# U-Pb zircon dates for the Granite Mountain batholith, Burgess Creek stock, and Sheridan Creek stock, Gibraltar Mine area, south-central British Columbia

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**Abstract**

The Granite Mountain batholith (Late Triassic), host to the Gibraltar porphyry Cu-Mo deposit, is east of the Fraser River between Williams Lake and Quesnel. Previously considered part of Cache Creek terrane, the batholith is in a panel of Quesnel terrane rocks that is faulted against Cache Creek terrane to the east and south, as established by mapping carried out in 2013 and 2014. Samples collected during this mapping, dated using the U-Pb zircon chemical abrasion thermal ionization mass spectrometry method (CA-TIMS), provide crystallization ages for the batholith and two adjacent plutonic units. Three samples from the Granite Mountain batholith yield Late Triassic dates of 217.15 ±0.37 Ma (Granite Mountain phase leucocratic tonalite), 215.71 ±0.36 Ma (Mine phase tonalite), and 214.98 ±0.38 Ma (quartz-plagioclase porphyry dike cutting Mine phase tonalite). The Burgess Creek stock, on the northeast margin of the Granite Mountain batholith, provides dates of 222.71 ±0.39 Ma (tonalite) and 221.25 ±0.39 Ma (quartz diorite), demonstrating that it is also Late Triassic, but several million years older than the Granite Mountain batholith. Tonalite from the Sheridan Creek stock, south of the Granite Mountain batholith, returns an Early Cretaceous date of 108.57 ±0.18 Ma. The Sheridan Creek contains a foliation with the same orientation and characteristics as a prominent foliation in the southern part of the Granite Mountain batholith, demonstrating that deformation of both is mid-Cretaceous or younger.

**Keywords:** Triassic, Granite Mountain batholith, Burgess Creek stock, Cretaceous, Sheridan Creek stock, Quesnel terrane, U-Pb, zircon, CA-TIMS

## 1. Introduction

The Granite Mountain batholith (Late Triassic), host to the Gibraltar porphyry Cu-Mo deposit, is on the Fraser Plateau, about 18 km east of the Fraser River, in the traditional territories of the Secwepemc, Tsilhqot'in, and Lhtako Dené First Nations (Fig. 1). Schiarizza (2014, 2015) carried out geological mapping of the batholith and surrounding rocks to better understand its geologic setting and terrane affinity. This work established that the batholith, previously included in Cache Creek terrane, is part of Quesnel terrane, and forms the south end of a panel of Quesnel rocks that is in fault contact with Cache Creek terrane to the east and south. Supporting this mapping we conducted isotopic dating (U-Pb zircon CA-TIMS method) at the University of British Columbia. Herein we present the geochronologic data and age interpretations for six samples: three from the Granite Mountain batholith (Late Triassic); two from the Burgess Creek stock (Late Triassic); and one from the Sheridan Creek stock (Early Cretaceous).

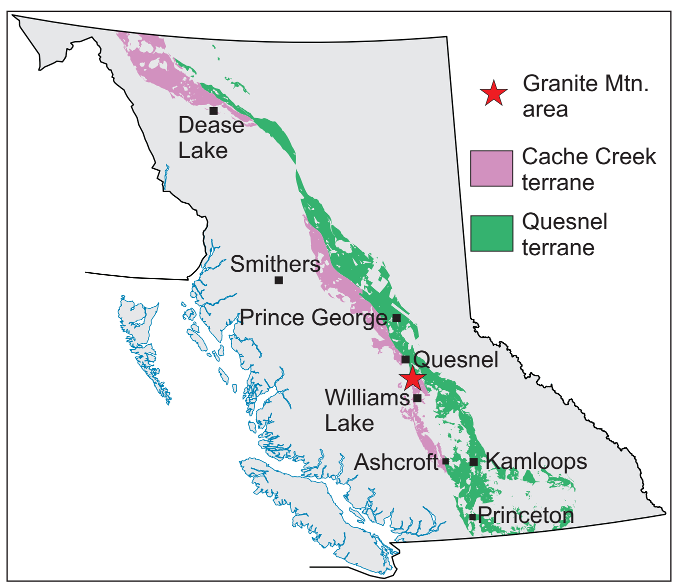


**Fig. 1.** Location of the Granite Mountain area and the main exposures of Quesnel and Cache Creek terranes in British Columbia.

## 2. Geology of the Granite Mountain area

The Granite Mountain area (Fig. 2) is underlain by a north-

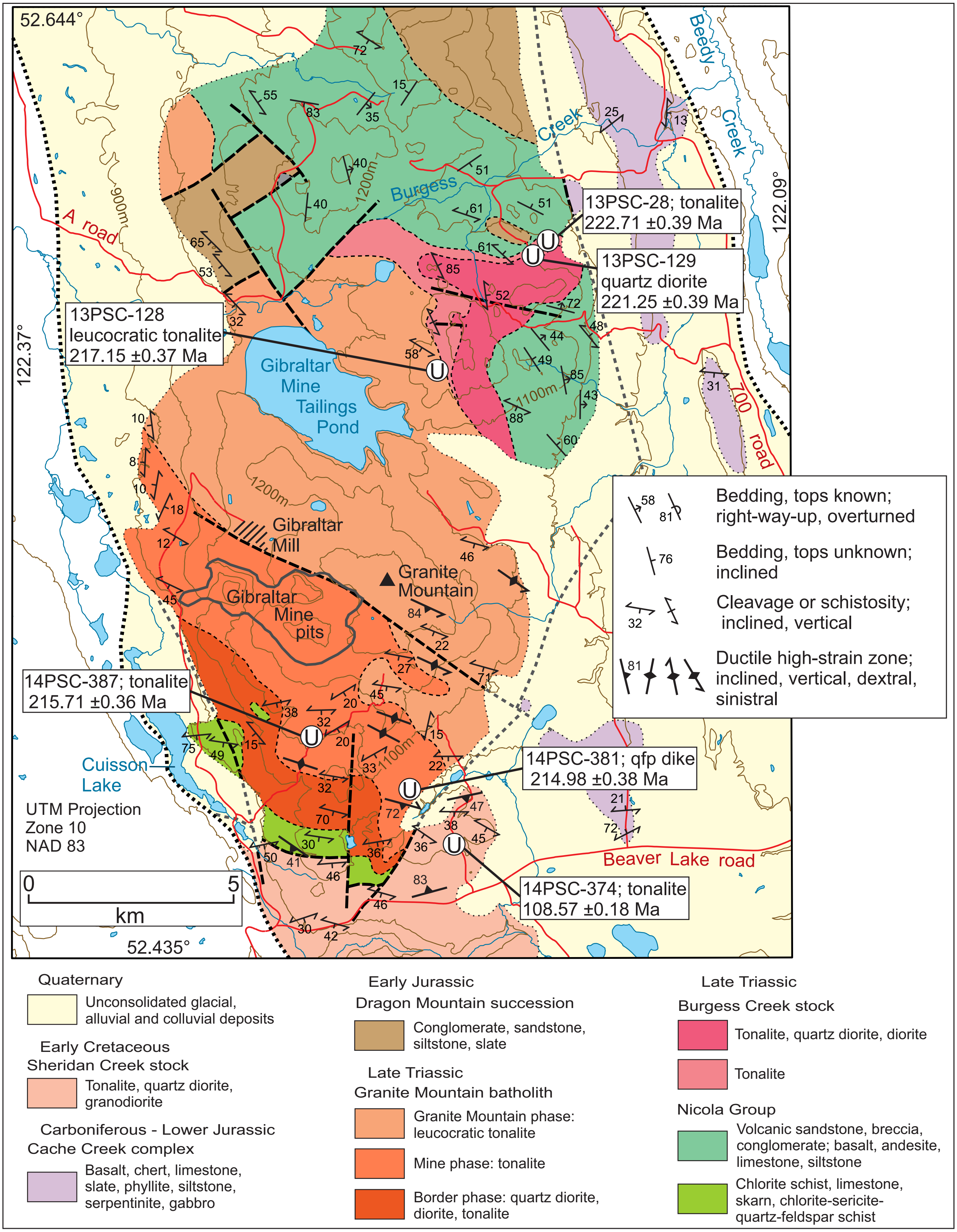


**Fig. 2.** Geology of the Granite Mountain area, showing the locations of samples dated in this study. Geology modified from Schiarizza (2015).

