connected via a Teflon squid to an Agilent 7700x quadrupole ICP-MS housed at PCIGR. A pre-ablation shot was used to ensure that the spot area on grain surface was free of contamination. Samples and reference materials were analyzed for 36 isotopes, including Pb (^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb), ^{232}Th, and U (^{235}U, ^{238}U) with a dwell time of 0.02 seconds for each isotope. Pb/U and Pb/Pb ratios were determined on the same spots along with trace element concentrations. The settings for the laser were: spot size of 34 µm with a total ablation time of 30 seconds, frequency of

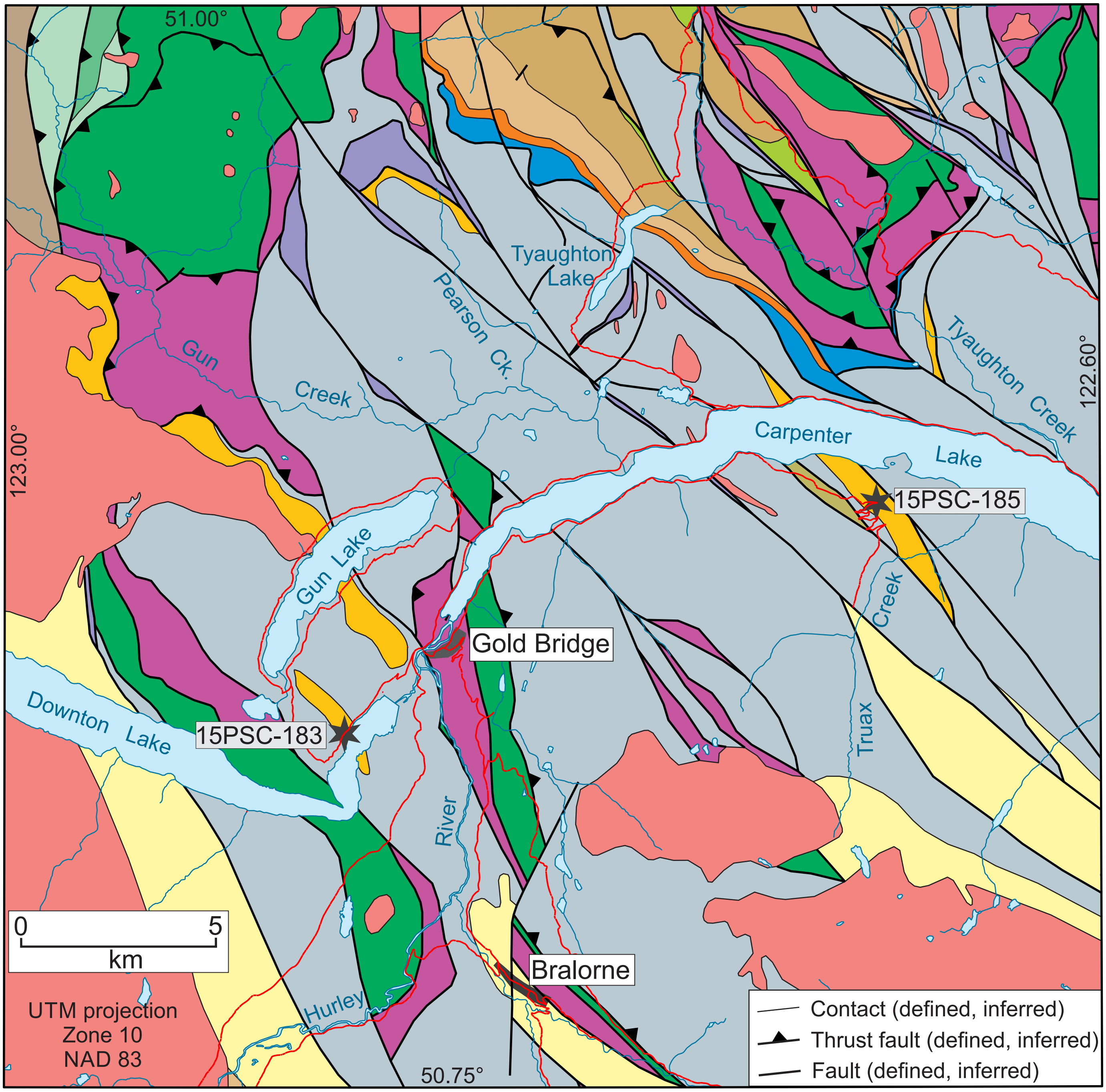

Fig. 2. Geologic map of the Gold Bridge area showing locations of the two samples discussed in this report. Geology mainly from Schiarizza et al. (1997) and Monger and Journeay (1994).

5 Hz, fluence of 5 J/cm^2, power of 7.8 mJ after attenuation, pit depths of approximately 15 µm, He flow rate of 800 mL/min, N_2 flow rate of 2 mL/min, and a carrier gas (Ar) flow rate of 0.57 L/min.

Reference materials were analyzed throughout the sequence to allow for drift correction and to characterize downhole fractionation for Pb/U and Pb/Pb isotopic ratios. For U-Pb analyses, natural zircon reference materials were used, including Plešovice (Sláma et al., 2008) or 91500 (Wiedenbeck et al., 1995, 2004) as the internal reference material, and both Temora2 (Black et al., 2004) and Plešovice and/or 91500 as monitoring reference materials; the zircon reference materials were placed between the unknowns. Raw data were reduced using the Iolite 3.4 extension (Paton et al., 2011) for Igor Pro™ yielding U/Pb ages, and their respective uncertainties. Final interpretation and plotting of the analytical results employed the ISOPLOT software of Ludwig (2003).

