

# Geological setting of the Granite Mountain batholith, host to the Gibraltar porphyry Cu-Mo deposit, south-central British Columbia

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## Abstract

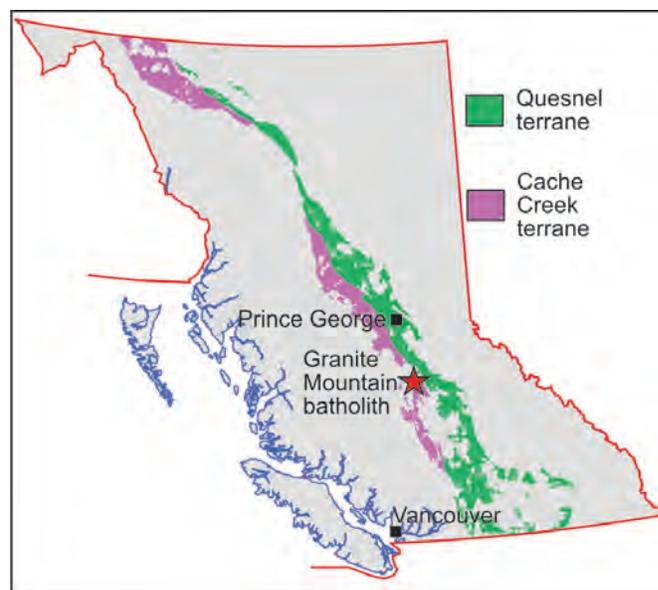
The Granite Mountain project was initiated in 2013 to clarify the contact relationships, structural history, and terrane affinity of the Granite Mountain batholith (Late Triassic), host to the Gibraltar porphyry Cu-Mo deposit. Rocks mapped along the northeast margin of the batholith include a succession of predominantly volcanogenic sandstone (locally gritty to pebbly), intercalated with conglomerate, mafic and felsic volcanic breccia, siltstone, limestone, and basalt. This succession has yielded Middle or Late Triassic conodonts from one locality. On the basis of its strong lithologic similarity, this succession is likely part the Nicola Group of Quesnel terrane. Felsic volcanic breccias, which have no counterpart in nearby Nicola exposures, suggest possible affinities with the western Nicola belt of the Merritt-Ashcroft area. In contrast to historical interpretations, the Granite Mountain batholith is inferred to be part of Quesnel terrane, on the basis of its spatial association with the Nicola Group, and a link provided by a common overlap assemblage, the Dragon Mountain succession, which is part of a Lower to Middle Jurassic intra-Quesnel clastic basin. The Granite Mountain batholith, together with adjacent Nicola Group and Dragon Mountain succession, form a panel of Quesnel rocks that is bounded to the east, south, and west by rocks of Cache Creek terrane. The eastern boundary is inferred to be a significant north-northwest striking fault, previously unrecognized, that may record more than 20 km of sinistral strike slip.

**Keywords:** Granite Mountain batholith, Late Triassic tonalite, Burgess Creek stock, Nicola Group, Cache Creek Complex, Dragon Mountain succession, Gibraltar Cu-Mo porphyry deposit, Quesnel terrane, Cache Creek terrane

## 1. Introduction

The Gibraltar Mine is a large Cu-Mo deposit hosted by the Granite Mountain batholith (Late Triassic) near McLeese Lake in south-central British Columbia (Fig. 1). It began production in 1972, reopened in 2004, and currently has a projected mine life extending to 2037 (van Straaten et al., 2013).

Geological work near the Granite Mountain batholith prior to the late 1990s included regional mapping of the Quesnel River (93B) map area by Tipper (1959, 1978), geological mapping of the Granite Mountain batholith by Panteleyev (1978), and more detailed studies of the geology and mineralization in and near the Gibraltar deposits by Sutherland Brown (1958, 1967, 1974), Eastwood (1970), Drummond et al. (1973, 1976), and Bysouth et al. (1995). These early workers considered the batholith part of Cache Creek terrane because of widespread Cache Creek rocks to the south and east (Tipper, 1959, 1978) and because skarns and schists along the southwest margin of the batholith were interpreted as Cache Creek rocks altered during batholith emplacement (Drummond et al., 1976; Panteleyev, 1978; Bysouth et al., 1995). Tipper (1978) and Bysouth et al. (1995) inferred that siliciclastic, volcanoclastic, and local volcanic rocks along the northeast and north margins of the batholith were predominantly younger (Jurassic) than the batholith. Sutherland Brown (1974) Drummond et al. (1976) and Bysouth et al. (1995) regarded Gibraltar as a porphyry Cu-Mo deposit, but noted that it had some unusual characteristics, including a spatial association of orebodies with zones of



**Fig. 1.** Map of British Columbia showing location of the Granite Mountain batholith and distribution of Quesnel and Cache Creek terranes.

ductile deformation.

Ash et al. (1999a, b) carried out a geological mapping program of the Granite Mountain batholith and surrounding rocks in 1998. This was followed by a description of the Gibraltar deposit by Ash and Riveros (2001), based on mapping

of the Gibraltar pits in 1998, 1999 and 2000, mainly during a hiatus in mining activity that lasted from 1999 to 2003. Ash et al. (1999a, b) challenged earlier interpretations by suggesting that the Granite Mountain batholith is a part of Quesnel terrane, and that volcanoclastic rocks on the northeast margin of the batholith belong to the Late Triassic Nicola Group. They suggested that the batholith was faulted against Cache Creek rocks in post-Triassic time, and that ductile shear zones within the Gibraltar deposit formed during this tectonic event. This implied that Gibraltar might not be a porphyry deposit, or at least that mineralization had been significantly remobilized during younger deformation.

Oliver et al. (2009) and van Straaten et al. (2013) presented summaries of the deposit as it is currently understood. They stressed that the styles of vein and disseminated mineralization are consistent with an origin as a calcalkaline porphyry, as also suggested by Late Triassic Re-Os ages on molybdenum that overlap the age of the host tonalite (Harding, 2012). van Straaten et al. (2013) also argued that mineralization was before or during deformation because ductile deformation zones contain abundant, folded, sheared, and transposed hydrothermal veins, but generally lack crosscutting veins.

This report summarizes preliminary results from the first field season of a two-year bedrock mapping program designed to clarify the geological setting and structural history of the Granite Mountain batholith. This initial work focuses on the package of volcanoclastic rocks on the northeast margin of the Granite Mountain batholith that were assigned to a Lower-Middle Jurassic siliciclastic assemblage by Tipper (1978), but correlated with the Nicola Group (Late Triassic) of Quesnel terrane by Ash et al. (1999a, b). The main conclusion from the 2013 fieldwork is that these rocks are part of the Nicola Group.

## 2. Regional setting

The Granite Mountain batholith crops out on the Fraser Plateau, seven to eighteen kilometres east of the Fraser River, within the traditional territories of the Northern Secwepemc te Qelmuw and Tsilhqot'in First Nations (Fig. 2). The community of McLeese Lake, on Highway 97, is 10 km south-southwest of the Gibraltar ore deposits, and is linked to the mine site by paved road. Access to other parts of the batholith and surrounding areas is by extensive networks of logging and Forest Service roads, although many roads have been deactivated and are no longer accessible by truck.