trending belt of rocks assigned to Quesnel terrane, including the Nicola Group (Upper Triassic), the Burgess Creek stock (Late Triassic), the Granite Mountain batholith (Late Triassic) and the Dragon Mountain succession (Lower Jurassic). This panel of Quesnel terrane rocks is in fault contact with the Cache Creek complex (Cache Creek terrane) to the east, and with Early Cretaceous tonalite of the Sheridan Creek stock to the south.

The Nicola Group is exposed mainly in the northern part of the area, where it is cut by the Burgess Creek stock and, locally, the north end of the Granite Mountain batholith. It consists of feldspathic volcanic sandstone and gritty to pebbly sandstone, with local intercalations of conglomerate, mafic and felsic volcanic breccia, siltstone, limestone and basalt (Schiarizza, 2014). These rocks are dated at one locality, 4 km north of the Gibraltar tailings pond, where a limestone lens intercalated with volcanic sandstone yielded a conodont of probable Lower Norian age (M.J. Orchard in Schiarizza, 2015).

Rocks assigned to the Nicola Group also form a narrow belt of feldspathic chlorite schists, foliated limestones and skarns along the southwest margin of the Granite Mountain batholith (Fig. 2). These rocks were included in the Cache Creek complex by Drummond et al. (1976), Panteleyev (1978), Bysouth et al. (1995), and Ash and Riveros (2001), but Schiarizza (2015) inferred a protolith of feldspathic volcaniclastic rocks, mafic volcanic rocks, and limestones that is more likely correlated with the Nicola Group. Narrow units of sericite-chlorite-quartz-plagioclase schist in the northern part of the succession may have been derived from quartz diorite dikes related to the adjacent Granite Mountain batholith (Schiarizza, 2015).

The Burgess Creek stock intrudes the Nicola Group on the northeast margin of the Granite Mountain batholith (Fig. 2). It comprises two mappable units (Schiarizza, 2015): a mixed unit that includes hornblende-biotite tonalite, hornblende-biotite quartz diorite, and hornblende diorite; and a tonalite unit consisting mainly of leucocratic hornblende-biotite tonalite. Panteleyev (1978) and Bysouth et al. (1995) thought that the Burgess Creek stock was younger than the Granite Mountain batholith, whereas Ash et al. (1999a, b) considered it a border phase of the batholith. The U-Pb zircon dates presented here show that it is Late Triassic, and several million years older than the Granite Mountain batholith.

The Granite Mountain batholith is exposed across an area measuring up to 20 km north-south by 10 km east-west. It is subdivided into three northwest-trending map units that show a trend of decreasing mafic content and increasing quartz content from southwest to northeast (Fig. 2). The Border phase, in the south, consists of medium- to coarse-grained quartz diorite, diorite and mafic tonalite. The Mine phase, which hosts the orebodies at the Gibraltar mine, is mainly medium- to coarse-grained tonalite with 15-25% chloritized mafic grains (mainly or entirely hornblende) and 25-35% quartz. The Granite Mountain phase, which forms most of the batholith, is predominantly coarse-grained leucocratic tonalite with 5-10% mafic minerals (hornblende and biotite) and 45-55% quartz. Fine- to coarse-grained leucotonalite (0-5% mafic minerals) and quartz-plagioclase porphyry occur as dikes in all three units. The dikes are commonly a few cm to tens of cm wide, but range to several tens of m in the Border phase and Mine phase. Contacts between phases of the Granite Mountain batholith and adjacent map units are not well exposed, but the Granite Mountain phase apparently intrudes the Burgess Creek stock and Nicola Group on the northeast margin of the batholith, and the Border phase intrudes Nicola rocks along the batholith's southwest margin.

Lower Jurassic sedimentary rocks in the Granite Mountain area are assigned to the Dragon Mountain succession (Logan and Moynihan, 2009; Schiarizza, 2015). These include a small outlier of thin-bedded slate, siltstone, and sandstone that overlies the Nicola Group 200 m north of the Burgess Creek stock, and a larger, mainly fault-bounded outlier to the west, consisting of slate, sandstone, and polymictic pebble conglomerate, that in part sits directly above the Granite Mountain batholith (Barker and Grubisa, 1994, diamond-drill hole 94-3). The succession also includes a northeast-dipping panel of polymictic conglomerates and sandstones that overlies the Nicola Group near the northern boundary of the area (Fig. 2). The conglomerates, here and to the north, include pebbles and cobbles of tonalite that are very similar to tonalites of the Granite Mountain batholith (Tipper, 1978; Schiarizza, 2015).

The Cache Creek complex is represented by scattered exposures of mainly chert, argillite, slate, limestone, and basalt east of the Triassic and Jurassic rocks of Quesnel terrane, from which they are separated by an inferred north-northwest trending fault (Fig. 2). These Cache Creek rocks are undated, but a limestone unit 10 km east of the southern part of the Granite Mountain batholith has yielded Permian fossils (Tipper, 1978).

The Sheridan Creek stock (Early Cretaceous) crops out in the southern part of the Granite Mountain area and consists mainly of massive to well-foliated medium-grained hornblende tonalite. It is in fault contact with the Quesnel terrane rocks to the north (Nicola Group and Granite Mountain batholith), and apparently intrudes the Cache Creek complex to the south (Ash et al., 1999a, b).

Rocks of the Granite Mountain batholith commonly display a tectonic foliation that dips at gentle to moderate angles to the south, and which shows a general increase in intensity from north to south. A foliation with the same orientation and characteristics in the Sheridan Creek stock is parallel to a well-developed schistosity in the narrow belt of Nicola rocks that separates the two plutonic units. The foliation in all three of these units is locally cut by a crenulation cleavage that strikes east-southeast and dips steeply, mainly to the south-southwest, and by narrow shear zones of similar orientation (Schiarizza, 2015). At the Gibraltar mine the foliation (S1) is ascribed to a period of deformation (D1) that also produced south-dipping top-to-the-north ductile shear zones that host or bound ore zones (Mostaghimi, 2016; van Straaten et al., 2020). A south-dipping fault is also inferred to form the contact between the Nicola Group and the Sheridan Creek stock because the foliation in both units becomes progressively stronger, and is locally mylonitic, as the contact is approached (Schiarizza, 2015).

## 3. Geochronology

Here we present U-Pb zircon isotopic dating results obtained by the chemical abrasion thermal ionization mass spectrometry method (CA-TIMS) for samples collected from the Granite Mountain batholith, the Burgess Creek stock and the Sheridan Creek stock (Table 1). Samples were collected in 2013 and 2014. Soon thereafter sample preparation and analytical work 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.

