# Late Early to Middle Jurassic Hazelton Group volcanism and mineral occurrences in the McBride-Tanzilla area, northwest British Columbia

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**Abstract**

A previously poorly understood volcanic succession (Horn Mountain Formation) on the northeastern margin of Stikinia hosts several early-stage porphyry copper exploration projects. Stratigraphic and structural data based on 1:20,000-scale mapping, and preliminary geochronology indicate that the oldest units in the McBride-Tanzilla area are mafic volcanic rocks of the Stuhini Group (Triassic) that are cut by the Cake Hill pluton (Late Triassic). Separated by a regional unconformity, these units are overlain by the Spatsizi Formation (Hazelton Group, late Pliensbachian to Toarcian), a sedimentary succession up to 1 km thick. The unconformity provides one of the few well-documented examples of unroofed Stuhini arc in northern Stikinia. The Spatsizi Formation grades laterally and vertically to a volcanic succession (about 4.5 km thick), recently defined as the Horn Mountain Formation (late Early to Middle Jurassic) in the upper part of the Hazelton Group. This succession is unusual because it postdates typical Late Triassic to Early Jurassic arc volcanism in northern Stikinia, and is concurrent with accretion of the Stikine and Cache Creek terranes. Units in the lower part of the Horn Mountain Formation include massive green augite-plagioclase-phyric volcanic breccia and rare grey coarse platy plagioclase-phyric lapilli tuff and pillows that were, at least in part, deposited in a subaqueous environment. Overlying units of interlayered maroon augite-plagioclase-phyric flows, volcanic breccia and tuff suggest increasingly greater volumes of volcanism and the formation of a subaerial volcanic edifice. During a hiatus in volcanism, these rocks were cut and hydrothermally altered by a 173 Ma (Aalenian) porphyry. An unconformity separates these units from Bajocian mafic volcanic flows in the upper part of the Horn Mountain Formation. The Horn Mountain Formation is cut by the Three Sisters pluton (ca. 173-169 Ma, Aalenian-Bajocian), and is unconformably overlain by sedimentary rocks of the Bowser Lake Group (Bajocian). In the northern part of the map area, folded Takwahoni Formation siliciclastic rocks deposited in the Whitehorse trough (Laberge Group, Pliensbachian) are in the hanging wall of the south-verging Kehlechoa thrust fault, and structurally overlie the Horn Mountain volcanic succession. Regionally, these sedimentary rocks record unroofing of the Stuhini arc. The Snowdrift Creek pluton (Late Jurassic) cuts the Kehlechoa fault and constrains movement on the foreland thrust of the Stikinia-Quesnellia accretionary welt to ca. 170-160 Ma.

At least three magmatic-hydrothermal events are recognized in the map area. Late Triassic porphyry-style copper mineralization occurs at the Gnat Pass developed prospect and nearby Moss showing. The Horn Mountain Formation hosts aerially extensive gossans at Tanzilla and McBride (both early-stage porphyry projects) interpreted as Middle Jurassic in age. Molybdenum mineralization is locally in the Snowdrift Creek pluton (Late Jurassic) and its immediate wall rocks, and in a satellite stock to the south. At Tanzilla, an advanced argillic lithocap overlies porphyry-style alteration at depth. Quartz-sericite-pyrite to potassic alteration with anomalous copper and molybdenum is hosted by a syn-mineral 173 Ma plagioclase porphyry. Our mapping extends the advanced argillic alteration at Tanzilla for at least 17 km along strike. It is interpreted as a lithocap formed by acidic hydrothermal fluid flow along an unconformity or fault in the upper Horn Mountain Formation. At the McBride showing, widespread quartz-sericite-pyrite and local potassic alteration hosts elevated copper and gold.

The Horn Mountain Formation and Three Sisters plutonic suite are coeval with accretion of the Stikine and Quesnel island arcs. The syncollisional Middle Jurassic magmatic event represents a potential new metallogenic epoch for the Canadian Cordillera and is prospective for porphyry- and epithermal-style mineralization.