Quesnel terrane is an important metallogenic province that extends along most of the length of the Canadian Cordillera (Nelson et al., 2013). It is characterized by a Late Triassic to Early Jurassic magmatic arc complex that formed outboard of the western margin of ancestral North America. Quesnel terrane is flanked to the east by Proterozoic and Paleozoic siliciclastic, carbonate and volcanic rocks of pericratonic affinity, and locally by an intervening assemblage of mid to Late Paleozoic oceanic basalt and chert assigned to Slide Mountain terrane, which is commonly interpreted as the imbricated remnant of a Late Paleozoic marginal basin. Late Paleozoic through

mid-Mesozoic oceanic rocks of Cache Creek terrane west of Quesnel terrane are interpreted as part of the accretion-subduction complex that was responsible for generating the Quesnel magmatic arc.

At the latitude of McLeese Lake, rocks of Quesnel terrane crop out mainly in a ~ 30 km-wide, northwest-trending belt, 20 km east of the Granite Mountain batholith (Fig. 2). The terrane is represented mainly by Middle to Upper Triassic volcanic and sedimentary rocks of the Nicola Group, together with abundant Late Triassic to Early Jurassic calcalkaline and alkaline intrusions (Logan et al., 2010). Lower to Middle Jurassic siliciclastic sedimentary rocks that outcrop along the western margin of the terrane are assigned to the Dragon Mountain succession (Logan and Moynihan, 2009). These rocks represent a basin derived from, and deposited on, Quesnel terrane (Petersen et al., 2004; Logan and Moynihan, 2009).

Cache Creek terrane, represented by the Cache Creek Complex, lies to the west of the main Quesnel belt, and is represented by abundant exposures to the east and south of the Granite Mountain batholith (Fig. 2). These exposures include chert, argillite, basalt, limestone, conglomerate, and greywacke (Tipper, 1959; Ash et al., 1999a, b). The complex is not well dated in the area represented by Fig. 2, although one limestone exposure, 10 km east of the southern part of the Granite Mountain batholith, yielded Permian fossils (Tipper, 1978). Contiguous, but better-studied parts of the Cache Creek Complex to the south and north include rocks ranging from Carboniferous to Early Jurassic (Cordey and Read, 1992; Read, 1993; Struik et al., 2001).

The youngest rocks in the region include Middle Jurassic and Early Cretaceous plutons, Eocene volcanic and local sedimentary rocks, Oligocene-Pliocene siliciclastic sequences localized along parts of the Fraser River, and widespread Miocene-Pleistocene basalt of the Chilcotin Group (Fig. 2). The Cretaceous plutonic suite includes tonalite of the Sheridan Creek stock, directly south of the Granite Mountain batholith. The Burgess Creek stock, on the northeast margin of the Granite Mountain batholith (Fig. 3), has been interpreted as a relatively young, post-batholith intrusion (Panteleyev, 1978; Bysouth et al., 1995), or a border phase of the Granite Mountain batholith (Ash et al., 1999a, b).

## 3. Geology of the northeastern margin of the Granite Mountain batholith

The southwestern part of the area mapped in 2013 is underlain by coarse-grained leucocratic tonalite of the Granite Mountain phase of the Granite Mountain batholith (Fig. 3). The area to the north and east of the batholith is underlain mainly by a succession of volcanoclastic and volcanic rocks that are assigned to the Nicola Group. The Nicola Group is cut by undated, predominantly tonalitic intrusive rocks of the Burgess Creek stock, and is locally overlain by a small outlier of slate and siltstone correlated with the Dragon Mountain succession. Chert, basalt, and limestone exposed in the eastern part of the area are part of the Cache Creek Complex, and are inferred

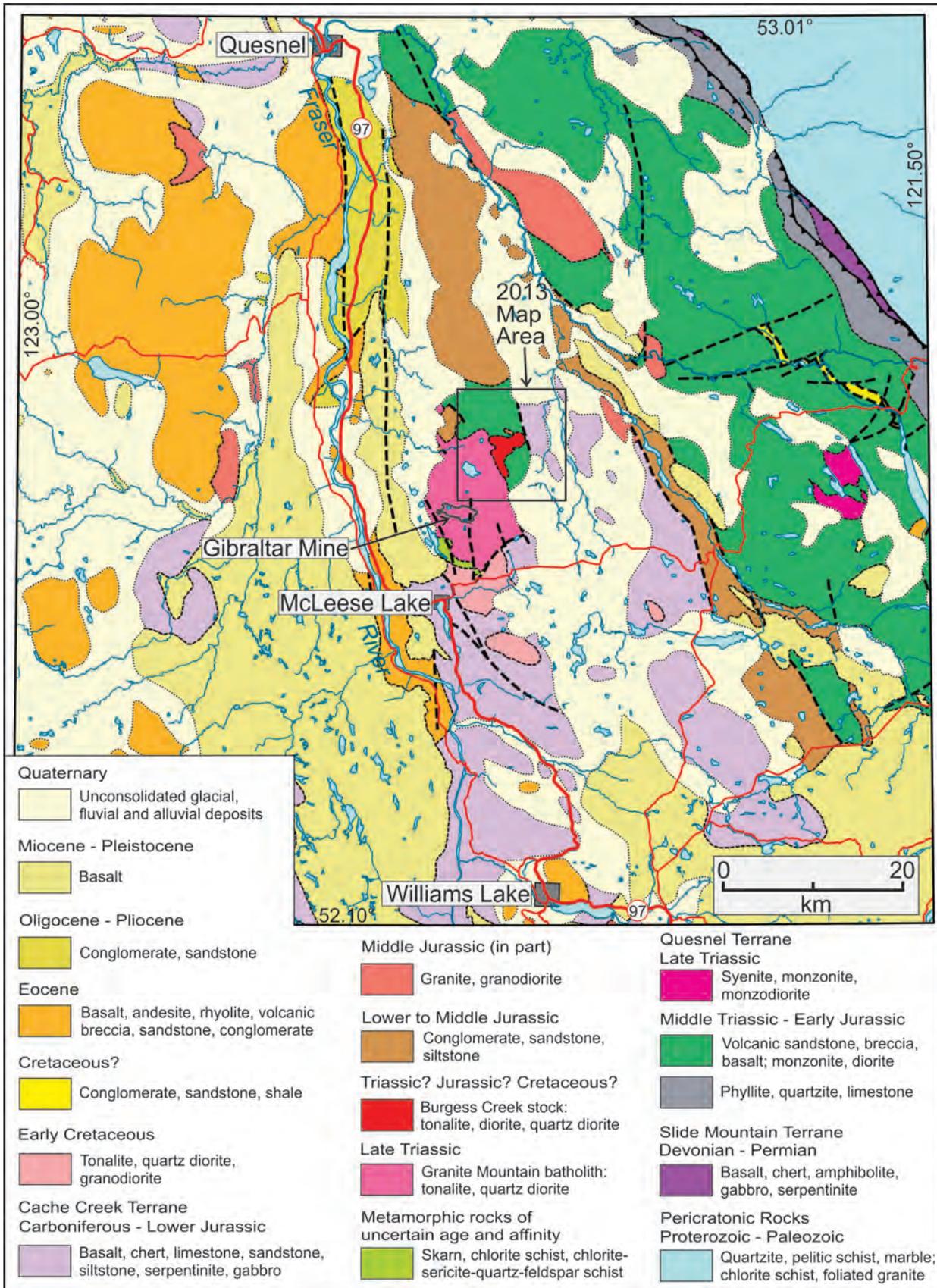


Fig. 2. Geological map of the area between Williams Lake and Quesnel, showing the location and setting of the Granite Mountain batholith.