Fig. 2. Continued.

3.1. Sample 15PSC-183, Downton Lake

Sample 15PSC-183 was collected from a roadside outcrop (508736E, 5631125N, UTM Zone 10, NAD 83) on the north side of Downton Lake, 1.5 km southwest of the Lajoie dam at the northeast end of the lake. Here, the Gun Lake unit forms a narrow northwest-trending outlier that was mapped as Noel Formation by Cairnes (1937) and inferred to form the core of a minor synform. The surrounding Bridge River complex is mostly undated, but chert exposed about 800 m southwest of the sample site yielded Late Triassic (Late Norian) radiolarians (F. Cordey in Schiarizza et al., 1997). The sampled outcrop (Fig. 3) consists of medium to dark grey, medium- to coarse-grained sandstone, locally intercalated with lenses (2-30 cm) of dark grey slaty argillite. Sample 15PSC-183 is a medium-gained sandstone that consists mainly of feldspathic volcanic lithic grains and plagioclase. It also contains about 10% monocrystalline quartz grains, some with markedly angular outlines, and uncommon grains of fine-grained sedimentary rock, polycrystalline quartz, and quartz-plagioclase (tonalite?) aggregates. Epidote alteration is conspicuous in some of the volcanic lithic grains, and some grains (rare) are almost entirely epidote.

The $^{206}Pb/^{238}U$ ages for most of the analyzed zircons (N=65) range from 117.6 ±4.3 Ma to 179.6 ±6.2 Ma, with a strong peak at 141 Ma on the probability density curve (Fig. 4, Table 1). Two older grains have ages of 211.3 ±6.5 Ma and 242 ±13 Ma.

Fig. 3. Downton Lake outcrop of Gun Lake unit from which sample 15PSC-183 was collected. View is northwest.

The youngest grains (117.6 ±4.3 Ma, 118.3 ±4.1 Ma, 122.5 ±7.1 Ma, 125.7 ±3.9 Ma) suggest a maximum depositional age of around 120 Ma (Aptian).

3.2. Sample 15PSC-185, Truax Creek

Sample 15PSC-185 is from a panel of siliciclastic sedimentary rocks first mapped as Gun Lake unit by Schiarizza et al. (1993) that outcrops on the south side of Carpenter Lake, about 12 km east-northeast of Gold Bridge. Here, the Gun Lake unit comprises medium to dark grey slaty siltstone intercalated with grey to green fine- to coarse-grained sandstone. These rocks dip to the west or southwest but are overturned, as indicated by graded beds and cross stratification at several localities (Schiarizza et al., 1997). They are truncated to the northeast by a major strand of the Castle Pass dextral strike-slip fault system and pass southwestward, across an indistinct contact in a zone of slaty argillite with lenses of sandstone and chert, into the Bridge River complex, represented by structurally interleaved chert, argillite, sandstone, basalt, limestone and serpentinite. This panel of Bridge River rocks is juxtaposed against an extensive belt of Bridge River complex farther west by southwest-dipping thrust(?) faults that enclose the Truax Creek conglomerate lens (Fig. 2).

Sample 15PSC-185 was collected from an outcrop on the south side of the road at the first major switchback on the Truax Creek logging road (522380E, 5637101N, UTM Zone 10, NAD 83). The outcrop is predominantly medium grey, medium- to coarse-grained sandstone that forms thin to thick beds and rare boudinaged lenses, intercalated with dark grey slaty siltstone (Fig. 5). The sample, comprising coarse-grained sandstone from a thick bed at the east end of the outcrop, consists mainly of plagioclase and plagioclase-rich volcanic lithic grains, but also includes a substantial amount of monocrystalline quartz (10%), and minor amounts of polycrystalline quartz, and fine-grained sedimentary lithic grains.

The ^{206}Pb/^{238}U ages for most of the analyzed zircons (N=59) fall between 142.2 ±2.8 Ma and 164.7 ±3.7 Ma, with a strong peak at 151 Ma on the probability density curve (Fig. 6, Table 2) Five older grains have ages ranging from 207.8 ±8.1 Ma to 214.2 ±5.9 Ma. The youngest grains (17 grains between 142.2 ±2.8 Ma and, 149.8 ±3.4 Ma) indicate a maximum depositional age near the Jurassic-Cretaceous boundary (145 Ma).