**Keywords:** Horn Mountain Formation, Spatsizi Formation, Hazelton Group, Stuhini Group, Cake Hill pluton, Three Sisters pluton, Snowdrift Creek pluton, Takwahoni Formation, Kehlechoa fault, Jurassic, McBride, Tanzilla, lithocap, advanced argillic alteration, Stikine terrane

## 1. Introduction

This paper describes a volcano-sedimentary succession southeast of Dease Lake (northern Stikinia; Fig. 1) that hosts the McBride and Tanzilla porphyry copper mineral occurrences. Previously, this succession was poorly understood. In published maps, part of it was assigned to the Takwahoni Formation (Lower Jurassic), part to the Stuhini Group (Triassic), and part to a unit of Triassic-Jurassic volcanic rocks that could correlate with either the Stuhini Group or the Hazelton Group (Gabrielse, 1998). Detailed mapping by van

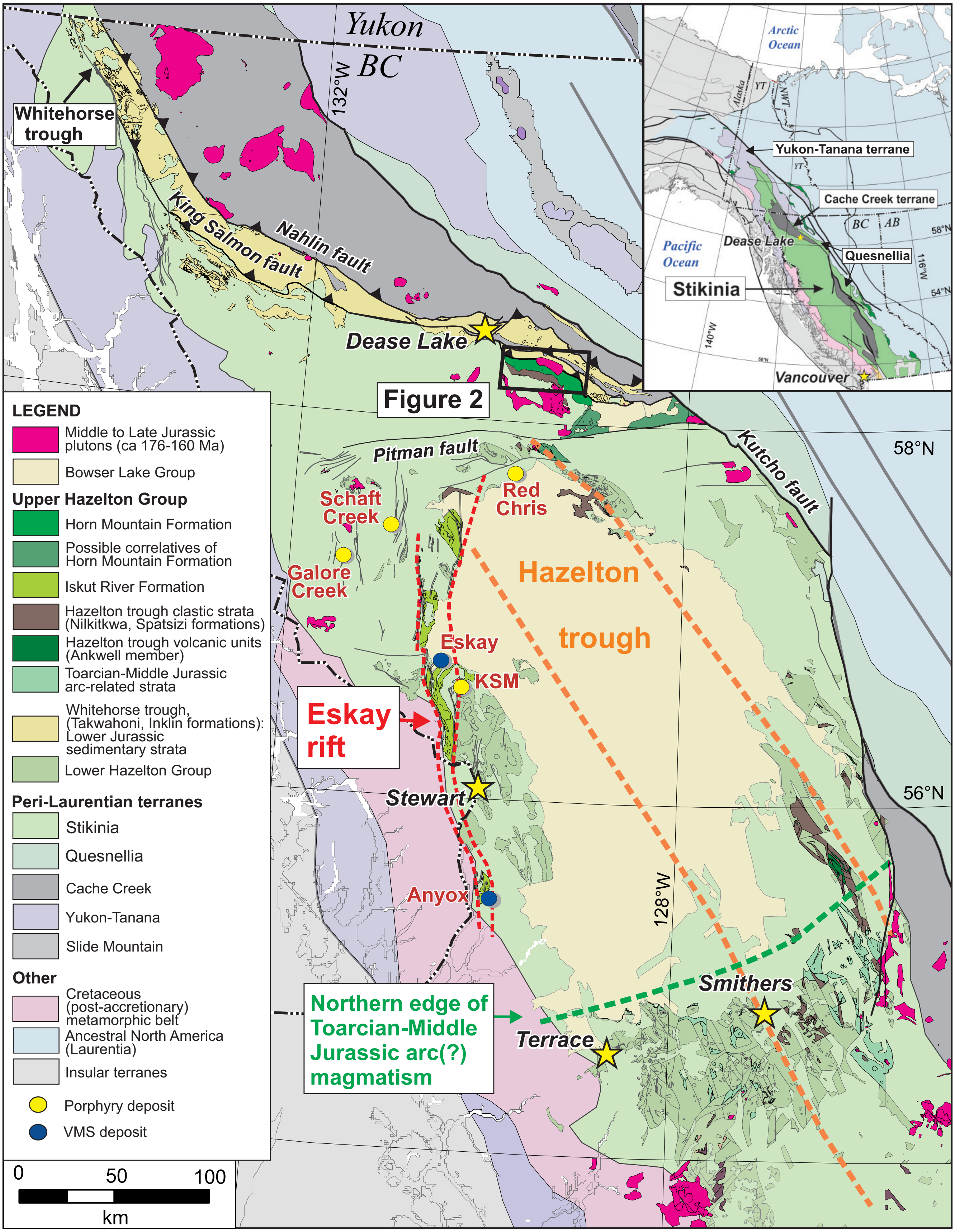


**Fig. 1.** Geology of northern Stikinia with emphasis on Middle to Late Jurassic geology and tectonic elements. Boundary of Hazelton trough from Marsden and Thorkelsen (1992); boundary of Eskay rift from Gagnon et al. (2012). Modified from van Straaten and Nelson (2016).