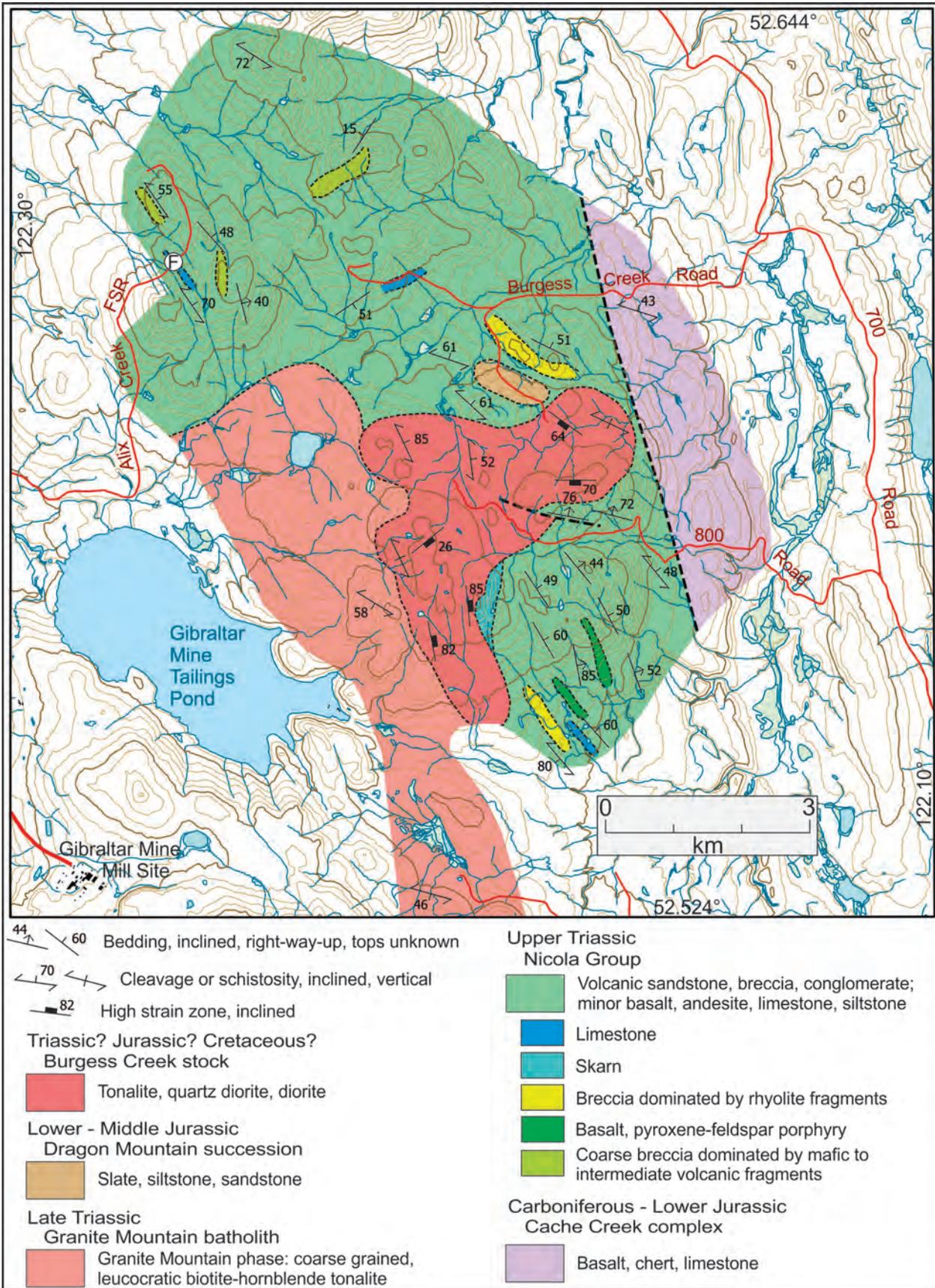


Fig. 3. Geology of the northeast margin of the Granite Mountain batholith, based on 2013 fieldwork.

to be separated from the Nicola Group by a significant north-northwest-striking fault (Fig. 3).

### 3.1. Nicola Group

Rocks assigned to the Nicola Group consist mainly of sandstone and gritty to pebbly sandstone, with local intercalations of conglomerate, breccia, siltstone, limestone, and basalt (Fig. 3). These rocks were included in the upper (Lower to Middle Jurassic) part of the Quesnel River Group (equivalent to the Dragon Mountain succession) by Tipper (1978), and were assigned to an unnamed unit of suspected Early Jurassic age by Panteleyev (1978). Correlation with the Nicola Group follows the interpretation of Ash et al. (1999a, b). This correlation is based mainly on lithology, but is corroborated by the only fossils, Middle or Late Triassic conodonts, known from the succession.

The Nicola Group consists mainly of medium green, locally grey to purplish-grey, fine- to coarse-grained, commonly gritty to pebbly, volcanogenic sandstone. The sandstone is well bedded in places, but elsewhere forms massive units, up to several tens of metres thick, in which bedding is not apparent. In well-bedded sections (Fig. 4), thin to medium beds of sandstone are intercalated with thin beds of green to grey siltstone, and locally display normal grading and erosive bases. The sandstones are rich in feldspar, and also contain grey to green volcanic lithic grains and altered mafic mineral or lithic grains. Gritty and pebbly sandstone intervals contain angular to subrounded fragments of mainly grey and green, locally feldspar and/or pyroxene-phyric volcanic rock (Fig. 5). Local medium- to thick-beds of sand matrix-supported pebble conglomerate in well-stratified intervals contain a similar suite. Less common clasts include fine-grained diorite, quartz diorite, hornblende porphyry, quartz-feldspar-phyric rhyolite, limestone, argillite, and siltstone.

Siltstone is uncommon, and typically forms cm-scale layers intercalated with substantially thicker beds of sandstone. However, at one isolated outcrop along the 800 road, 300 m



Fig. 5. Pebbly sandstone, Nicola Group, north of Burgess Creek stock.

west of the Cache Creek contact, several metres of grey-green, rusty-weathered, weakly cleaved siltstone lacking intercalations of coarser rock are exposed.