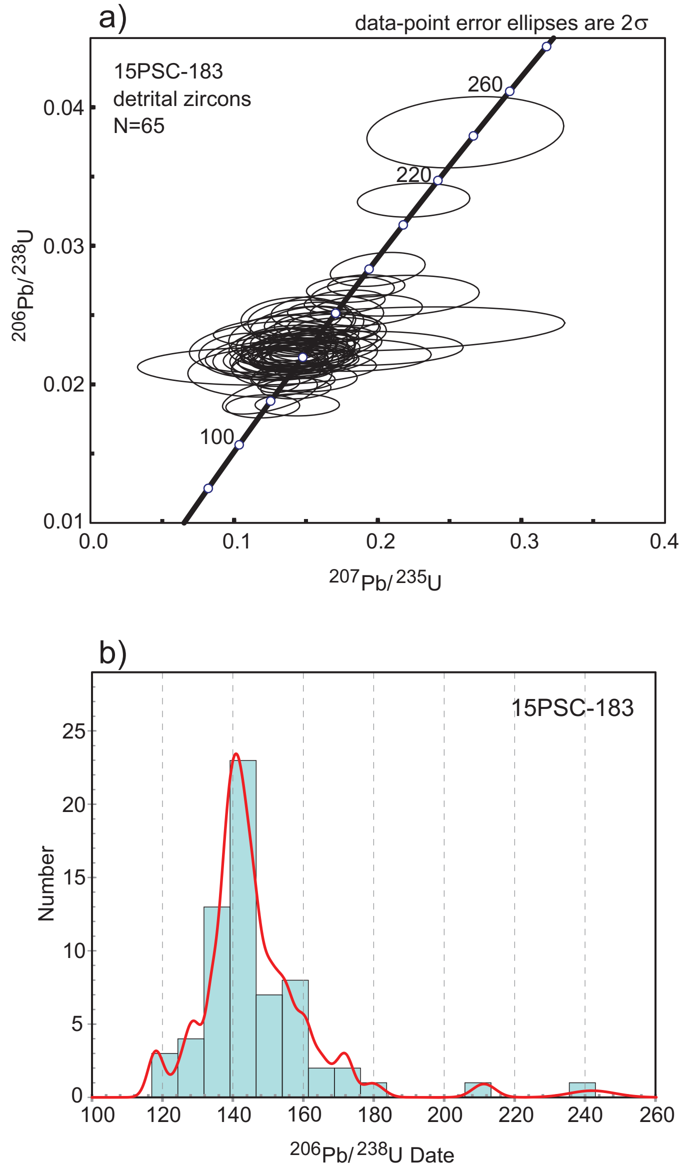

Fig. 4. a) Concordia plot of all detrital zircons analyzed from sample 15PSC-183. **b)** Histogram of detrital zircon ages and superimposed probability density curve.

4. Discussion

Schiarizza et al. (1997) suggested that the Gun Lake unit correlates with the lower unit of the Relay Mountain Group. However, the detrital zircon data presented here show that the Gun Lake unit includes at least two separate subunits, both younger than the lower unit of the Relay Mountain Group, which necessitates revised correlations. We now correlate Gun

Table 1. Zircon U-Pb laser ablation analytical data for sample 15PSC-183, Downton Lake outcrop.