Straaten and Nelson (2016) studied a complete cross section of this enigmatic volcano-sedimentary sequence in the Tanzilla area (Fig. 1), and identified a volcanic succession (ca. 5.4 km thick) overlying a sedimentary succession (up to 1 km thick). They found the units to be late Early to Middle Jurassic, and defined the volcanic unit as the Horn Mountain Formation (part of the upper Hazelton Group). Herein we present the results of two months of 1:20,000-scale mapping carried out by two field teams between Gnat Pass and the McBride River (Fig. 2). The study was aimed at constraining the age, nature and along-strike stratigraphy of this volcano-sedimentary sequence and establishing a geological framework for alteration and mineralization.

## 2. Geological setting

The study area is in the Intermontane belt of the Canadian Cordillera, near the northeastern margin of the Stikine terrane (Stikinia; Fig. 1). Stikinia represents a volcanic island arc complex that was accreted to ancestral North America during the Middle Jurassic (Nelson and Mihalynuk, 1993; Mihalynuk et al., 1994; Evenchick et al., 2007; Nelson et al., 2013). Volcanic and sedimentary rocks of the Stikine assemblage (Devonian to Permian), basement to Stikinia, are overlain by volcanic and related sedimentary rocks of the Stuhini Group (Triassic) and the Hazelton Group (Early to Middle Jurassic; Tipper and Richards, 1976; Marsden and Thorkelson, 1992). Also in the Intermontane belt, the Quesnel terrane (Quesnellia), is a volcanic island arc with a similar Devonian to Early Jurassic history. The two volcanic arcs are separated by the Cache Creek terrane, an accretionary complex of oceanic crustal rocks, primitive arc ophiolites, pelagic rocks, and carbonate rocks (Fig. 1). The northeastern margin of Stikinia and adjacent Cache Creek terrane are covered by Early Jurassic siliciclastic rocks of the Whitehorse trough (Fig. 1; Colpron et al., 2015). Combined, Stikinia and Quesnellia host most of the porphyry copper deposits in the Canadian Cordillera (Logan and Mihalynuk, 2014).

A volcano-sedimentary succession assigned to the Spatsizi and Horn Mountain formations is in Stikinia, forming a westerly trending belt, about 50 km long and 10 km wide, north and northeast of the Hotailuh batholith (Figs. 1, 2). The succession unconformably overlies Late Triassic rocks of the Cake Hill pluton. Previous workers considered it part of the Takwahoni Formation (Lower Jurassic), structurally overlain by volcano-sedimentary rocks of the Stuhini Group (Triassic) above an inferred thrust (Hotailuh fault; Anderson, 1983; Gabrielse, 1998). However, Iverson et al. (2012) demonstrated that rocks previously mapped as part of the Stuhini Group contain an Early to Middle Jurassic detrital zircon population (ca. 176 Ma peak), leading to the interpretation that the entire volcano-sedimentary succession is part of the Hazelton Group, and removing the need for the putative Hotailuh thrust (Fig. 2). The Hazelton Group volcano-sedimentary succession is bounded to the north and northeast by the Kehlechoa thrust fault, which separates it from rocks of the Whitehorse trough (Takwahoni Formation), and to the west by the Gnat Pass and related faults; its southeastern extent is unknown. Farther north, Cache Creek terrane rocks in the hanging wall of the King Salmon thrust (north dipping) structurally overlie the Takwahoni Formation (Figs. 1, 2).

## 3. Lithostratigraphic units

Rocks in the study area lie within two tectonostratigraphic domains. Stratigraphic units in the footwall (south) of the Kehlechoa thrust fault are part of Stikinia; those in the hanging wall (north) are part of the Whitehorse trough (Figs. 2, 3; Table 1). Classifications for sedimentary rocks (Hallsworth and Knox, 1999) and igneous rocks (Gillespie and Styles, 1999) are used throughout the following.