Relatively coarse, mafic volcanic breccias outcrop at three locales in the northwestern part of the map area; although contacts are not exposed, the breccias appear to be intercalated with typical sandstones and pebbly sandstones (Fig. 3). The breccias are medium to dark green, greenish-brown to rusty-brown weathered, matrix supported, poorly sorted and apparently unstratified. Angular to subrounded fragments 1-10 cm in long dimension, float in a matrix of sand-size feldspar, pyroxene, and mafic volcanic-lithic grains (Fig. 6). The fragments are mainly pyroxene and/or plagioclase-phyric basalt, but fragments of aphyric feldspathic volcanic rock and hornblende-feldspar porphyry are also present. The easternmost mafic breccia unit contains rare subrounded clasts of pyroxenite.

Distinctive breccia units with predominantly felsic volcanic fragments outcrop north and south of the Burgess Creek stock



Fig. 4. Thinly bedded sandstone and siltstone, Nicola Group, north of Burgess Creek stock.



Fig. 6. Mafic volcanic breccia, Nicola Group, northwest part of map area.

(Fig. 3). These breccias consist of angular to subrounded fragments in a mixed matrix of fine-grained foliated chlorite and sericite, and sand-size grains and granules of quartz, feldspar, and felsic volcanic lithoclasts. They are typically medium green on fresh surfaces, and weather to pale shades of green, grey-green or brownish-green. Coarse intervals with poorly sorted, angular to subangular fragments up to 20 cm across (Fig. 7) are intercalated with beds containing pebble fragments, and well foliated granulestones with sparse pebbles (Fig. 8). The fragments consist mainly of pale green, grey or purplish-grey aphanitic felsic volcanic rocks, commonly with 1-2 mm phenocrysts of quartz  $\pm$  feldspar (Fig. 9). Medium to dark green intermediate to mafic volcanic rock fragments, some with small pyroxene phenocrysts, form a small proportion of the clast population. The felsic breccia unit on the north side of the Burgess Creek stock is at least 100 m thick, and was traced for about 1 km, with possible strike extensions to both the northwest and southeast concealed by overburden. The base of the unit is not exposed; it is overlain by sandstones and pebbly sandstones in which rhyolite fragments constitute a



**Fig. 7.** Felsic volcanic breccia, Nicola Group, north of Burgess Creek stock.



**Fig. 8.** Well foliated granulestone, Nicola Group, felsic volcanic breccia unit, south part of map area.



**Fig. 9.** Quartz-feldspar-phyric rhyolite fragment from felsic breccia, Nicola Group, north of Burgess Creek stock.

minor component of the clast population.

Two mafic volcanic units outcrop within the Nicola Group south of the Burgess Creek stock (Fig. 3). The eastern unit is a dark green amygdaloidal basalt flow. The flow is about 10 m thick and was traced for 350 m. It features abundant ovoid to irregularly-shaped vesicles, filled with combinations of epidote, quartz, actinolite and albite, in a very-fine-grained groundmass of plagioclase laths and altered mafic grains (Fig. 10). The western unit is a pyroxene-feldspar porphyry flow or sill. It contains 1-6 mm pyroxene and feldspar phenocrysts (~20%) in a fine-grained groundmass of relict plagioclase and secondary epidote, actinolite, and chlorite (Fig. 11). Units of coherent plagioclase  $\pm$  pyroxene porphyry, similar to this unit, occur elsewhere in the Nicola succession, but are not abundant and are typically not well-enough exposed to determine if they are flows, sills, or dikes. The Nicola Group also hosts dikes and small plugs of diorite, hornblende  $\pm$  feldspar porphyry and diabase.

Narrow limestone units are intercalated with volcanic sandstones of the Nicola Group at three localities (Fig. 3). Relationships are best exposed near the southern limit of Nicola outcrops, where a unit of grey, weakly foliated limestone (Fig. 12), at least 10 m thick, was traced intermittently for 250 m. This unit is overlain by variably calcareous volcanic



**Fig. 10.** Amygdaloidal basalt, Nicola Group, south of Burgess Creek stock.



**Fig. 11.** Pyroxene-plagioclase porphyry, Nicola Group, south of Burgess Creek stock.



**Fig. 12.** Foliated limestone, Nicola Group, south part of map area.

sandstone that includes a few narrow limestone lenses. The interval of calcareous rocks projects north-northwestward to

the southeast margin of the Burgess Creek stock, where the Nicola Group is represented by poorly exposed epidote-garnet skarn (Fig. 3). The limestone unit near the northwestern edge of the map area was sampled by Jim Logan (British Columbia Geological Survey) in 2005; this sample yielded conodonts of Middle or Late Triassic age (Orchard, 2006; GSC Loc. No. C-307484). This is currently the only age constraint available for the Nicola Group on the northeast margin of the Granite Mountain batholith. Samples collected from all limestone units encountered in 2013 have been submitted for microfossil extraction.

### 3.2. Granite Mountain batholith

The Granite Mountain batholith is commonly subdivided into three main units (Panteleyev, 1978; Bysouth et al., 1995; Ash et al., 1999a, b). These are, from southwest to northeast: Border phase diorite to quartz diorite; Mine phase tonalite; and Granite Mountain phase leucocratic tonalite. The rocks exposed in the 2013 map area are part of the Granite Mountain phase. They are very uniform in composition and texture, comprising light grey, light grey to white-weathered, coarse-grained, equigranular biotite-hornblende tonalite (Fig. 13). A typical rock contains approximately equal proportions of quartz and plagioclase, and 5-10% mafic minerals, with biotite slightly more abundant than hornblende. The rocks are commonly isotropic, but locally display a weak, southwest-dipping foliation defined by imperfect alignment of plagioclase and/or mafic grains. Variably oriented dikes and veins, 1-25 cm thick, are uncommon, and include aplite, quartz porphyry, and medium-grained leucotonalite.



**Fig. 13.** Coarse-grained leucocratic tonalite, Granite Mountain phase, south part of map area.

Late Triassic U-Pb zircon magmatic ages have been reported from the Granite Mountain phase of the Granite Mountain batholith:  $215 \pm 0.8$  Ma (Ash and Riveros, 2001; Ash et al., 199a), and  $209.6 \pm 6.3$  Ma (Oliver et al. 2009). Geochronologic work on samples taken from the batholith and Burgess Creek stock in 2013 is ongoing.

### 3.3. Burgess Creek stock

The Burgess Creek stock (Panteleyev, 1978) comprises a heterogeneous assemblage of tonalites, quartz diorites, and diorites that intrude the Nicola Group (Fig. 3). Panteleyev (1978) considered the stock to be younger than the Granite Mountain batholith, but Ash et al. (1999a, b) concluded that the assemblage represents part of the batholith, and referred to them as border phase quartz diorite (unit EJGb). The present study confirms that the rocks in the stock intrude the Nicola Group, and can be mapped separately from the Granite Mountain phase of the batholith. However, age relationships between the stock and the Granite Mountain phase remain uncertain and the possibility that it is a component of the Granite Mountain batholith remains open.