Sample no.	**Isotopic Ratios**							**Isotopic Ages**					
Analysis ID	$^{207}Pb/^{235}U$	2σ (abs)	$^{206}Pb/^{238}U$	2σ (abs)	ρ	$^{207}Pb/^{206}Pb$	2σ (abs)	$^{207}Pb/^{235}U$	2σ (Ma)	$^{206}Pb/^{238}U$	2σ (Ma)	$^{207}Pb/^{206}Pb$	2σ (Ma)
X15PSC_183_1	0.1410	0.0240	0.02033	0.00064	0.018	0.0487	0.0082	136	20	129.7	4.0	130	320
X15PSC_183_2	0.1200	0.0210	0.01841	0.00068	0.080	0.0463	0.0078	118	19	117.6	4.3	-10	290
X15PSC_183_3	0.1450	0.0320	0.02286	0.00096	0.031	0.0463	0.0100	133	28	145.7	6.1	-90	390
X15PSC_183_4	0.1440	0.0320	0.02470	0.00130	0.069	0.0408	0.0093	133	28	157.3	7.9	-260	380
X15PSC_183_5	0.1540	0.0400	0.02260	0.00110	0.371	0.0500	0.0120	140	36	143.7	7.0	-40	450
X15PSC_183_6	0.1440	0.0240	0.01852	0.00065	0.005	0.0548	0.0096	138	20	118.3	4.1	310	330
X15PSC_183_7	0.1180	0.0410	0.02080	0.00140	0.006	0.0410	0.0140	107	36	132.8	8.5	-300	520
X15PSC_183_8	0.1310	0.0230	0.02169	0.00082	0.068	0.0446	0.0082	127	21	138.3	5.2	-60	330
X15PSC_183_9	0.1410	0.0350	0.02150	0.00100	0.357	0.0460	0.0110	130	31	137.2	6.4	-100	450
X15PSC_183_11	0.1430	0.0200	0.01970	0.00061	0.097	0.0531	0.0079	135	18	125.7	3.9	190	270
X15PSC_183_12	0.1400	0.0210	0.02176	0.00068	0.165	0.0471	0.0071	132	18	138.7	4.3	30	290
X15PSC_183_13	0.1330	0.0300	0.02330	0.00140	0.127	0.0430	0.0098	124	27	148.4	8.6	-140	410
X15PSC_183_14	0.1650	0.0320	0.02510	0.00110	0.048	0.0464	0.0120	153	28	159.9	6.8	0	370
X15PSC_183_15	0.1300	0.0260	0.02120	0.00110	0.065	0.0453	0.0090	121	23	134.9	6.8	-90	360
X15PSC_183_16	0.2080	0.1000	0.02400	0.00130	0.273	0.0670	0.0260	186	71	153.1	7.9	390	550
X15PSC_183_19	0.1380	0.0230	0.02239	0.00078	0.143	0.0434	0.0073	133	20	142.7	4.9	-20	310
X15PSC_183_20	0.1440	0.0320	0.02213	0.00097	0.062	0.0470	0.0110	133	29	141.1	6.1	-110	410
X15PSC_183_21	0.1250	0.0270	0.01920	0.00110	0.584	0.0500	0.0099	116	26	122.5	7.1	-10	420
X15PSC_183_22	0.1480	0.0160	0.02097	0.00045	0.077	0.0520	0.0057	140	14	133.8	2.8	260	230
X15PSC_183_24	0.1700	0.0260	0.02391	0.00074	0.182	0.0531	0.0087	157	22	152.3	4.7	270	330
X15PSC_183_25	0.1490	0.0300	0.02047	0.00083	0.024	0.0504	0.0100	138	26	130.6	5.2	30	390
X15PSC_183_26	0.1240	0.0450	0.02270	0.00150	0.224	0.0440	0.0170	123	43	144.5	9.2	-280	600
X15PSC_183_27	0.1410	0.0230	0.02210	0.00092	0.003	0.0478	0.0084	132	20	140.7	5.8	30	300
X15PSC_183_29	0.1590	0.0230	0.02311	0.00069	0.199	0.0496	0.0074	148	20	147.3	4.3	120	290
X15PSC_183_30	0.1510	0.0300	0.02226	0.00090	0.366	0.0510	0.0110	140	26	141.9	5.7	30	370
X15PSC_183_31	0.2000	0.0270	0.02830	0.00100	0.288	0.0510	0.0077	182	22	179.6	6.2	320	230
X15PSC_183_32	0.1510	0.0260	0.02235	0.00068	0.152	0.0476	0.0081	141	23	142.5	4.3	140	320
X15PSC_183_33	0.2610	0.0560	0.03820	0.00210	0.175	0.0502	0.0110	238	42	242.0	13.0	160	390
X15PSC_183_34	0.1350	0.0310	0.02169	0.00110	0.048	0.0490	0.0120	126	27	138.3	6.7	-70	400
X15PSC_183_35	0.1310	0.0120	0.02006	0.00054	0.212	0.0443	0.0047	124	11	128.0	3.4	-50	190
X15PSC_183_36	0.1500	0.0330	0.02450	0.00130	0.045	0.0390	0.0098	136	30	156.0	7.9	-290	390