### 3.1. Analytical procedures

CA-TIMS procedures described here are modified from Mundil et al. (2004), Mattinson (2005) and Scoates and Friedman (2008). After rock samples underwent standard mineral separation procedures, zircons were handpicked in alcohol. The clearest, crack- and inclusion-free grains were selected, photographed and then annealed in quartz glass crucibles at 900°C for 60 hours. Annealed grains were transferred into 3.5 mL PFA screwtop beakers, ultrapure HF (up to 50% strength, 500 µL) and $HNO_3$ (up to 14 N, 50 µL) were added and caps were closed finger tight. The beakers were placed in 125 mL PTFE liners (up to four per liner) and about 2 mL HF and 0.2 mL $HNO_3$, of the same strength as the acid in the beakers containing the samples, were added to the liners. The liners were then slid into stainless steel Parr™ high-pressure dissolution devices, which were sealed and brought to a maximum of 200°C for 8-16 hours (typically 175°C for 12 hours). Beakers were removed from the liners and zircon was separated from the leachate. Zircons were rinsed with >18 MΩ.m water and subboiled acetone. Then 2 mL of subboiled 6N HCl was added and beakers were set on a hotplate at 80-130°C for 30 minutes and again rinsed with water and acetone. Masses were estimated from the dimensions (volumes) of grains. Single grains were transferred into clean 300 µL PFA microcapsules (crucibles), and 50 µL 50% HF and 5 µL 14 N $HNO_3$ were added. Each was spiked with a $^{233\text{-}235}$U-$^{205}$Pb tracer solution (EARTHTIME ET535), capped and again placed in a Parr liner (8-15 microcapsules per liner). HF and nitric acids, in a 10:1 ratio, were added to the liner, which was then placed in a Parr high-pressure device and dissolution was achieved at 240°C for 40 hours. The resulting solutions were dried on a hotplate at 130°C, 50 µL 6N HCl was added to microcapsules and fluorides were dissolved in high-pressure Parr devices for 12 hours at 210°C. HCl solutions were transferred into clean 7 mL PFA beakers and dried with 2 µL of 0.5 N $H_3PO_4$. Samples were loaded onto degassed, zone-refined Re filaments in 2 µL of silicic acid emitter (Gerstenberger and Haase, 1997).

Isotopic ratios were measured by a modified single collector VG-54R or 354S (with Sector 54 electronics) thermal ionization mass spectrometer equipped with analogue Daly photomultipliers. Analytical blanks were 0.2 pg for U and up to 1 pg for Pb. U fractionation was determined directly on individual runs using the EARTHTIME ET535 mixed $^{233\text{-}235}$U-$^{205}$Pb isotopic tracer. Pb isotopic ratios were corrected for fractionation of 0.25 ±0.03%/amu, based on replicate analyses of NBS-982 reference material and the values recommended by Thirlwall (2000). Data reduction employed the Excel-based program of Schmitz and Schoene (2007). Standard concordia diagrams were constructed and weighted averages calculated with Isoplot (Ludwig, 2003). Interpreted ages for all samples are based on weighted $^{206}$Pb/$^{238}$U dates reported at the 2 sigma confidence level in the three error, ±X (Y) [Z] format of Schoene et al. (2006), where X includes internal errors only, largely comprised of analytical (counting statistics), mass fractionation and common lead composition uncertainties. The (Y) error includes X plus isotopic tracer calibration uncertainty and [Z] additionally includes uranium decay constant errors. Isotopic dates are calculated with the decay constants $\lambda_{U238}$=1.55125E$^{-10}$ and $\lambda_{U235}$=9.8485E$^{-10}$ (Jaffey et al., 1971). EARTHTIME U-Pb synthetic solutions were analyzed on an on-going basis to monitor the accuracy of results.

### 3.2. Granite Mountain batholith

Three samples from the Granite Mountain batholith were dated: one from the Granite Mountain phase, one from the Mine phase, and one from a quartz-feldspar porphyry dike that cuts the Mine phase.

#### 3.2.1. Sample 13PSC-128, Granite Mountain phase

Sample 13PSC-128 was collected from the Granite Mountain phase near the northeast margin of the batholith, 1.8 km east of the Gibraltar mine tailings pond and about 150 m west of the

**Table 1.** Summary of samples dated in this study. Locations given by Easting and Northing for UTM Zone 10, NAD 83.

| Sample | Easting | Northing | Rock Type | Unit | Age (Ma) |
|---|---|---|---|---|---|
| 13PSC-128 | 553132 | 5824059 | leucocratic tonalite | Granite Mountain batholith, Granite Mountain phase | 217.15 ±0.37 |
| 14PSC-387 | 550105 | 5815070 | tonalite | Granite Mountain batholith, Mine phase | 215.71 ±0.36 |
| 14PSC-381 | 552439 | 5813890 | quartz-plagioclase porphyry | Granite Mountain batholith, dike cutting Mine phase | 214.98 ±0.38 |
| 13PSC-028 | 555635 | 5827248 | tonalite | Burgess Creek stock, tonalite unit | 222.71 ±0.39 |
| 13PSC-129 | 555392 | 5827019 | quartz diorite | Burgess Creek stock, mixed unit | 221.25 ±0.39 |
| 14PSC-374 | 553598 | 5812478 | tonalite | Sheridan Creek stock | 108.57 ±0.18 |

(unexposed) contact with the Burgess Creek stock (Fig. 2). It is a coarse-grained equigranular tonalite consisting of subequal proportions of plagioclase and quartz, and less than 10% chloritized mafic grains (Fig. 3). Three of the four zircon grains analyzed (Table 2) are mutually overlapping on concordia, with a weighted mean $^{206}Pb/^{238}U$ date of 217.15 ±0.20 (0.29) [0.37] Ma (MSWD=0.45), interpreted as the crystallization age of the tonalite at this locality (Fig. 4). The fourth grain plots slightly below concordia near 215 Ma, possibly due to minor Pb loss.


**Fig. 3.** Leucocratic quartz-rich tonalite, Granite Mountain phase of the Granite Mountain batholith, sample site 13PSC-128.

### 3.2.2. Sample 14PSC-387, Mine phase

Sample 14PSC-387 was collected from the Mine phase about 2 km south of the Gibraltar mine pits (Fig. 2). It is a coarse-grained, moderately foliated tonalite containing 15-20% chloritized mafic grains, 30-35% quartz, and 50% saussuritic plagioclase (Fig. 5). Five zircon grains were analyzed. Three are mutually overlapping on concordia and yield a weighted mean $^{206}Pb/^{238}U$ date of 215.71 ±0.17 (0.27) [0.36] Ma (MSWD=1.2), interpreted as the best estimate of the crystallization age of this tonalite (Table 2, Fig. 4). The other two grains give slightly older $^{206}Pb/^{238}U$ results (216.56 and 217.17 Ma) and may include inherited zircon components.