### 3.1. Stikinia

#### 3.1.1. Stuhini Group (Triassic)

Mafic volcanic rocks of the Stuhini Group are exposed in the southwest corner of the map area. They comprise flows, massive volcanic breccia and lapilli tuff (Figs. 2, 4; Table 1). The rocks are commonly chlorite-epidote altered, a feature that may distinguish them from the generally weakly altered Horn Mountain volcanic rocks. Crosscutting relationships with the Gnat Pass plagioclase±quartz porphyry (216.5 ±1.4 Ma, U-Pb zircon, van Straaten et al., 2012) confirms they are Triassic rather than Jurassic. The succession likely represents Late Triassic arc construction.

An atypical unit of clast-supported polymictic volcanic breccia with sea green-grey amygdaloidal aphanitic, lesser green plagioclase-augite-phyric and maroon aphanitic clasts outcrops northeast to east of the Bell showing. It extends for at least 800 metres in a northwest to southeast direction.

At the western edge of the map area, a volcanic breccia and lapilli tuff unit (TrSTvm? in Fig. 2) contains clasts with 10-30% fresh euhedral augite (1-4 mm) and 10-40% lath-shaped plagioclase (0.5-1 mm). The volcanic rocks appear to overlie a NNE-dipping volcaniclastic sandstone and siltstone unit (TrSTs? in Fig. 2). Farther south, these sedimentary rocks are cut by a clinopyroxene-rich diorite to gabbro (Triassic to Jurassic; Section 4.1.). Limited field observations and a lack of ages prevent us from confidently assigning this succession. Following mapping by Logan et al. (2012a; b) to the west, we tentatively assign these rock units to the Stuhini Group rather than the Hazelton Group. We interpret that a NNW-trending fault separates these rocks from the Horn Mountain and Spatsizi formations (Fig. 2; Section 5.3.).

#### 3.1.2. Hazelton Group (Lower to Middle Jurassic)

Volcano-sedimentary rocks of the upper part of the Hazelton Group are exposed in the central part of the map area, forming an east-trending, north-dipping belt about 10 km wide (Fig. 2). The belt contains a lower sedimentary sequence (Spatsizi Formation) and an upper volcanic sequence (Horn Mountain Formation; Fig. 3). In the southwestern part of the map area, the Hazelton Group is inferred to unconformably overlie the