The most common and widespread component of the Burgess Creek stock is light grey, light grey-weathered, medium-grained, equigranular hornblende-biotite tonalite (Fig. 14). The tonalite is typically leucocratic, with 7-10% mafic minerals (hornblende > biotite), 30-40% quartz, and 50-60% plagioclase, but darker varieties, with 15-25% mafic minerals, are also present. An older, less abundant but equally widespread phase comprises greenish-grey, light brownish-grey-weathered, medium- to coarse-grained hornblende-biotite quartz diorite. It typically contains 20-30% mafic minerals, 5-10% quartz, and 60-70% plagioclase, but quartz content is highly variable, such that some rocks are diorites and others are mafic tonalites. Locally, this phase contains irregular mafic patches several centimetres to tens of centimetres in size, consisting mainly of hornblende and magnetite, intergrown with minor amounts of quartz and plagioclase (Fig. 15). A third component of the stock comprises fine-grained diorite, consisting of hornblende (30-40%) and plagioclase. It is most common as screens and xenoliths in the predominant tonalite phase (Fig. 16), but is the main rock type in some exposures along the southeast



**Fig. 14.** Medium-grained tonalite, northeast part of Burgess Creek stock.



**Fig. 15.** Coarse-grained quartz diorite with hornblende-magnetite segregation, cut by leucotonalite dike, northeast part of Burgess Creek stock.



**Fig. 16.** Tonalite with screens of fine-grained diorite, central part of Burgess Creek stock.

margin of the stock. It is typically equigranular, but locally displays a porphyritic texture, with phenocrysts of hornblende and/or plagioclase scattered through a fine-grained dioritic groundmass. The youngest component of the Burgess Creek stock is leucotonalite, which forms dikes, commonly 1-30 cm thick, that occur throughout the stock and cut all other rock types (Fig. 15). The dikes consist of quartz and plagioclase with only a few per cent chloritized mafic minerals. They display a variety of textures, ranging from fine grained aplitic, to coarse

grained with pegmatitic patches. Quartz porphyry, comprising phenocrysts of quartz  $\pm$  plagioclase  $\pm$  hornblende in a fine-grained leucotonalite groundmass, is locally developed, but contact relationships with adjacent components of the stock were not observed.

Most phases of the Burgess Creek stock display textures that vary from isotropic to weakly foliated. The foliation dips steeply to the northeast or southwest, and is defined by weakly flattened plagioclase and mafic mineral grains and/or by discontinuous narrow seams of oriented sericite. The stock is locally cut by high-strain zones, 40 cm to 30 m wide, defined by strongly foliated, locally mylonitic rock (Fig. 3). Steeply dipping shear zones in the southern and eastern parts of the stock incorporate various tonalite, quartz diorite, and diorite phases, but, where relationships are exposed, are cross-cut by younger tonalite and leucotonalite phases (Fig. 17). A well-foliated zone that dips gently to the southeast in the west-central part of the stock is localized in a quartz porphyry unit, and locally displays S-C fabrics indicating northwest-directed thrust movement.

The intrusive contact between the Burgess Creek stock and Nicola Group is exposed at one outcrop, north of the 800 road. This intrusive relationship is corroborated by observations elsewhere, including dikes of tonalite and quartz diorite cutting the Nicola Group near the contact, xenoliths of Nicola rock in the stock near the contact, and a zone of skarn-altered rocks in the Nicola Group along the southeast margin of the stock. The contact between the Burgess Creek stock and the Granite Mountain phase is locally well defined, but is not exposed. Burgess Creek rocks near the contact consist of tonalite that is distinguished from the adjacent Granite Mountain tonalite by finer grain size, lower quartz content, and higher mafic content. The contact is inferred to be intrusive, but it is unclear which unit intrudes which.

### 3.4. Dragon Mountain succession

Exposed in a small area along and near a branch of the Burgess Creek road, north of the Burgess Creek stock (Fig. 3), is an assemblage of dark grey slate with laminae and thin interbeds of lighter grey siltstone and less common thin beds of quartz-rich, fine- to medium-grained yellowish-brown-weathered sandstone (Fig. 18). Sandstone beds are commonly graded, and locally display scour-and-fill structures. These rocks differ from the Nicola Group, but are similar to the basal unit of the Dragon Mountain succession (Lower to Middle Jurassic; dark banded phyllite unit of Logan and Moynihan, 2009). Hence these rocks are interpreted as a small outlier of the Dragon Mountain succession, resting above the Nicola Group across an unconformity. Five km west of the present map area, is another likely Dragon Mountain succession outlier in which slate and siltstone overlap both Nicola Group and adjacent granitic rocks of the Granite Mountain batholith (Fig. 2; Ash et al., 1999b). Twenty-five km north of the map area, along the French Creek Road, the basal Dragon Mountain unit contains Early Jurassic (Late Pliensbachian) fossils (Petersen et al., 2004; Logan and Moynihan, 2009).



Fig. 17. Strongly foliated tonalite cut by unstrained leucotonalite, southwest part of Burgess Creek stock.



Fig. 18. Stacked, cm-scale, sharp-based, fining-upward sequences of sandstone, siltstone, and slate; slaty cleavage from upper left to lower right; Dragon Mountain succession, north of Burgess Creek stock.

### 3.5. Cache Creek Complex

Rocks included in the Cache Creek Complex crop out at a few scattered localities in the eastern part of the area (Fig. 3). Exposures along the 800 Road comprise grey to greenish-grey chert, which forms lenses and layers, 1-5 cm thick, separated by partings or thin interbeds of greenish-grey argillite (Fig. 19). Farther north, in cutblocks south of the Burgess Creek road, are small exposures of green, carbonate-altered, rusty-brown-weathered basalt, and basalt breccia, which locally contains fragments and lenses of grey limestone. The contact between the Cache Creek Complex and adjacent rocks of the Nicola Group is not exposed, but is inferred to be a significant north-northwest trending fault.

### 3.6. Structure

A weak to moderately developed cleavage, typically



**Fig. 19.** Chert with mudstone partings, Cache Creek Complex, 800 road.

with steep dips to the northeast or southwest, cuts siltstone, limestone, and some breccia units of the Nicola Group, and fine-grained portions of the Dragon Mountain succession (Fig. 18), but is generally not developed in the sandstones and pebbly sandstones that form most of the Nicola Group. The cleavage, typically defined by oriented chlorite and/or sericite, is accentuated by variably flattened lithic fragments in breccia units. Plutonic rocks of the Granite Mountain batholith and Burgess Creek stock locally display a weak foliation defined by discontinuous foliae of sericite and chlorite, and/or weakly flattened plagioclase grains and mafic mineral clots. This foliation dips at steep angles to the northeast or southwest in the Burgess Creek stock, congruent with cleavage in the adjacent Nicola Group, but dips at moderate angles to the south-southwest in the Granite Mountain batholith (Fig. 3). Local, narrow, high-strain zones in the Burgess Creek stock are of uncertain significance, but seem to be restricted to the stock itself, and are commonly cross-cut by the youngest phases of the stock.

Nicola rocks south of the Burgess Creek stock comprise a right-way-up homoclinal panel that dips at moderate angles to the east-northeast (Fig. 3). Mesoscopic folds of bedding were observed in uncleaved, thin to medium-bedded volcanic sandstone at one locality near the southern margin of the belt. The folds plunge at moderate angles to the north and verge to the west. Although not exposed, a west-northwest trending fault is inferred from an apparent 300 m sinistral offset of the southern contact of the Burgess Creek stock (Fig. 3). The wedge of Nicola rocks between this structure and the stock have dips that are steeper and oriented more to the north than those displayed by the main panel of Nicola rocks to the south.