### 3.2.3. Sample 14PSC-381, quartz-feldspar porphyry dike

Sample 14PSC-381 is from the southeastern part of the Granite Mountain batholith, about 900 m west of the fault contact with the Sheridan Creek stock (Fig. 2). Here, a quartz-feldspar porphyry dike, 10-20 m wide, cuts Mine phase tonalite and was traced for 80 m along a west-northwest trend (contacts not exposed). The sample, representative of most of the dike, comprises 30% quartz and plagioclase phenocrysts (2-8 mm) in a fine-grained crystalline groundmass consisting of quartz, plagioclase, and minor amounts of chloritized hornblende. Locally however, the dike is highly strained and the groundmass has been converted to quartz-plagioclase-sericite schist (Fig. 6). Three of four zircon grains analyzed from sample 14PSC-381 are mutually overlapping on concordia and yield a weighted mean $^{206}Pb/^{238}U$ date of 214.98 ±0.22 (0.30) [0.38] Ma (MSWD=0.28), interpreted as the crystallization age of the dike (Table 2, Fig. 4). The fourth grain yields an older $^{206}Pb/^{238}U$ date of 220.44 ±0.93 Ma and may include an inherited zircon component.

## 3.3. Burgess Creek stock

Two samples from the Burgess Creek stock were dated: a tonalite from the tonalite unit, and a quartz diorite from the mixed unit.

### 3.3.1. Sample 13PSC-28, tonalite unit

Sample 13PSC-28 was collected from the tonalite unit along the northern margin of the Burgess Creek stock, 900 m west of the fault inferred to mark the eastern limit of Quesnel terrane (Fig. 2). It is a medium-grained equigranular tonalite estimated to contain 10% mafic minerals (hornblende>biotite), 35% quartz, and 55% plagioclase (Fig. 7). Three of six zircon grains analyzed from sample 13PSC-28 are mutually overlapping on concordia and yield a weighted mean $^{206}Pb/^{238}U$ date of 222.71 ±0.22 (0.31) [0.39] Ma (MSWD=1.5), interpreted as the crystallization age of the tonalite at this locality (Table 3, Fig. 8). Two other grains overlap concordia at slightly younger ages ($^{206}Pb/^{238}U$ dates of 221.84 ±0.33 Ma and 220.51 ±0.44 Ma), and the sixth grain plots below concordia near 209.5 Ma, probably due to Pb loss.

### 3.3.2. Sample 13PSC-129, mixed unit

Sample 13PSC-129 was collected from the mixed unit in the northeastern part of the Burgess Creek stock, 350 m southwest of sample site 13PSC-28 (Fig. 2). It is a coarse-grained quartz diorite (Fig. 9) with 30-35% mafic minerals (hornblende>biotite>magnetite). The five zircon grains analyzed form a cluster on or very near concordia, with $^{206}Pb/^{238}U$ dates ranging from 221.06 ±0.45 Ma to 221.93 ±0.31 Ma (Table 3, Fig. 8). The three youngest grains, mutually overlapping on concordia, yield a weighted mean $^{206}Pb/^{238}U$ date of 221.25 ±0.20 (0.30) [0.39] Ma (MSWD=0.60), interpreted as the crystallization age of the quartz diorite.

## 3.4. Sheridan Creek stock, Sample 14PSC-374

Sample 14PSC-374 was collected from the northeastern part of the Sheridan Creek stock, about 1 km east of its fault contact with the Granite Mountain batholith (Fig. 2). It is a medium-grained, equigranular, weakly to moderately foliated tonalite with 20% mafic grains (hornblende>biotite), 30% quartz, and 50% plagioclase (Fig. 10). Five zircon grains were analyzed, all of which fall on concordia, with $^{206}Pb/^{238}U$ dates ranging from 108.43 ±0.22 Ma to 108.95 ±0.16 Ma (Table 3, Fig. 8). The four youngest grains form a very tight overlapping cluster that yields a weighted mean $^{206}Pb/^{238}U$ date of 108.57 ±0.09 (0.14) [0.18] Ma (MSWD=1.0), interpreted as the best estimate of the crystallization age.

**Table 2.** U-Th-Pb analytical results for samples from the Granite Mountain batholith.

| | Compositional Parameters | | | | | | | | | Radiogenic Isotope Ratios | | | | | | | | Isotopic Ages | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | Wt. mg | U ppm | Pb ppm | $\frac{Th}{U}$ | $^{206}Pb^*$ x$10^{-13}$ mol | mol % $^{206}Pb^*$ | $\frac{Pb^*}{Pb_c}$ | $Pb_c$ (pg) | $\frac{^{206}Pb}{^{204}Pb}$ | $\frac{^{208}Pb}{^{206}Pb}$ | $\frac{^{207}Pb}{^{206}Pb}$ | % err | $\frac{^{207}Pb}{^{235}U}$ | % err | $\frac{^{206}Pb}{^{238}U}$ | % err | corr. coef. | $\frac{^{207}Pb}{^{206}Pb}$ | ± | $\frac{^{207}Pb}{^{235}U}$ | ± | $\frac{^{206}Pb}{^{238}U}$ | ± |
| (a) | (b) | (c) | (c) | (d) | (e) | (e) | (e) | (e) | (f) | (g) | (g) | (h) | (g) | (h) | (g) | (h) | | (i) | (h) | (i) | (h) | (i) | (h) |
| **13PSC-128** | | | | | | | | | | | | | | | | | | | | | | | |
| A | 0.0196 | 58 | 1.9 | 0.200 | 1.5950 | 99.67% | 83 | 0.44 | 5534 | 0.064 | 0.0507 | 0.410 | 0.2370 | 0.446 | 0.03390 | 0.138 | 0.410 | 227.4 | 9.5 | 215.96 | 0.87 | 214.91 | 0.29 |
| C | 0.0145 | 55 | 1.9 | 0.273 | 1.1287 | 98.97% | 27 | 0.97 | 1803 | 0.087 | 0.0505 | 0.497 | 0.2386 | 0.546 | 0.03424 | 0.135 | 0.471 | 219 | 12 | 217.2 | 1.1 | 217.05 | 0.29 |
| D | 0.0136 | 20 | 0.7 | 0.290 | 0.3873 | 98.69% | 22 | 0.42 | 1411 | 0.093 | 0.0508 | 0.881 | 0.2403 | 0.935 | 0.03428 | 0.169 | 0.400 | 234 | 20 | 218.7 | 1.8 | 217.26 | 0.36 |
| F | 0.0037 | 39 | 1.4 | 0.307 | 0.2062 | 97.48% | 11 | 0.44 | 733 | 0.098 | 0.0509 | 1.413 | 0.2403 | 1.500 | 0.03427 | 0.211 | 0.471 | 234 | 33 | 218.7 | 3.0 | 217.20 | 0.45 |
| **14PSC-387** | | | | | | | | | | | | | | | | | | | | | | | |
| A | 0.0033 | 88 | 3.1 | 0.222 | 0.4123 | 97.65% | 12 | 0.81 | 788 | 0.071 | 0.0507 | 0.865 | 0.2376 | 0.937 | 0.03401 | 0.160 | 0.516 | 225 | 20 | 216.4 | 1.8 | 215.60 | 0.34 |
| B | 0.0030 | 104 | 4.5 | 0.225 | 0.4419 | 91.83% | 3 | 3.24 | 225 | 0.072 | 0.0507 | 1.041 | 0.2376 | 1.121 | 0.03400 | 0.193 | 0.485 | 227 | 24 | 216.4 | 2.2 | 215.51 | 0.41 |
| C | 0.0021 | 81 | 3.0 | 0.178 | 0.2440 | 96.48% | 8 | 0.73 | 526 | 0.056 | 0.0503 | 1.718 | 0.2377 | 1.793 | 0.03426 | 0.174 | 0.470 | 210 | 40 | 216.6 | 3.5 | 217.17 | 0.37 |
| D | 0.0027 | 80 | 2.8 | 0.260 | 0.3072 | 98.10% | 15 | 0.49 | 976 | 0.083 | 0.0508 | 0.736 | 0.2393 | 0.803 | 0.03416 | 0.165 | 0.489 | 232 | 17 | 217.8 | 1.6 | 216.56 | 0.35 |
| E | 0.0025 | 405 | 13.8 | 0.277 | 1.4355 | 99.42% | 49 | 0.69 | 3171 | 0.088 | 0.0504 | 0.219 | 0.2364 | 0.273 | 0.03405 | 0.110 | 0.642 | 211.6 | 5.1 | 215.48 | 0.53 | 215.83 | 0.23 |
| **14PSC-381** | | | | | | | | | | | | | | | | | | | | | | | |
| B | 0.0030 | 25 | 1.0 | 0.278 | 0.1084 | 94.48% | 5 | 0.52 | 335 | 0.087 | 0.0499 | 2.322 | 0.2394 | 2.496 | 0.03479 | 0.430 | 0.478 | 191 | 54 | 217.9 | 4.9 | 220.44 | 0.93 |
| C | 0.0025 | 52 | 2.0 | 0.264 | 0.1841 | 95.76% | 6 | 0.67 | 436 | 0.084 | 0.0502 | 1.562 | 0.2348 | 1.668 | 0.03393 | 0.185 | 0.606 | 203 | 36 | 214.1 | 3.2 | 215.10 | 0.39 |
| D | 0.0044 | 75 | 2.9 | 0.314 | 0.4681 | 96.00% | 7 | 1.61 | 461 | 0.100 | 0.0507 | 0.959 | 0.2370 | 1.041 | 0.03390 | 0.172 | 0.541 | 227 | 22 | 216.0 | 2.0 | 214.94 | 0.36 |
| E | 0.0025 | 52 | 1.9 | 0.264 | 0.1851 | 96.77% | 8 | 0.51 | 572 | 0.084 | 0.0509 | 1.407 | 0.2378 | 1.494 | 0.03390 | 0.173 | 0.551 | 235 | 32 | 216.6 | 2.9 | 214.91 | 0.37 |