X15PSC_183_37	0.1110	0.0290	0.02210	0.00130	0.015	0.0380	0.0100	104	26	141.0	8.0	-330	420
X15PSC_183_38	0.1490	0.0310	0.02172	0.00073	0.129	0.0483	0.0099	138	27	138.5	4.6	60	380
X15PSC_183_39	0.1400	0.0490	0.02210	0.00130	0.201	0.0570	0.0180	125	42	141.0	8.2	-120	580
X15PSC_183_40	0.1550	0.0220	0.02426	0.00074	0.112	0.0480	0.0073	144	19	154.5	4.7	20	290
X15PSC_183_41	0.1380	0.0270	0.02260	0.00120	0.040	0.0490	0.0093	129	25	143.7	7.9	-40	400
X15PSC_183_42	0.1810	0.0250	0.02685	0.00076	0.123	0.0510	0.0071	171	22	170.8	4.8	210	260
X15PSC_183_43	0.1620	0.0360	0.02360	0.00120	0.205	0.0520	0.0120	148	31	150.1	7.3	20	430
X15PSC_183_44	0.2120	0.0480	0.02640	0.00120	0.162	0.0580	0.0140	188	39	167.9	7.2	360	460
X15PSC_183_45	0.1920	0.0220	0.02711	0.00065	0.068	0.0526	0.0063	180	19	172.5	4.1	220	240
X15PSC_183_46	0.1690	0.0260	0.02416	0.00088	0.055	0.0512	0.0076	156	22	153.9	5.5	190	310
X15PSC_183_47	0.1480	0.0220	0.02458	0.00084	0.376	0.0447	0.0066	138	19	156.5	5.3	-70	280
X15PSC_183_48	0.1480	0.0310	0.02194	0.00079	0.080	0.0515	0.0110	141	27	139.9	5.0	50	390
X15PSC_183_49	0.1480	0.0300	0.02430	0.00110	0.285	0.0430	0.0096	136	27	154.7	7.0	-140	390
X15PSC_183_50	0.1320	0.0290	0.02266	0.00110	0.168	0.0436	0.0094	123	26	144.4	6.8	-160	380
X15PSC_183_52	0.1420	0.0250	0.02301	0.00082	0.061	0.0452	0.0083	136	23	146.6	5.1	-20	340
X15PSC_183_53	0.1660	0.0170	0.02363	0.00055	0.095	0.0521	0.0057	155	15	150.5	3.5	220	230
X15PSC_183_54	0.1280	0.0290	0.02182	0.00095	0.098	0.0413	0.0092	120	26	139.1	6.0	-190	380
X15PSC_183_55	0.1220	0.0300	0.02170	0.00110	0.038	0.0415	0.0099	113	27	138.1	6.8	-310	390
X15PSC_183_56	0.1810	0.0460	0.02211	0.00095	0.031	0.0630	0.0160	170	40	141.0	6.0	370	490
X15PSC_183_57	0.1580	0.0170	0.02522	0.00058	0.042	0.0440	0.0049	148	15	160.6	3.6	-40	220
X15PSC_183_58	0.1480	0.0260	0.02249	0.00097	0.136	0.0520	0.0097	138	22	143.3	6.1	90	340
X15PSC_183_59	0.1450	0.0160	0.02220	0.00058	0.074	0.0465	0.0059	140	15	141.5	3.6	20	220
X15PSC_183_60	0.1460	0.0210	0.02280	0.00061	0.040	0.0449	0.0063	137	18	145.3	3.8	0	280
X15PSC_183_61	0.1510	0.0270	0.02260	0.00130	0.078	0.0513	0.0097	140	23	143.9	8.0	70	350
X15PSC_183_62	0.2250	0.0320	0.03330	0.00100	0.113	0.0492	0.0071	212	24	211.3	6.5	200	260
X15PSC_183_63	0.1410	0.0200	0.02161	0.00077	0.220	0.0480	0.0069	132	18	137.8	4.9	30	280
X15PSC_183_64	0.1500	0.0250	0.02195	0.00086	0.277	0.0556	0.0082	152	21	140.0	5.4	290	310
X15PSC_183_65	0.1770	0.0230	0.02595	0.00070	0.230	0.0506	0.0071	164	20	165.1	4.4	220	300
X15PSC_183_66	0.1920	0.0320	0.02535	0.00091	0.220	0.0548	0.0096	175	27	161.4	5.7	350	310
X15PSC_183_67	0.1160	0.0680	0.02130	0.00110	0.039	0.0360	0.0160	108	37	136.0	7.0	-350	490
X15PSC_183_68	0.1520	0.0390	0.02270	0.00120	0.462	0.0480	0.0130	141	37	144.5	7.7	120	480
X15PSC_183_69	0.1390	0.0310	0.02177	0.00087	0.013	0.0450	0.0100	134	28	138.8	5.5	-50	400
X15PSC_183_70	0.1910	0.0560	0.02260	0.00100	0.066	0.0630	0.0170	179	47	144.3	6.5	270	560
X15PSC_183_71	0.1430	0.0340	0.02280	0.00120	0.078	0.0470	0.0120	132	29	145.5	7.6	20	450