The Nicola Group directly north of the Burgess Creek stock, and near the western edge of the map area farther to the northwest, displays moderate northeast dips, with rare right-way-up younging indicators, that are congruent with those to the south of the stock. Bedding observations in a poorly exposed area along, and north of, the east end of the Burgess Creek road,

are more variable, indicating structural complications that have not yet been resolved. The only mesoscopic folds observed in this part of the map area are in the small outlier of Dragon Mountain succession that is inferred to overlie the Nicola Group. These folds plunge gently to the northwest, and slate beds within the folded sandstone, siltstone, slate succession display an axial planar slaty cleavage that dips at moderate angles to the north-northeast.

The most significant structure in the area is an inferred fault that separates the Nicola Group from the Cache Creek Complex to the east. The orientation of the fault is not well constrained, but exposures within and adjacent to the map area indicate a general north-northwest trend. The anomalous geometry of Nicola rocks to the west of Cache Creek rocks could be explained by at least 20 km of sinistral displacement along this structure. This fault, and potentially related structures inferred along or near the south margin of the Granite Mountain batholith, will be a major focus of the 2014 field program.

## 4. Discussion

### 4.1. Correlation of the volcanoclastic succession with the Nicola Group

The Nicola Group comprises a diverse assemblage of Middle and Upper Triassic volcanic, volcanoclastic, and sedimentary rocks that extend across a broad area in south-central British Columbia. It, and coeval to slightly younger intrusions, form the characteristic units of the Quesnel arc terrane. The Nicola Group has not been formally subdivided on a regional scale, but informal subdivisions have been applied in areas where it has been studied in reasonable detail.

The predominantly sandstone succession on the northeast margin of the Granite Mountain batholith is similar to Nicola Group units mapped elsewhere (e.g. Unit uTrNvs of Logan et al., 2010; Bosk Lake succession of Schiarizza et al., 2013) and, in particular, to those along the western part of the main Quesnel belt near Granite Mountain. These include: the green volcanoclastic succession in the Quesnel River map area to the northwest (Logan and Moynihan, 2009); the western volcanoclastic succession in the Cottonwood map area farther north (Logan, 2008); and, east of the Granite Mountain area, rocks referred to as the Gavin Lake succession by Logan and Bath (2006) and mapped as units LTrNs and LTrNvb by Logan et al. (2007). These contiguous units consist mainly of feldspathic volcanic sandstone, siltstone, and conglomerate and include mafic volcanic breccia, basalt, and limestone. Late Triassic conodonts have been extracted from limestone in the green volcanoclastic succession (Logan and Moynihan, 2009) and from limestone in the Gavin Lake succession (Logan and Bath, 2006). Correlation is further supported by the fact that, like the volcanoclastic succession in the current map area, these Upper Triassic units are overlain by Lower-Middle Jurassic rocks of the Dragon Mountain succession (Logan et al., 2007; Logan and Moynihan, 2009).

Felsic volcanic breccias in the Granite Mountain area have not been reported from otherwise remarkably similar Nicola

successions in adjacent areas. Felsic volcanic rocks are uncommon in most parts of the Nicola Group, where volcanic rocks are almost exclusively feldspar-pyroxene-phyric basalts and andesites. However, rhyolites, dacites, and associated felsic breccias form a significant part of a belt along the western edge of Quesnel terrane in the Merritt-Ashcroft area of southern British Columbia. These rocks, referred to as the western Nicola belt by Preto (1979) and the western volcanic facies of the Nicola Group by Monger and McMillan (1989), host the Guichon Creek batholith (Late Triassic). The felsic breccias in the current map area suggest that the Nicola rocks here have an affinity with the western Nicola belt of southern British Columbia. This is consistent with their location in the westernmost part of Quesnel terrane, and their association with the Granite Mountain batholith (same age as the Guichon Creek batholith).

#### **4.2. Contact relationships and terrane affinity of the Granite Mountain batholith**

The Granite Mountain batholith is interpreted to be part of Quesnel terrane (Fig. 20). This is based mainly on its spatial association with the Nicola Group mapped along its north and northeastern margins (Ash et al., 1999a, b; this study). Intrusive contacts were not observed between the Granite Mountain phase and adjacent Nicola rocks, but this reflects poor exposure in critical areas. The Burgess Creek stock clearly intrudes the Nicola Group, but it remains to be established if this unit is part of the Granite Mountain batholith, as proposed by Ash et al. (1999a, b), or is a younger pluton, as suggested by Panteleyev (1978) and Bysouth et al. (1995). Outliers of Dragon Mountain succession overlie both the Nicola Group and the Granite Mountain batholith, and conglomerate that is part of this unit farther north contains clasts that may have been derived from the Granite Mountain batholith (Tipper, 1978). The Dragon Mountain succession provides an additional link between the Granite Mountain batholith and Quesnel terrane, as regional studies suggest that this succession represents an intra-Quesnel basin that was derived from, and deposited on, older units of Quesnel terrane (Petersen et al., 2004; Logan and Moynihan, 2009).