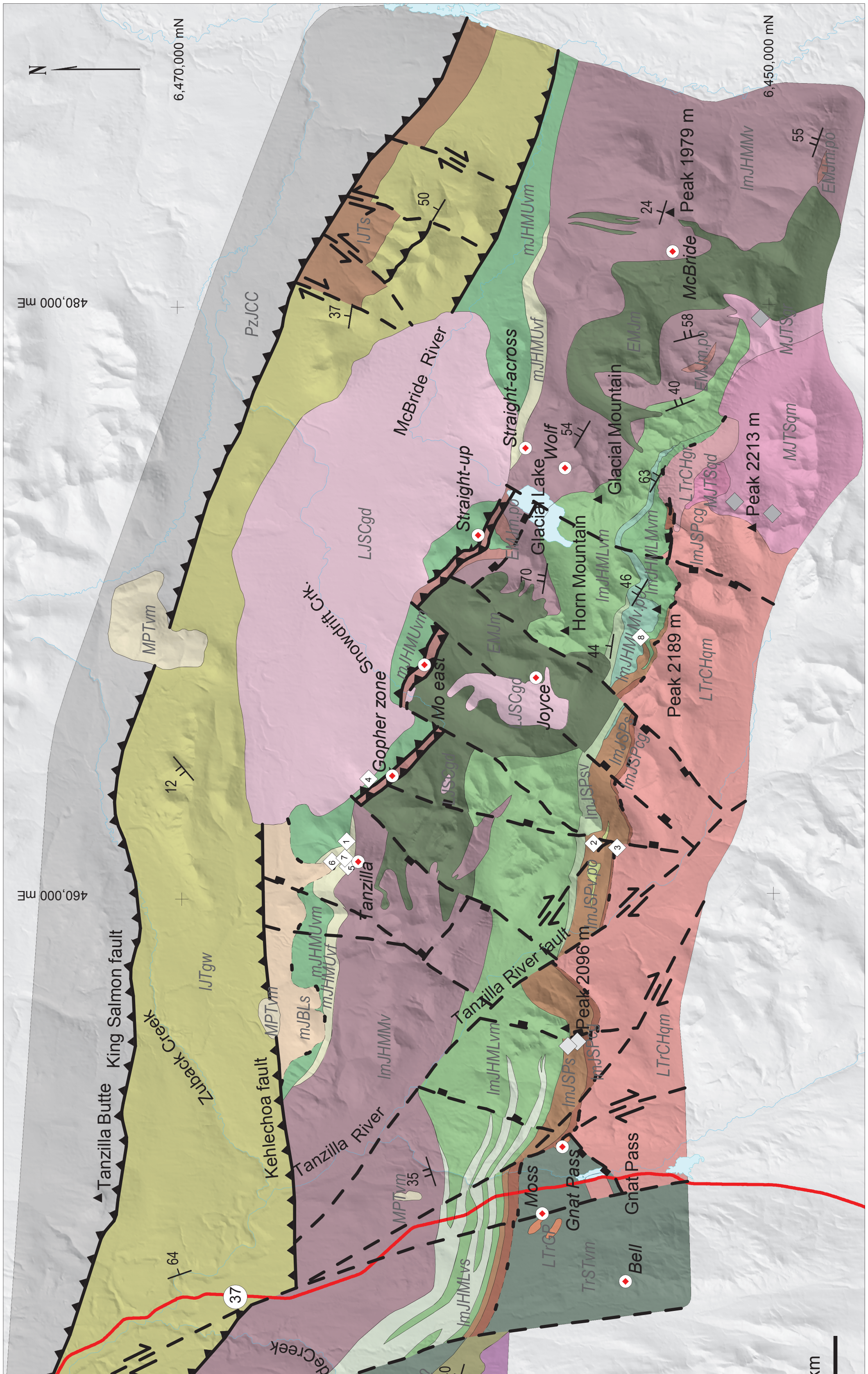


**Fig. 2.** Geologic map of field area. See Figure 1 for location.

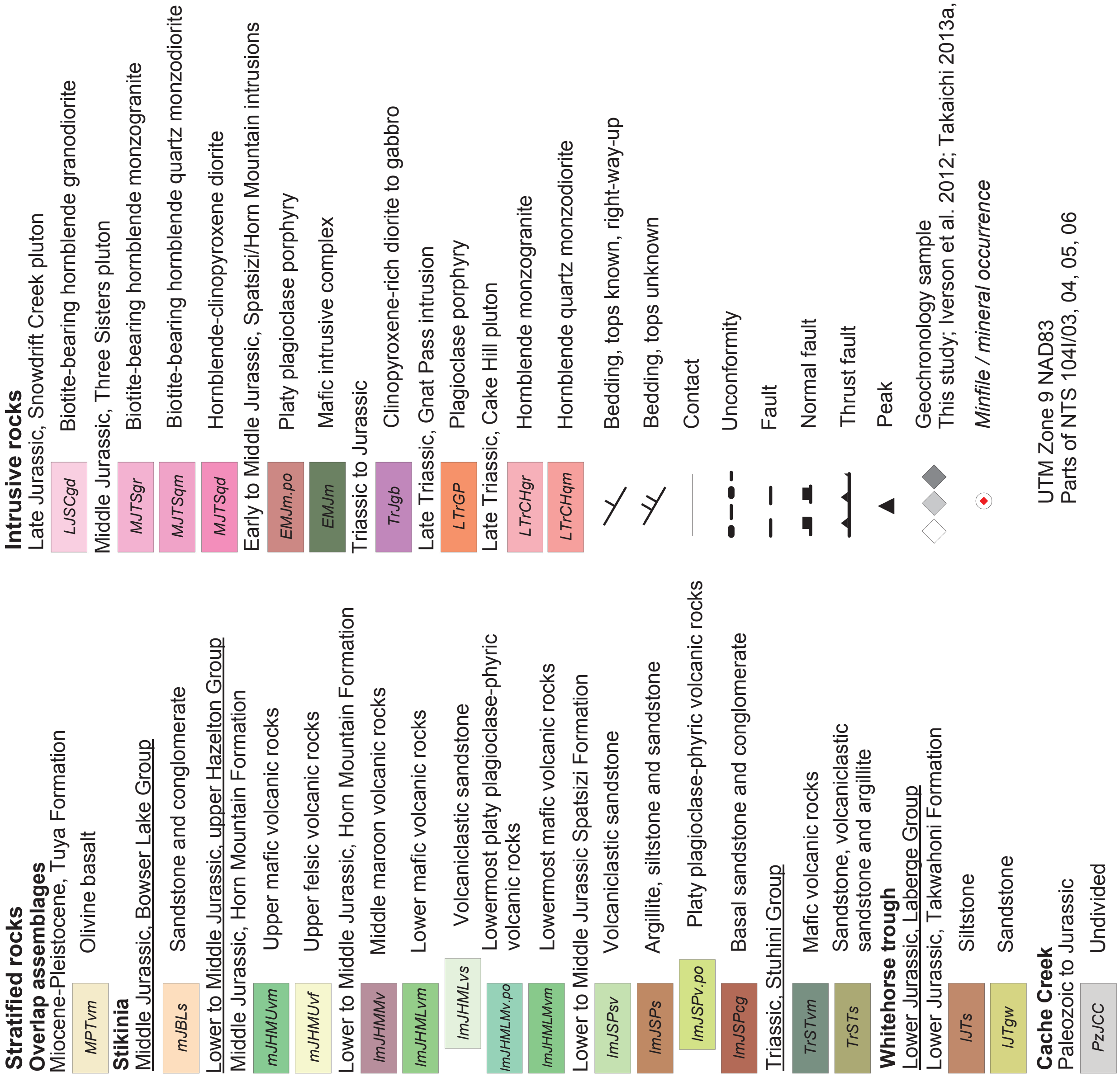


**Fig. 2.** Continued.

**Table 1.** Summary of volcano-sedimentary units. Mineral abbreviations after Kretz (1983).

| Age | Unit | | Description | Position |
|---|---|---|---|---|
| Miocene-Pleistocene | | Tuya Formation | **Olivine basalt (MPT*vm*;** Gabrielse, 1998) | Overlap |
| Lower Jurassic | Laberge Group | Takwahoni Formation | **Siltstone (lJT*s*).** Dark grey to black parallel laminated to massive siltstone unit. Interbedded with 5-25%, 5-40 cm thick, fine- to medium-grained feldspathic arenite and rare feldspathic wacke beds containing 5-10% Qtz and 10% lithic grains. Recessive, crumbly to platy, brownish grey weathering. | Whitehorse trough |
| Lower Jurassic | Laberge Group | Takwahoni Formation | **Greywacke (lJT*gw*).** Interbedded sandstone and siltstone. Fine- to medium-grained (rare coarse-grained) feldspathic arenite to feldspathic wacke in 10-400 cm-thick internally massive, lesser fining upward and rare parallel-laminated beds. Sandstone contains 5-15% Qtz and 10-15% lithic grains. Rare calcareous feldspathic arenite. Interbedded with 0-25%, recessive, dark grey to black, laminated, non-calcareous siltstone. Fairly resistant, grey to orange weathering, well-stratified. Contains (early) Pliensbachian macrofossils (Gabrielse, 1998). | Whitehorse trough |
| Middle Jurassic | Bowser Lake Group | | **Sandstone and conglomerate (mJBL*s*)[1].** Interbedded calcareous (locally fossiliferous) sandstone, cross-bedded sandstone, and polymictic conglomerate containing mafic volcanic, Pl-phyric, hypabyssal, and pyritic clasts. Moderately resistant, brownish weathering. Contains a probable Toarcian ammonite (T. Poulton, pers. comm., 2015); Middle Jurassic detrital zircon population. | Stikinia |