Table 2. Zircon U-Pb laser ablation analytical data for sample 15PSC-185, Truax Creek outcrop.

Sample no.	**Isotopic Ratios**							**Isotopic Ages**					
Analysis ID	$^{207}Pb/^{235}U$	2σ (abs)	$^{206}Pb/^{238}U$	2σ (abs)	ρ	$^{207}Pb/^{206}Pb$	2σ (abs)	$^{207}Pb/^{235}U$	2σ (Ma)	$^{206}Pb/^{238}U$	2σ (Ma)	$^{207}Pb/^{206}Pb$	2σ (Ma)
PSC185_6	0.1760	0.0110	0.02503	0.00060	0.077	0.0498	0.0033	160.4	9.6	159.3	3.8	140	110
PSC185_7	0.1660	0.0076	0.02414	0.00054	0.182	0.0494	0.0024	156.8	6.7	153.7	3.4	166	91
PSC185_8	0.1790	0.0120	0.02393	0.00080	0.000	0.0532	0.0038	166	10	152.4	5.0	300	140
PSC185_9	0.1621	0.0088	0.02347	0.00066	0.079	0.0487	0.0028	151.2	7.6	149.5	4.2	140	100
PSC185_10	0.2200	0.0130	0.03380	0.00094	0.107	0.0459	0.0028	200	11	214.2	5.9	20	110
PSC185_11	0.1681	0.0050	0.02469	0.00052	0.351	0.0489	0.0014	157.5	4.3	157.2	3.3	140	57
PSC185_12	0.1750	0.0130	0.02479	0.00082	0.156	0.0509	0.0040	162	11	157.7	5.1	220	140
PSC185_13	0.1541	0.0056	0.02287	0.00043	0.100	0.0492	0.0019	145.5	4.8	145.7	2.7	149	74
PSC185_14	0.1466	0.0049	0.02232	0.00044	0.220	0.0472	0.0017	138.9	4.4	142.2	2.8	84	67
PSC185_15	0.1674	0.0092	0.02493	0.00065	0.140	0.0482	0.0027	156.3	7.9	158.7	4.1	120	100
PSC185_16	0.1570	0.0060	0.02355	0.00061	0.259	0.0480	0.0020	147.4	5.3	150.0	3.9	106	79
PSC185_17	0.1726	0.0085	0.02394	0.00057	0.035	0.0516	0.0027	161.9	7.4	152.5	3.6	243	99
PSC185_18	0.1890	0.0099	0.02514	0.00071	0.006	0.0525	0.0032	175.9	8.4	160.0	4.4	320	120
PSC185_19	0.1746	0.0075	0.02584	0.00060	0.206	0.0499	0.0023	162.1	6.4	164.7	3.7	176	86
PSC185_20	0.1770	0.0120	0.02366	0.00069	0.057	0.0540	0.0038	165.7	9.6	150.7	4.3	340	130
PSC185_21	0.1599	0.0043	0.02386	0.00050	0.258	0.0472	0.0014	150.4	3.7	151.9	3.1	72	55
PSC185_22	0.1755	0.0071	0.02425	0.00055	0.266	0.0507	0.0022	163.0	6.1	154.4	3.5	211	83
PSC185_23	0.1684	0.0070	0.02459	0.00058	0.181	0.0484	0.0022	158.1	6.1	156.5	3.7	109	83
PSC185_24	0.1507	0.0092	0.02277	0.00059	0.140	0.0468	0.0030	141.4	8.1	145.1	3.7	70	110
PSC185_25	0.1700	0.0150	0.02589	0.00093	0.161	0.0462	0.0041	156	13	164.7	5.9	90	150
PSC185_26	0.1673	0.0059	0.02449	0.00055	0.353	0.0500	0.0018	156.4	5.2	155.9	3.5	192	71
PSC185_27	0.1564	0.0082	0.02378	0.00062	0.191	0.0492	0.0027	147.2	7.1	151.4	3.9	180	100
PSC185_28	0.1601	0.0047	0.02383	0.00047	0.328	0.0501	0.0015	150.9	4.1	151.8	2.9	197	60
PSC185_29	0.1684	0.0070	0.02490	0.00063	0.304	0.0503	0.0021	158.4	5.9	158.5	4.0	201	79
PSC185_30	0.1511	0.0074	0.02351	0.00053	0.119	0.0476	0.0025	144.0	6.5	149.8	3.4	103	92
PSC185_31	0.1840	0.0100	0.02527	0.00067	0.090	0.0541	0.0033	169.0	8.8	160.8	4.2	250	110
PSC185_32	0.1550	0.0088	0.02320	0.00078	0.113	0.0492	0.0031	147.0	7.6	147.8	4.9	130	110
PSC185_33	0.1663	0.0073	0.02373	0.00060	0.187	0.0500	0.0023	155.9	6.4	151.1	3.8	188	89
PSC185_34	0.1553	0.0059	0.02307	0.00055	0.236	0.0479	0.0019	145.9	5.2	147.0	3.5	102	74
PSC185_35	0.1762	0.0079	0.02457	0.00072	0.233	0.0525	0.0026	164.2	6.8	156.4	4.5	269	97
PSC185_36	0.1710	0.0090	0.02271	0.00061	0.286	0.0544	0.0028	162.0	7.9	144.7	3.9	350	100
PSC185_37	0.1650	0.0100	0.02355	0.00065	0.028	0.0514	0.0035	154.9	8.4	150.0	4.1	180	110
PSC185_38	0.2300	0.0120	0.03320	0.00100	0.271	0.0507	0.0027	211.4	9.7	210.3	6.3	230	100
PSC185_39	0.1544	0.0084	0.02363	0.00067	0.153	0.0474	0.0027	145.9	7.3	150.5	4.2	110	100
PSC185_40	0.2405	0.0070	0.03316	0.00060	0.249	0.0520	0.0016	218.2	5.8	210.2	3.7	263	60
PSC185_41	0.2361	0.0079	0.03369	0.00078	0.415	0.0517	0.0017	214.5	6.5	213.5	4.9	243	65
PSC185_42	0.1783	0.0077	0.02510	0.00070	0.434	0.0509	0.0021	165.6	6.7	159.7	4.4	224	84
PSC185_43	0.1680	0.0110	0.02449	0.00074	0.101	0.0510	0.0035	159.1	9.4	155.9	4.7	250	120
PSC185_44	0.1693	0.0045	0.02437	0.00063	0.546	0.0499	0.0013	159.3	3.9	155.1	4.0	180	53
PSC185_45	0.1501	0.0078	0.02251	0.00069	0.395	0.0493	0.0026	141.1	6.9	143.5	4.4	170	100
PSC185_47	0.1623	0.0055	0.02348	0.00051	0.306	0.0499	0.0018	152.0	4.8	149.8	3.2	184	69
PSC185_48	0.1680	0.0140	0.02450	0.00120	0.178	0.0518	0.0047	158	13	155.7	7.6	210	170
PSC185_49	0.1656	0.0090	0.02348	0.00058	0.181	0.0500	0.0027	154.8	7.8	149.5	3.7	210	100
PSC185_50	0.1561	0.0091	0.02311	0.00072	0.213	0.0481	0.0029	148.0	8.0	147.2	4.5	120	110
PSC185_51	0.1602	0.0034	0.02316	0.00046	0.488	0.0494	0.0010	150.6	2.9	147.6	2.9	178	44
PSC185_52	0.1716	0.0070	0.02504	0.00074	0.283	0.0497	0.0021	161.3	6.3	159.4	4.6	175	85
PSC185_53	0.1635	0.0068	0.02388	0.00059	0.328	0.0489	0.0020	153.4	5.9	152.1	3.7	139	77
PSC185_54	0.2230	0.0180	0.03260	0.00130	0.229	0.0488	0.0040	204	15	207.8	8.1	160	160
PSC185_55	0.1620	0.0081	0.02358	0.00067	0.244	0.0491	0.0024	152.2	7.0	150.2	4.2	199	95
PSC185_56	0.1800	0.0150	0.02530	0.00095	0.178	0.0527	0.0044	166	12	160.9	6.0	270	150
PSC185_57	0.1610	0.0100	0.02352	0.00077	0.166	0.0505	0.0034	151.2	8.7	149.8	4.8	210	120
PSC185_58	0.1618	0.0098	0.02468	0.00074	0.233	0.0499	0.0031	152.4	8.6	157.1	4.7	160	120
PSC185_59	0.1633	0.0082	0.02350	0.00074	0.138	0.0504	0.0027	153.1	7.0	149.6	4.7	200	100
PSC185_60	0.1601	0.0080	0.02324	0.00063	0.255	0.0502	0.0025	149.5	7.0	148.4	4.0	186	93
PSC185_61	0.1700	0.0180	0.02340	0.00120	0.140	0.0529	0.0057	160	16	148.9	7.3	280	200
PSC185_62	0.1644	0.0055	0.02364	0.00053	0.375	0.0503	0.0016	155.3	4.8	150.6	3.3	197	65
PSC185_63	0.1730	0.0130	0.02368	0.00088	0.146	0.0561	0.0044	161	11	150.8	5.5	350	150
PSC185_64	0.1594	0.0063	0.02309	0.00056	0.188	0.0502	0.0020	150.2	5.4	147.1	3.5	214	77
PSC185_65	0.1827	0.0095	0.02503	0.00079	0.404	0.0523	0.0026	171.5	8.2	159.3	5.0	282	99

Fig. 5. Truax Creek outcrop of Gun Lake unit from which sample 15PSC-185 was collected. View is south, rocks dip west but are overturned.