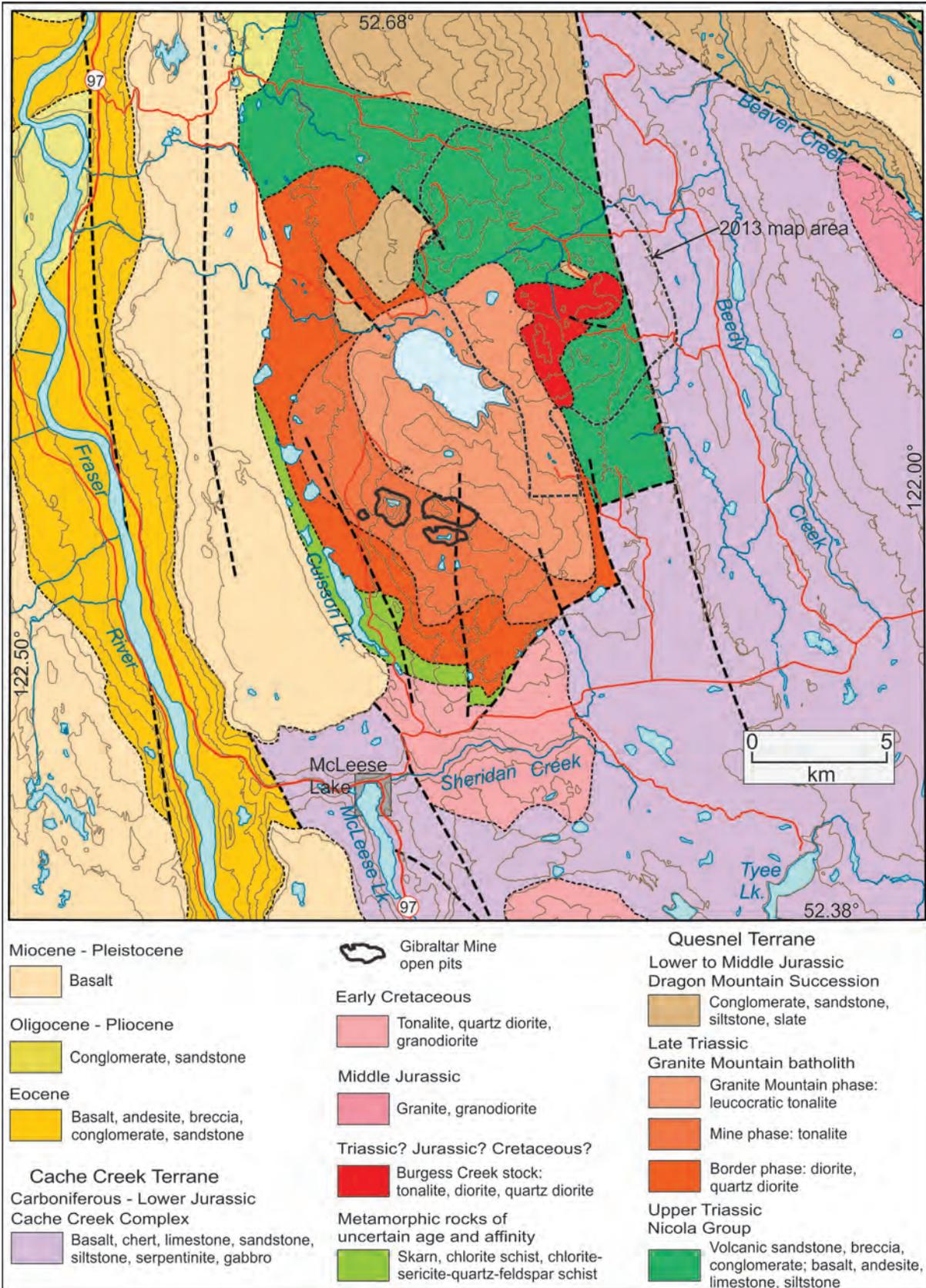
The Granite Mountain batholith is in contact with definitive Cache Creek rocks over a small area along its southeast margin. Contacts are not exposed, but are reasonably inferred to be north-northwest and northeast-striking faults that have similar orientations to structures that separate Cache Creek from Nicola Group to the east and northeast (Fig. 20; Ash et al., 1999a, b). Relationships between the Cache Creek Complex and Granite Mountain batholith farther west are largely obscured by the intervening Sheridan Creek stock (Early Cretaceous). A belt of metamorphic rocks along the southwest margin of the Granite Mountain batholith is bounded to the south by the Sheridan Creek stock and is overlapped to the west by Neogene basalt flows of the Chilcotin Group (Fig. 20). This belt was inferred to be contact-metamorphosed Cache Creek Complex by many previous workers (Drummond et al., 1976; Panteleyev, 1978;

Bysouth et al., 1995), but was interpreted as a sheared, mafic-rich border phase of the Granite Mountain batholith by Ash et al. (1999a, b). Reconnaissance work in the present study revealed mainly garnet-epidote skarn, with subsidiary amounts of chlorite schist and sericite-chlorite-quartz-feldspar schist. A sedimentary  $\pm$  volcanic  $\pm$  plutonic protolith is inferred, but the rocks observed could have been derived from either the Nicola Group or the Cache Creek Complex. This belt will be studied in detail in 2014.

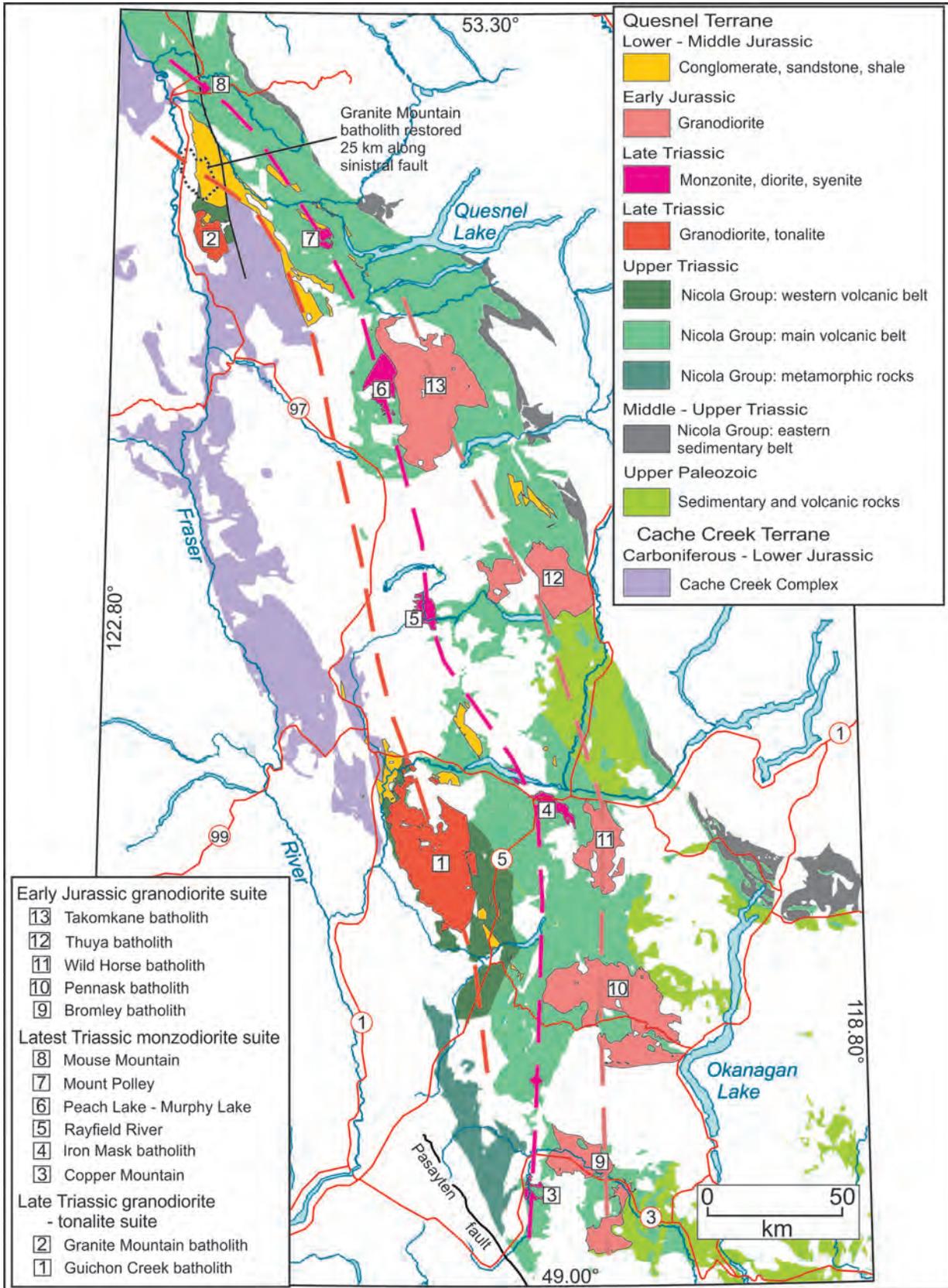
#### **4.3. Structural implications of Quesnel terrane correlation**