| Middle Jurassic | upper part of Hazelton Group | Horn Mountain Formation | **Upper mafic volcanic rocks (mJHM*Uvm*); >650 m thick.** Predominantly Aug-Pl-phyric coherent rocks (15-20%, 2-3 mm Aug; 40%, 1-3 mm equant Pl; locally amygdaloidal) interpreted as flows. Minor volcanic breccia, medium to very thickly bedded lapilli tuff, lapillistone and tuff. Fragmental volcanic rocks contain cm-sized angular Aug-Pl-phyric clasts in an Aug and Pl crystal-rich matrix. Very rare volcanic breccia with minor felsic, Pl-phyric and grey siliceous clasts[1]. Very rare flows, volcanic breccia and tuff with coarse platy Pl crystals. Resistant, dark grey weathering. Middle Jurassic detrital zircon population. | Stikinia |
| Middle Jurassic | upper part of Hazelton Group | Horn Mountain Formation | **Upper felsic volcanic rocks (mJHM*Uvf*)[1]; 235 m thick.** Relatively well-stratified crystal tuff, fine tuff, and pyroclastic breccia of sparsely Pl-phyric clasts in a grey glassy groundmass, medium-dark grey aphanitic to glassy clasts and lesser (Aug-Hbl-)Pl-phyric clasts. Common bomb sags. Includes rare pebble conglomerate with well-rounded clasts, and calcareous sandstone (locally fossiliferous). | Stikinia |
| Early-Middle Jurassic | upper part of Hazelton Group | Horn Mountain Formation | **Middle maroon volcanic rocks (lmJHM*Mv*); ≤3000 m thick.** Interlayered flows, volcanic breccia, tuff and lapilli-tuff; upper volcaniclastic subunit. Aug-Pl-phyric flows (maroon, medium grey, rarely green) transition to monomictic autoclastic breccia. Rare glassy felsic (?) flows (blood-red to maroon)[1]. Massive maroon volcanic breccia with angular-subangular