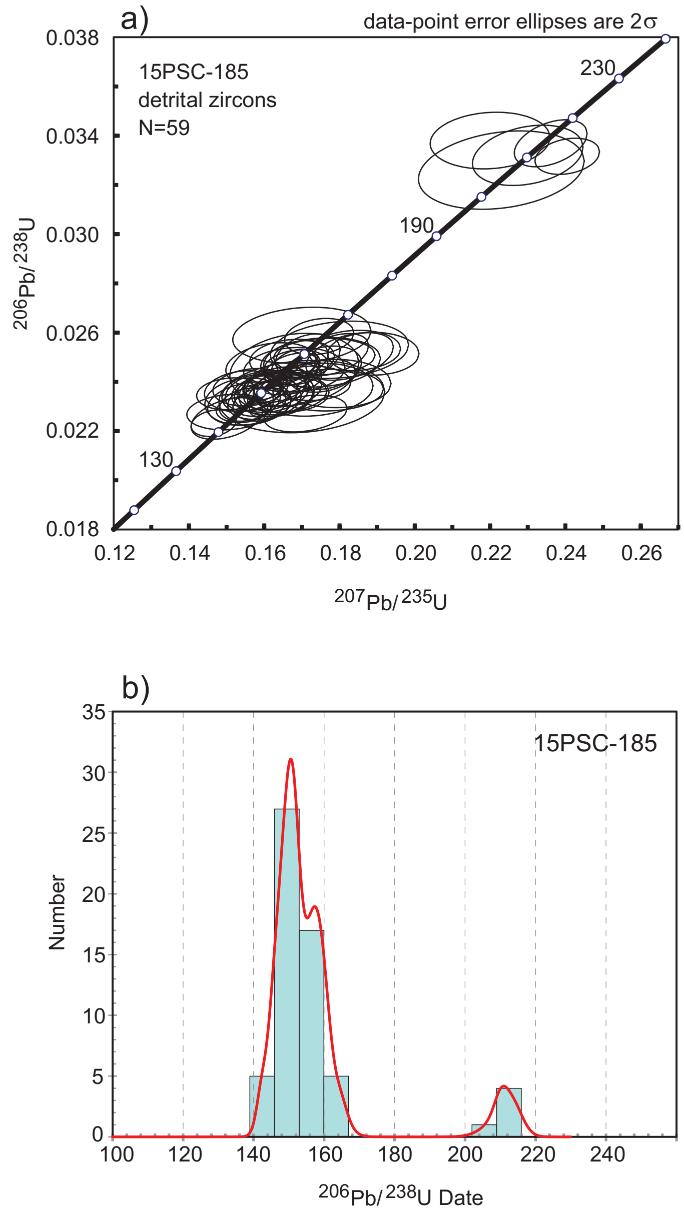

Fig. 6. a) Concordia plot of all detrital zircons analysed from sample 15PSC-185. **b)** Histogram of detrital zircon ages and superimposed probability density curve.

Lake unit exposures near Downton Lake with the Paradise Formation of the Taylor Creek Group, and those at Truax Creek with the middle unit of the Relay Mountain Group.

4.1. Downton Lake sample

The Gun Lake unit sampled at Downton Lake is a feldspathic volcanic-lithic sandstone with a maximum depositional age of about 120 Ma. The age and composition indicate that it correlates with the Paradise Formation (Taylor Creek Group), which is well exposed in the Relay Mountain area, 30 km north-northwest of the Downton Lake sample site (Garver, 1992; Schiarizza et al., 1997). Here, it forms that base of the Taylor Creek Group and is overlain by the Dash and Lizard formations which form the upper part of the group. The Paradise Formation is missing in the Tyaughton Lake area, 15 km north of Downton Lake, where the Dash Formation is directly above the Bridge River complex (Fig. 2).

The Paradise Formation is mostly shale and sandstone (consisting mainly of volcanic lithic grains and plagioclase), but also includes thick lenses of volcanic-pebble conglomerate (Garver, 1992). It is older than the mid-Albian Dash Formation which overlies it, and an Aptian to early Albian depositional age was inferred by Garver and Brandon (1994) based on a date of 113 ±6.5 Ma from the youngest detrital zircon fission-track peak. Paleocurrent indicators are sparse, but indicate sediment transport from the west (Garver, 1989). Garver (1989, 1992) suggested that the Paradise Formation was deposited as a submarine fan derived from an active volcanic source built on a substrate that included older metavolcanic and plutonic rocks. He also considered that sediment was likely derived from erosion of the southwestern Coast belt directly west of the Bridge River terrane and Tyaughton basin. The ages of detrital zircons from our Downton Lake sample (180 to 120 Ma) are entirely consistent with this interpretation. The zircons may have been derived from volcanic units within, or correlative with, the Lower to Middle Jurassic Harrison Lake Formation, the Upper Jurassic Billhook Creek Formation, and the Lower Cretaceous Gambier Group (Arthur et al., 1993; Monger and Journeay, 1994), as well as from the voluminous Middle Jurassic to Cretaceous plutons in this part of the Coast Mountains (Friedman and Armstrong, 1995).