(a) Letters are labels for fractions composed of single zircon grains or fragments; all fractions annealed and chemically abraded after Mattinson (2005) and Scoates and Friedman (2008).
(b) Nominal fraction weights estimated from photomicrographic grain dimensions, adjusted for partial dissolution during chemical abrasion.
(c) Nominal U and total Pb concentrations subject to uncertainty in photomicrographic estimation of weight and partial dissolution during chemical abrasion.
(d) Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{206}Pb/^{238}U$ date.
(e) Pb* and Pbc represent radiogenic and common Pb, respectively; mol % $^{206}Pb^*$ with respect to radiogenic, blank and initial common Pb.
(f) Measured ratio corrected for spike and fractionation only. Mass discrimination of 0.25 ± 0.03%/amu, based on analysis of NBS-982; all Daly analyses.
(e) Corrected for fractionation, spike, and common Pb; up to 1 pg common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb$ = 18.50 ± 1.0%; $^{207}Pb/^{204}Pb$ = 15.50 ± 1.0%; $^{208}Pb/^{204}Pb$ = 38.40 ± 1.0% (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb with Stacey and Kramers (1975) model Pb composition at interpreted age of sample.
(g) Corrected for fractionation, spike, and common Pb; All common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb$ = 18.50±1.0%; $^{207}Pb/^{204}Pb$ = 15.50±1.0%; $^{208}Pb/^{204}Pb$ = 38.40±1.0% ( 1σ errors).
(h) Errors are 2-sigma, propagated using the algorithms of Schmitz and Schoene (2007) and Crowley et al. (2007).
(i) Calculations are based on the decay constants of Jaffey et al. (1971). $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages corrected for initial disequilibrium in $^{230}Th/^{238}U$ using Th/U [magma] = 3.

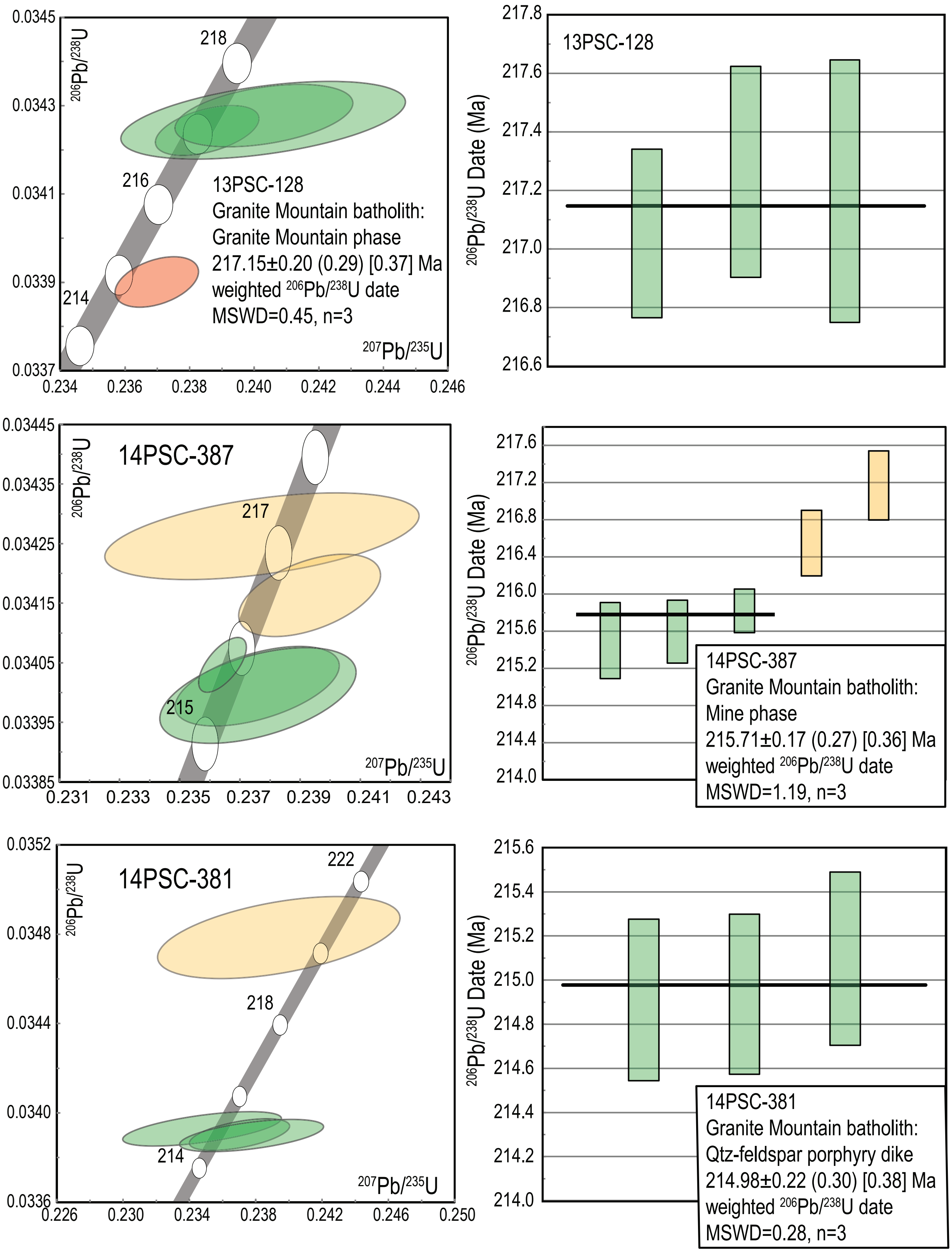


**Fig. 4.** Concordia plots and $^{206}Pb/^{238}U$ weighted mean age diagrams for samples from different units in the Granite Mountain batholith. Green ellipses are zircons used for the $^{206}Pb/^{238}U$ weighted mean calculation. Yellow are zircons that may have inherited components; red are zircons with lead loss.