varicoloured 0.2-100 cm Aug-Pl-phyric clasts, common maroon aphyric clasts and very rare platy Pl-phyric clasts. Reddish-maroon laminated to medium-bedded tuff, crystal tuff, lapillistone, and rare welded lapilli tuff with sub-cm fiamme and lithic fragments. Upper subunit of laminated to thinly bedded maroon volcaniclastic sandstone and tuff. Resistant to moderately resistant, dark grey to maroon weathering, moderately to crudely stratified. | Stikinia |
| Early-Middle Jurassic | upper part of Hazelton Group | Horn Mountain Formation | **Lower mafic volcanic rocks (lmJHM*Lvm*); 850-1500 m thick.** Massive monomictic volcanic breccia and lapilli tuff; predominantly clast-supported. Subangular, Aug-Pl-phyric, 1-10 cm (locally up to 100 cm) clasts in a sand- to granule-sized Aug and Pl crystal matrix. Rare volcaniclastic sandstone, Aug-Pl crystal tuff and tuff interbeds. Very resistant, dark grey to green and hackly weathering.<br>**Lower mafic volcanic rocks with felsic clasts (lmJHM*Lvm.fc*)[1]; 0-75 m thick.** Similar to lower mafic volcanic rocks, but contains flow-banded Pl-phyric clasts, epidote-altered clasts, and fine-grained to aphyric off-white felsic clasts.<br>**Lower mafic volcanic rocks with epidote-altered clasts (lmJHM*Lvm.ep*)[1]; 0-220 m thick.** Massive volcanic breccia with epidote-altered clasts, Aug diorite clasts (15-20%, 2-3 mm Aug; 80-85%, 0.5-1 mm Pl) and moderately crystalline Aug-Pl-phyric clasts (15%, 2-3 mm Aug; 20-40%, 0.5-1 mm Pl). Resistant, dark green to green weathering.<br>**Lower volcaniclastic sandstone (lmJHM*Lvs*); 0 to >150 m thick.** Laminated to thickly bedded volcaniclastic sandstone with abundant Pl grains, lesser siltstone. Minor lapilli tuff and Aug-Pl crystal tuff. Recessive, brown weathering. | Stikinia |