4.2. Truax Creek sample

The Gun Lake unit sampled near Truax Creek is a feldspathic volcanic-lithic sandstone with a maximum depositional age of about 145 Ma. If this age is close to the actual depositional age then these exposures of Gun Lake unit are coeval with rocks in the middle unit of the Relay Mountain Group, which consists mainly of sandstones that are lithologically similar to those of the Gun Lake unit. Likewise, the nearby Truax Creek conglomerate (Late Jurassic) is similar, in age and lithology, to volcanic-clast conglomerates that occur locally in the middle unit of the Relay Mountain Group (Umhoefer et al., 2002). We therefore correlate the Gun Lake unit at Truax Creek, and the nearby Truax Creek conglomerate, with the middle unit of the Relay Mountain Group (lower Tyaughton basin). We infer that the two units were part of the same stratigraphic succession, which was deformed and segmented by northeast vergent thrust faults (including faults that bound the Truax Creek conglomerate) and associated overturned folds. This is essentially the interpretation of Schiarizza et al. (1997; their Figure 19b, section F), who correlated the structures near Truax Creek with the northeast-vergent North Cinnabar fold-fault system, which deforms rocks as young as the Late Cretaceous Powell Creek Formation and is along strike, just 12 km to the northwest (Fig. 2). However, Schiarizza et al. (1997) correlated the unit with the lower unit of the Relay Mountain Group (Callovian and early Oxfordian, ~166-160 Ma). Detrital zircons show that, at Truax Creek, Gun Lake rocks are no older than about 145 Ma, indicating that the entire lower unit and part of the middle unit of the Relay Mountain Group, as exposed in the type locality 30 km to the northwest, are missing. This implies that the base of the Tyaughton basin is highly diachronous. It also has implications for the age of the Bridge River complex, suspected by Schiarizza et al. (1997) to be late Middle Jurassic and older because this was the age of the youngest dated chert from the complex, and also the age of the basal Relay Mountain Group which was inferred to overlie it. It is likely that the Bridge River complex, like the base of the Tyaughton basin, is a diachronous unit that at some localities may include rocks that are younger than Middle Jurassic.

Most detrital zircons from sample 15PSC185 define a restricted population between 165 and 142 Ma. Zircons of this age are common in the broader (180-120 Ma) age distribution from the Downton Lake sample, conceivably suggesting that both had a common westerly source. However, the 165-142 Ma age range coincides almost exactly with the age of a Late Jurassic volcanic-plutonic belt to the east, northeast, and north of Bridge River terrane and the Tyaughton basin, suggesting that derivation from these sources is more likely. This Late Jurassic volcanic-plutonic belt stretches northwest-southeast for more than 500 km, from near Anahim Lake (Hotnarko volcanic rocks, U-Pb zircon age of 153.75 ±0.95 Ma, van der Heyden, 2004) to the international boundary south of Princeton (Eagle and Zoa plutonic complexes, U-Pb zircon ages from 148 ±6 to 157 ±4 Ma, Greig et al., 1992). The nearest exposures are at Piltz Peak, 70 km north of Gold Bridge, where the Piltz Peak complex includes volcanic rocks that have yielded a U-Pb zircon age of 164.3 ±1.0 Ma, and tonalitic intrusions with U-Pb zircon ages between 145.5 ±2.0 Ma and 151.1 ±1.0 Ma (Mahoney et al., 2013). The substrate to the Piltz Peak volcanic-plutonic complex is not exposed, but is inferred to be Cadwallader terrane (Schiarizza, 2013), which is a likely source for the secondary population of 208-214 Ma zircon grains in sample 15PSC-185. This interpretation is consistent with that of Umhoefer et al. (2002), who argued that the lower and middle units of the Relay Mountain Group were derived from sources to the northeast.

4.3. Correlation of other Gun Lake occurrences

The belt of Gun Lake rocks that crosses Gun Lake northwest of Gold Bridge is spatially associated with the Downton Lake occurrence, is lithologically most similar to the Downton Lake occurrence (less argillite and siltstone than the Gun Lake occurrences to the north and east), and, like the Downton Lake occurrence, has a sharp contact with the underlying Bridge River complex. These rocks are therefore, like the Downton Lake occurrence, correlated with the Paradise Formation of the Taylor Creek Group. Correlation of the other two occurrences, one that crosses lower Tyaughton Creek and the other near the head of Pearson Creek (Fig. 2), remains uncertain. Likewise, data are insufficient to attempt correlation of the several belts of Cayoosh assemblage in the southern part of the Gold Bridge area with either of the two Gun Lake occurrences analyzed here.

5. Conclusions

The two samples analyzed in this study, both mapped as Gun Lake unit by Schiarizza et al. (1997), represent two different units. The sandstones near Downton Lake are correlated with the mid-Cretaceous Paradise Formation of the Taylor Creek Group, and those near Truax Creek are correlated with the middle unit of the Jura-Cretaceous Relay Mountain Group.

The Gun Lake unit sampled at Downton Lake is a feldspathic volcanic-lithic sandstone with a maximum depositional age of about 120 Ma. Correlation with the Paradise Formation of the Taylor Creek Group is based on age and composition. The 180 to 118 Ma age range of most detrital zircons is consistent with derivation from the adjacent southwest Coast Mountains, as suggested for the Paradise Formation by Garver (1989, 1992).

The Gun Lake unit sampled near Truax Creek is a feldspathic volcanic-lithic sandstone with a maximum depositional age near the Jurassic-Cretaceous boundary (145 Ma). It is compositionally similar to sandstone in the Jura-Cretaceous Relay Mountain Group, and a nearby fault-bounded lens of Upper Jurassic volcanic-clast conglomerate (Truax Creek conglomerate) is likewise similar to age-equivalent rocks of the Relay Mountain Group. These two units are interpreted as different parts of a stratigraphic succession that correlates with part of the middle unit of the Relay Mountain Group but was deformed and segmented during Late Cretaceous northeast-vergent contractional deformation. The entire lower unit and part of the middle unit of the Relay Mountain Group, as exposed in its type locality 30 km to the northwest, are missing at Truax Creek, suggesting that the base of the Tyaughton basin is highly diachronous. Detrital zircons (mainly 165-142 Ma, but also 214-208 Ma) were likely derived from sources to the northeast, including the Cadwallader arc terrane and a Late Jurassic volcanic-plutonic belt that cuts across it.

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