**Fig. 5.** Foliated tonalite, Mine phase of the Granite Mountain batholith, sample site 14PSC-387.

**Fig. 6.** Foliated quartz-feldspar porphyry, from high-strain zone in dike cutting Mine phase tonalite, near sample site 14PSC-381.

## 4. Discussion

Samples dated in this study provide Late Triassic crystallization ages for parts of the Burgess Creek stock and Granite Mountain batholith. The dates from the Burgess Creek stock (222.71 ±0.39 Ma and 221.25 ±0.39 Ma) are the only isotopic dates available for this unit and demonstrate that it is, at least in part, several million years older than the oldest dated rocks in the Granite Mountain batholith. The three dates from the Granite

**Fig. 7.** Hornblende-biotite tonalite, tonalite unit of the Burgess Creek stock, sample site 13PSC-28.

Mountain batholith (217.15 ±0.37 Ma, 215.71 ±0.36 Ma, and 214.98 ±0.38 Ma) demonstrate magmatic crystallization over a ~3 million-year period. A number of previously reported U-Pb zircon dates from the Granite Mountain batholith fall within this same time window, including: 1) a U-Pb zircon CA-TIMS date of 216.17 ±0.39 Ma reported by Mostaghimi (2016) for Mine phase tonalite from the Gibraltar mine; 2) a 215 ±0.8 Ma U-Pb zircon date reported by Ash and Riveros (2001), from a Granite Mountain phase sample collected 1.5 km north-northeast of the Gibraltar mill (Ash et al., 1999a); and 3) U-Pb zircon LA-ICP-MS dates of 211.9 ±4.3 Ma (Mine phase) and 209.6 ±6.3 Ma (Granite Mountain phase) reported by Oliver et al. (2009) for samples from the Gibraltar mine. However, younger intrusive rocks in the batholith are indicated by a recent study that included U-Pb zircon LA-ICP-MS dating of six samples, all mapped as Mine phase tonalite, from the Gibraltar mine area (Kobylinski et al., 2018). Two of the dates (218.9 ±3.1 Ma and 213.2 ±2.4 Ma) are within error of previous dates, but the other four, ranging from 201.9 ±5.0 Ma to 206.8 ±4.0 Ma, document a younger, latest Triassic, intrusive phase.

The Granite Mountain batholith and Burgess Creek stock are included in Quesnel terrane because they intrude Triassic rocks of the Nicola Group, the most widespread component of the terrane. They are inferred to be part of a belt of Late Triassic calcalkaline plutons that is restricted to the western part of Quesnel terrane in southern British Columbia (Schiarizza, 2014), although this belt is not exposed between the Granite Mountain area and Ashcroft, mainly due to extensive Neogene and Quaternary cover. The belt is best represented by Late Triassic granitic to tonalitic plutons between Ashcroft and Princeton (Fig. 1), including the Guichon Creek batholith (211-207 Ma, D’Angelo et al., 2017), the Allison pluton (223 Ma, Mihalynuk et al., 2016), and the Coldwater pluton (210 Ma, Mihalynuk et al., 2016).

The 108.57 ±0.18 Ma date for the Sheridan Creek stock demonstrates that the deformation that produced the foliations

**Table 3.** U-Th-Pb analytical results for samples from the Burgess Creek stock and Sheridan Creek stock.

| | Compositional Parameters | | | | | | | | | Radiogenic Isotope Ratios | | | | | | | | Isotopic Ages | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample (a) | Wt. mg (b) | U ppm (c) | Pb ppm (c) | Th/U (d) | $^{206}Pb^*$ x$10^{-13}$ mol (e) | mol % $^{206}Pb^*$ (e) | $Pb^*/Pb_c$ (e) | $Pb_c$ (pg) (e) | $^{206}Pb/^{204}Pb$ (f) | $^{208}Pb/^{206}Pb$ (g) | $^{207}Pb/^{206}Pb$ (g) | % err (h) | $^{207}Pb/^{235}U$ (g) | % err (h) | $^{206}Pb/^{238}U$ (g) | % err (h) | corr. coef. | $^{207}Pb/^{206}Pb$ (i) | ± (h) | $^{207}Pb/^{235}U$ (i) | ± (h) | $^{206}Pb/^{238}U$ (i) | ± (h) |
| **13PSC-28** | | | | | | | | | | | | | | | | | | | | | | | |
| A | 0.008 | 100 | 3.6 | 0.323 | 1.2078 | 99.00% | 29 | 1.01 | 1843 | 0.103 | 0.0505 | 0.700 | 0.2425 | 0.773 | 0.03480 | 0.204 | 0.474 | 220 | 16 | 220.5 | 1.5 | 220.51 | 0.44 |
| B | 0.008 | 129 | 4.2 | 0.273 | 1.4687 | 99.58% | 68 | 0.51 | 4435 | 0.088 | 0.0509 | 0.838 | 0.2317 | 0.885 | 0.03303 | 0.261 | 0.323 | 236 | 19 | 211.6 | 1.7 | 209.47 | 0.54 |
| C | 0.005 | 184 | 6.6 | 0.398 | 1.2943 | 99.58% | 69 | 0.46 | 4435 | 0.127 | 0.0508 | 0.741 | 0.2462 | 0.775 | 0.03512 | 0.163 | 0.311 | 234 | 17 | 223.5 | 1.6 | 222.53 | 0.36 |
| D | 0.006 | 45 | 1.7 | 0.428 | 0.4113 | 98.07% | 15 | 0.67 | 957 | 0.136 | 0.0507 | 1.101 | 0.2456 | 1.170 | 0.03513 | 0.204 | 0.416 | 227 | 25 | 223.0 | 2.3 | 222.60 | 0.45 |
| E | 0.007 | 139 | 4.9 | 0.369 | 1.3625 | 99.72% | 103 | 0.32 | 6676 | 0.117 | 0.0508 | 0.474 | 0.2450 | 0.524 | 0.03501 | 0.152 | 0.454 | 230 | 11 | 222.5 | 1.0 | 221.84 | 0.33 |
| F | 0.003 | 154 | 5.8 | 0.541 | 0.6996 | 99.34% | 46 | 0.38 | 2814 | 0.172 | 0.0508 | 0.554 | 0.2462 | 0.605 | 0.03519 | 0.157 | 0.443 | 230 | 13 | 223.5 | 1.2 | 222.94 | 0.34 |
| **13PSC-129** | | | | | | | | | | | | | | | | | | | | | | | |
| B | 0.003 | 167 | 5.8 | 0.309 | 0.7525 | 99.54% | 62 | 0.29 | 4022 | 0.098 | 0.0507 | 0.433 | 0.2442 | 0.475 | 0.03492 | 0.122 | 0.460 | 228 | 10 | 221.81 | 0.95 | 221.26 | 0.26 |
| D | 0.005 | 420 | 17.9 | 0.424 | 2.8736 | 94.54% | 5 | 13.77 | 337 | 0.135 | 0.0505 | 1.312 | 0.2435 | 1.374 | 0.03494 | 0.208 | 0.368 | 220 | 30 | 221.2 | 2.7 | 221.41 | 0.45 |
| E | 0.002 | 178 | 6.4 | 0.380 | 0.5712 | 99.20% | 36 | 0.38 | 2304 | 0.120 | 0.0505 | 0.644 | 0.2436 | 0.688 | 0.03501 | 0.137 | 0.412 | 217 | 15 | 221.4 | 1.4 | 221.80 | 0.30 |
| F | 0.004 | 258 | 9.1 | 0.347 | 1.3902 | 99.63% | 77 | 0.44 | 4942 | 0.111 | 0.0510 | 0.740 | 0.2452 | 0.817 | 0.03489 | 0.205 | 0.486 | 240 | 17 | 222.7 | 1.6 | 221.06 | 0.45 |
| G | 0.002 | 1063 | 37.5 | 0.359 | 2.7931 | 99.84% | 182 | 0.37 | 11524 | 0.115 | 0.0509 | 0.275 | 0.2456 | 0.319 | 0.03503 | 0.143 | 0.511 | 235 | 6 | 223.0 | 0.6 | 221.93 | 0.31 |
| **14PSC-374** | | | | | | | | | | | | | | | | | | | | | | | |
| A | 0.003 | 224 | 4.1 | 0.466 | 0.4589 | 98.46% | 20 | 0.58 | 1205 | 0.148 | 0.0479 | 1.537 | 0.1122 | 1.563 | 0.01698 | 0.155 | 0.216 | 96 | 36 | 108.0 | 1.6 | 108.53 | 0.17 |
| B | 0.025 | 18 | 0.3 | 0.503 | 0.3145 | 97.60% | 12 | 0.63 | 770 | 0.161 | 0.0482 | 1.164 | 0.1131 | 1.224 | 0.01700 | 0.145 | 0.459 | 112 | 27 | 108.8 | 1.3 | 108.65 | 0.16 |
| C | 0.004 | 178 | 3.9 | 0.283 | 0.4394 | 91.21% | 3 | 3.48 | 211 | 0.090 | 0.0479 | 1.582 | 0.1120 | 1.655 | 0.01696 | 0.201 | 0.414 | 94 | 37 | 107.8 | 1.7 | 108.43 | 0.22 |
| D | 0.003 | 124 | 2.4 | 0.449 | 0.2289 | 96.83% | 9 | 0.61 | 584 | 0.144 | 0.0483 | 1.548 | 0.1132 | 1.625 | 0.01699 | 0.206 | 0.430 | 114 | 36 | 108.8 | 1.7 | 108.61 | 0.22 |
| E | 0.003 | 260 | 4.7 | 0.398 | 0.4617 | 98.37% | 18 | 0.63 | 1134 | 0.127 | 0.0482 | 0.762 | 0.1133 | 0.810 | 0.01705 | 0.144 | 0.415 | 111 | 18 | 109.0 | 0.8 | 108.95 | 0.16 |