The Nicola Group mapped on the northeast margin of the Granite Mountain batholith, together with the batholith itself and overlying rocks of the Dragon Mountain succession, form a coherent panel of rocks that is part of Quesnel terrane. This panel is bounded to the east by a north-tapering wedge of Cache Creek rocks, indicating significant local shuffling of the terrane boundary because, regionally, Cache Creek terrane lies west of Quesnel terrane. The contact between the Quesnel panel and the Cache Creek wedge is inferred to be a north-northwest trending fault (Fig. 20). This fault is inferred to be Middle Jurassic or younger because it cuts the Dragon Mountain succession. It may have been the locus of more than 20 km of sinistral strike-slip displacement, as required to restore the southern end of the Quesnel block to the northern termination of the Cache Creek wedge. However, models involving predominantly vertical movement cannot be entirely ruled out, as this could result in the same map pattern if the pre-fault terrane contact had a gentle dip. The inferred fault has not previously been mapped, and no obvious strike extensions are apparent, although Logan (2008) documented local northwest-trending sinistral fault zones in Quesnel terrane along the Cottonwood River, 60 km north-northwest of Granite Mountain. Orogen-parallel sinistral faults with significant displacement are known elsewhere along or near the western margin of Quesnel terrane, including the Pasayten fault of southern British Columbia and adjacent Washington State, which records about 20 km of sinistral displacement in Early Cretaceous time (Greig, 1992; Hurlow, 1993).

A Quesnel terrane origin for the Granite Mountain batholith implies that it is separated from Cache Creek rocks to the south by one or more fault systems. These structures might include relatively old segments of the terrane boundary that have been displaced along the sinistral fault system, as well as contractional structures that are the same age as, and kinematically linked to, the sinistral fault system. Ongoing work will address four key structural questions. 1) Is the Cuisson Lake metamorphic belt part of a fault zone between the Granite Mountain batholith and Cache Creek terrane, or a zone of contact metamorphosed rocks (possibly Nicola Group) that were intruded by the Granite Mountain batholith? 2) To what extent is the Sheridan Creek stock, which locally contains south-dipping shear zones (Ash, 1999a) involved in the faulting? 3) What are the ages of faulting? 4) Are structures that deform the Gibraltar orebodies related to structures that juxtapose the batholith against Cache



**Fig. 20.** Geologic map of the Granite Mountain batholith and surrounding area. Based on Tipper (1959, 1978), Panteleyev (1978), Bysouth et al. (1995), Ash et al. (1999b), and this study. Extensive areas of Quaternary overburden are not shown in order to highlight bedrock geology.



**Fig. 21.** Simplified geology map of southern British Columbia highlighting selected elements of Quesnel terrane. Granite Mountain batholith is shown in its present location, but a separate outline shows its position after 25 km offset along the sinistral fault inferred from this study is restored.

Creek terrane?

#### 4.4. Plutonic patterns in southern Quesnel terrane

The Granite Mountain batholith is reasonably included in Quesnel terrane, based on its conformity to well established spatial and temporal patterns of magmatism, which are defined by parallel belts of calcalkaline or alkaline plutons that show a progressive younging from west to east (Fig. 21).

The western plutonic belt of southern Quesnel terrane includes the calcalkaline, Guichon Creek and Granite Mountain batholiths (Late Triassic). Each of these plutons hosts major calcalkaline porphyry Cu-Mo deposits. The Granite Mountain batholith is hosted in the western volcanic belt of the Nicola Group, and felsic volcanic breccias in Nicola rocks northeast of the Granite Mountain batholith suggest possible western belt affinities.

A well-defined belt to the east of the western calcalkaline belt comprises younger, latest Triassic alkaline plutons consisting of monzodiorite, monzonite, syenite, and diorite. This belt is remarkably well endowed with alkalic porphyry Cu-Au deposits, including producing mines at Copper Mountain, Afton and Mount Polley, and prospects at Rayfield River, Peach Lake and Mouse Mountain.

The eastern plutonic belt shown (Fig. 21) is defined by five large calcalkaline plutons, the Bromley, Pennask, Wild Horse, Thuya and Takomkane batholiths. These plutons consist mainly of Early Jurassic granodiorite. Locally they host calcalkaline porphyry Cu-Mo deposits, including the past-producing Brenda Mine in the Pennask batholith and the Woodjam SE zone in the Takomkane batholith.

The western Late Triassic calcalkaline plutonic belt (Fig. 21) is defined by only two plutons, the Guichon Creek and Granite Mountain batholiths. The paucity of known intrusions is because most of the belt is buried beneath Tertiary and Quaternary deposits (Fig. 21). Given the rich metal endowment of the Guichon Creek and Granite Mountain batholiths, this covered interval may be prospective for buried calcalkaline porphyry deposits.

#### 5. Summary and conclusions

The volcanoclastic succession that crops out on the northeast margin of the Granite Mountain batholith is correlated with the Late Triassic Nicola Group of Quesnel terrane. It consists of sandstone and gritty to pebbly sandstone, with local intercalations of conglomerate, mafic and felsic volcanic breccia, siltstone, limestone, and basalt. The succession is, at least in part, Middle or Late Triassic, based on conodonts previously extracted from limestone within the succession. Correlation with the Nicola Group is based on a strong similarity to nearby Late Triassic Nicola rocks, although felsic volcanic breccias, which have no counterpart in adjacent Nicola exposures, suggest affinities with the western Nicola belt of the Merritt-Ashcroft area. The Nicola Group is intruded by undated, predominantly tonalitic intrusive rocks of the Burgess Creek stock, and overlain by slate and siltstone correlated to

the Dragon Mountain succession (Lower to Middle Jurassic).

The Granite Mountain batholith (Late Triassic) was long thought to have intruded Cache Creek terrane because of its spatial association with Cache Creek rocks (Drummond et al., 1976; Tipper, 1978; Bysouth et al., 1995). The recognition that rocks on the northeast margin of the batholith are part of the Nicola Group (Ash et al., 1999a, b; this study), and are locally overlapped by the Dragon Mountain succession (part of an intra-Quesnel siliciclastic basin), indicate that it is more likely a part of Quesnel terrane, and correlative with the Late Triassic, calcalkaline Guichon Creek batholith, which hosts the Highland Valley porphyry Cu-Mo deposits 250 km to the south-southeast.

The Granite Mountain batholith, together with adjacent Nicola Group and Dragon Mountain succession, form a panel of Quesnel rocks that is bounded to the east by a north-tapering wedge of Cache Creek rocks. The boundary is inferred to be north-northwest striking fault, previously unrecognized, that may record more than 20 km of sinistral strike-slip displacement, as required to restore the southern end of the Quesnel block to the northern termination of the Cache Creek wedge.

The preliminary assessment of geological relationships presented here (Fig. 20) will be refined with ongoing paleontologic and geochronologic studies, and 2014 geological mapping, which will focus mainly on the southern part of the batholith. The Granite Mountain mapping project will compliment geological studies in and near the Gibraltar Mine that are part of the Geological Survey of Canada's TGI-4 intrusion-related ore systems program.

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