(a) Letters are labels for fractions composed of single zircon grains or fragments; all fractions annealed and chemically abraded after Mattinson (2005) and Scoates and Friedman (2008).
(b) Nominal fraction weights estimated from photomicrographic grain dimensions, adjusted for partial dissolution during chemical abrasion.
(c) Nominal U and total Pb concentrations subject to uncertainty in photomicrographic estimation of weight and partial dissolution during chemical abrasion.
(d) Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{206}Pb/^{238}U$ date.
(e) Pb* and Pbc represent radiogenic and common Pb, respectively; mol % $^{206}Pb^*$ with respect to radiogenic, blank and initial common Pb.
(f) Measured ratio corrected for spike and fractionation only. Mass discrimination of 0.25 ± 0.03%/amu, based on analysis of NBS-982; all Daly analyses.
(e) Corrected for fractionation, spike, and common Pb; up to 1 pg common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb$ = 18.50 ± 1.0%; $^{207}Pb/^{204}Pb$ = 15.50 ± 1.0%; $^{208}Pb/^{204}Pb$ = 38.40 ± 1.0% (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb with Stacey and Kramers (1975) model Pb composition at interpreted age of sample.
(g) Corrected for fractionation, spike, and common Pb; All common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb$ = 18.50±1.0%; $^{207}Pb/^{204}Pb$ = 15.50±1.0%; $^{208}Pb/^{204}Pb$ = 38.40±1.0% ( 1σ errors).
(h) Errors are 2-sigma, propagated using the algorithms of Schmitz and Schoene (2007) and Crowley et al. (2007).
(i) Calculations are based on the decay constants of Jaffey et al. (1971). $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages corrected for initial disequilibrium in $^{230}Th/^{238}U$ using Th/U [magma] = 3.

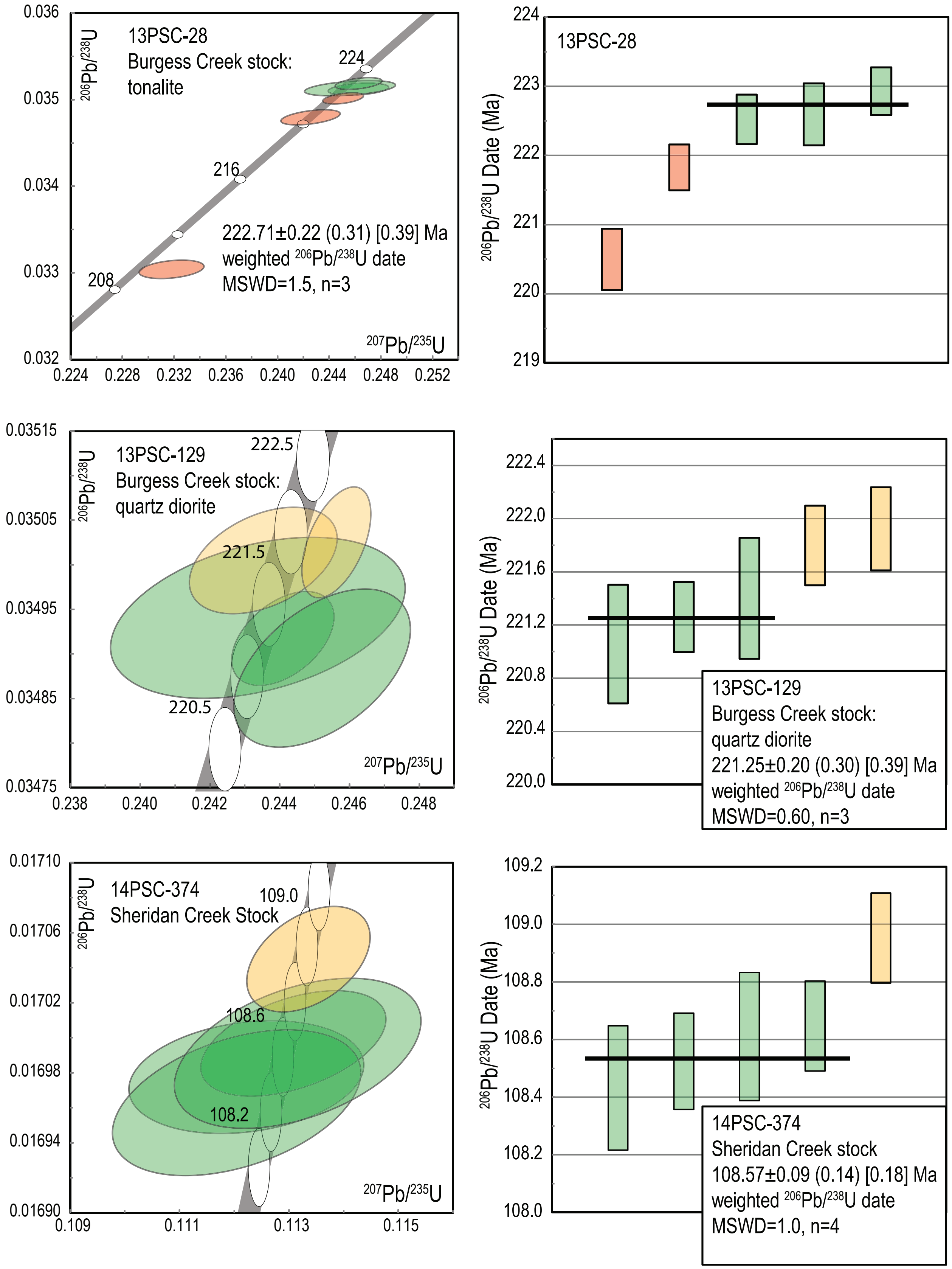


**Fig. 8.** Concordia plots and $^{206}$Pb/$^{238}$U weighted mean age diagrams for samples from the Burgess Creek stock and Sheridan Creek stock. Green ellipses are zircons used for the $^{206}$Pb/$^{238}$U weighted mean calculation. Yellow are zircons that may have inherited components; red are zircons with lead loss.

**Fig. 9.** Hornblende-biotite quartz diorite, mixed unit of the Burgess Creek stock, near sample site 13PSC-129. Leucotonalite veins and epidote-altered fractures, such as those in this photo, were avoided during sampling.

**Fig. 10.** Weakly foliated hornblende-biotite tonalite, Sheridan Creek stock, sample site 14PSC-374.

common to the Sheridan Creek stock, Nicola Group, and Granite Mountain batholith was mid-Cretaceous or younger. Based on the orientations of structures, and $^{40}Ar$-$^{39}Ar$ dates ranging from 54 to 36 Ma on white mica from fault zones at the Gibraltar mine, Mostaghimi (2016) linked development of the foliation and related north-directed thrust faults to northwest-striking Eocene dextral strike-slip faults. These structures were then offset by, and rotated between, faults related to the younger north-striking Fraser fault system. A northwest-striking fault mapped by Ash et al. (1999a, b) to the south of the Granite Mountain batholith (Fig. 11, fault PFE) may be the specific structure to which the south-dipping foliations and

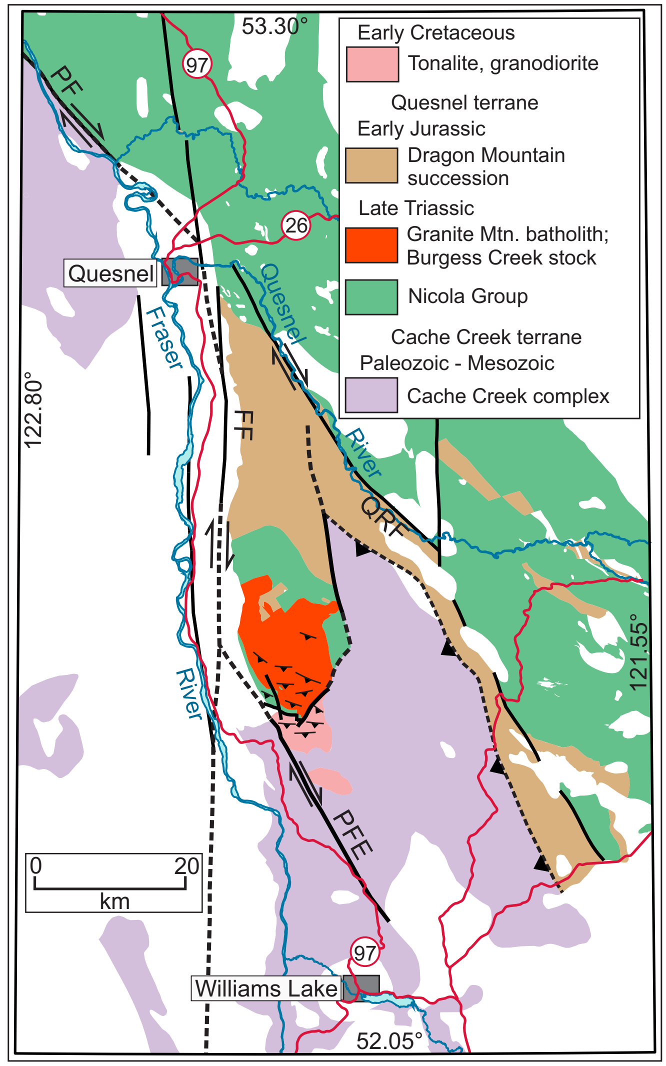


**Fig. 11.** Map of selected geologic units and structures in the Williams Lake-Quesnel area, showing location of the Granite Mountain batholith with respect to known and inferred dextral strike-slip faults. Geology from Cui et al. (2017). FF-Fraser fault; PF-Pinchi fault; PFE-inferred Pinchi fault extension; QRF-Quesnel River fault.

contractional faults are linked, and this fault may be a southern extension (offset by the Fraser fault system) of the Pinchi fault, which extends 400 km northwest from Quesnel, marking the contact between Cache Creek and Quesnel terranes for most of this length (Struik et al., 2001; Gabrielse et al., 2006).

The panel of Quesnel terrane rocks that includes the Granite Mountain batholith is juxtaposed against Cache Creek terrane to the east across an unexposed northerly trending fault (Figs. 2, 11). Schiarizza (2015) suggested that this fault might record mid-Cretaceous sinistral strike-slip movement. An alternative explanation is that the fault is an Eocene east-side-down normal fault that accommodated uplift of the Granite Mountain batholith and associated rocks as they were being deformed along the Pinchi and/or Fraser fault systems. This would imply that the Cache Creek rocks to the east and southeast of the

Granite Mountain batholith form a relatively thin thrust sheet that overlies the western part of Quesnel terrane (Fig. 11), including the belt of Late Triassic calcalkaline plutons.

## 5. Summary

Samples collected during mapping of the Granite Mountain area in 2013 and 2014 were dated using the U-Pb zircon chemical abrasion thermal ionization mass spectrometry method (CA-TIMS), providing crystallization ages for the Granite Mountain batholith, the Burgess Creek stock, and the Sheridan Creek stock. Leucocratic tonalite from the Granite Mountain phase of the batholith yields a Late Triassic date of 217.15 ±0.37 Ma; Mine phase tonalite is dated at 215.71 ±0.36 Ma; and a quartz-plagioclase porphyry dike cutting Mine phase tonalite is 214.98 ±0.38 Ma. The Burgess Creek stock, on the northeast margin of the batholith, is also Late Triassic, but several million years older than the Granite Mountain batholith. A tonalite sample from the stock yields a date of 222.71 ±0.39 Ma, and a sample of quartz diorite is dated at 221.25 ±0.39 Ma. The Sheridan Creek stock, south of the Granite Mountain batholith, is Early Cretaceous, based on a date of 108.57 ±0.18 Ma obtained from a tonalite sample collected from the stock.

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