**Table 1.** Continued.

| Age | Unit | | Description | Position |
|---|---|---|---|---|
| Lower-Middle Jurassic | upper part of Hazelton Group | Horn Mountain Formation | **Lowermost platy plagioclase-phyric volcanic rocks (lmJHM*LMv.po*); 0-350 m thick.** Coarse platy Pl-rich lapilli tuff, lesser lapillistone, tuff breccia and volcanic breccia. Local 0.5-2 m circular to elongate pillows with a light coloured centre, dark rim and inter-pillow laminated tuff, volcaniclastic sandstone and calcareous sandstone. Medium grey to creamy-grey volcanic clasts and pillows contain 20-35% platy Pl (0.5-2 cm), 0-5% Aug (0.5-1 mm) and common vesicles. Very resistant, dark grey weathering, moderately to crudely stratified.<br>**Felsic volcanic rocks (lmJHM*LMvf*); 0-70 m thick.** Clast-supported volcanic breccia. Clasts are angular to subangular, 0.5-30 cm, commonly vesicular, aphyric to Pl-phyric and sea green to light grey to creamy-purple. Some flow banded clasts. Moderately resistant, medium grey weathering. | Stikinia |
| | | | **Lowermost mafic volcanic rocks (lmJHM*LMvm*); 0-1000 m thick.** Clast-supported volcanic breccia with subangular Aug-Pl-phyric 1-100 cm clasts. Clasts vary in colour (light green, medium green, dark green, medium grey, dark grey, maroonish grey, maroon), Pl abundance (15-65%, 0.5-2 mm, lath to equant), Aug abundance (5-30%, 1-4 mm, equant) and amygdules (0-25%). Very thick (~70 m) internally massive beds of volcanic breccia are locally separated by well-stratified, rusty brown, recessive siltstone and sandstone. Breccia at the base of the unit and base of the second very thick bed contains subrounded to subangular 0.5-30 cm (locally 2-4 m) clasts of Hbl Qtz monzodiorite, Hbl Qtz monzonite and Hbl monzogranite. Resistant, dark grey and hackly weathering. | |
| | | Spatsizi Formation | **Volcaniclastic sandstone (lmJSP*sv*); 0-300 m thick.** Fine- to coarse-grained volcaniclastic sandstone interbedded with lesser siltstone. Common interlayers of monomictic volcanic breccia with Aug-Pl-phyric clasts. Subordinate light grey fine tuff laminae[1]. Local granule conglomerate with angular pale grey fine tuff rip-up clasts (up to 3 cm) in a matrix of angular to euhedral Pl and Aug crystals. Common soft-sediment deformation structures. Common parallel laminae and local normal grading. Moderately resistant, medium-dark brown weathering and well-stratified. | |
| | | | **Argillite, siltstone and sandstone (lmJSP*s*); 0-560 m thick.** Interbedded argillite, siltstone and fine-grained sandstone. Rare to locally common medium- to coarse-grained sandstone, granule conglomerate and clast-supported volcanic breccia. Conglomerate and breccia are mono- to polymictic and contain Aug-Pl-phyric, Pl-phyric, coarse platy Pl-phyric, aphyric and local siltstone clasts. Minor grey tuff laminae; rare volcaniclastic sandstone[1]. Generally recessive, rusty orange-brown weathering, well-stratified. Contains late Pliensbachian to Toarcian ammonites and bivalves (T. Poulton, pers. comm., 2016); Early to Middle Jurassic detrital zircon population (Iverson et al., 2012).<br>**Platy plagioclase-phyric volcanic rocks (lmJSP*v.po*)[1]; 0-75 m thick.** Monomictic clast-supported volcanic breccia with medium grey coarse platy Pl-phyric and pale grey aphyric, common vesicular clasts. Resistant, medium grey weathering.<br>**Mafic volcanic rocks (lmJSP*vm*); 0-60 m thick.** Polymictic clast-supported volcanic breccia with Aug-Pl-phyric and aphyric clasts. Resistant, dark grey-green weathering. | |
| | | | **Basal sandstone and conglomerate (lmJSP*cg*); 0-140 m thick.** Qtz-rich feldspathic arenite and clast-supported conglomerate containing Hbl Qtz monzonite to Hbl Qtz monzodiorite (and locally Hbl monzogranite) clasts similar to subjacent Cake Hill pluton. Local Aug-Pl-phyric, Aug-phyric, Pl-phyric and aphyric volcanic clasts set in a matrix of medium sand to grit-sized Fsp and Qtz grains. Rare fossiliferous calcareous sandstone and siltstone. Subfeldspathic arenite (likely grus) unconformably overlies the Cake Hill pluton. Recessive, orange-brown weathering. Contains early Toarcian fossils (Henderson and Perry, 1981); Late Triassic detrital zircon population. | |
| Triassic | Stuhini Group | | **Mafic volcanic rocks (TrST*vm*).** Volcanic breccia and lapilli tuff with (Pl-)Aug-phyric clasts. (Pl-)Aug-phyric flows. Minor (Aug-)Pl-phyric coherent rocks may represent flows. | |
| | | | **Sedimentary rocks (TrST*s*).** Sandstone, volcaniclastic sandstone and argillite (Gabrielse, 1998; van Straaten et al., 2012). | |

Note: [1] van Straaten and Nelson (2016)

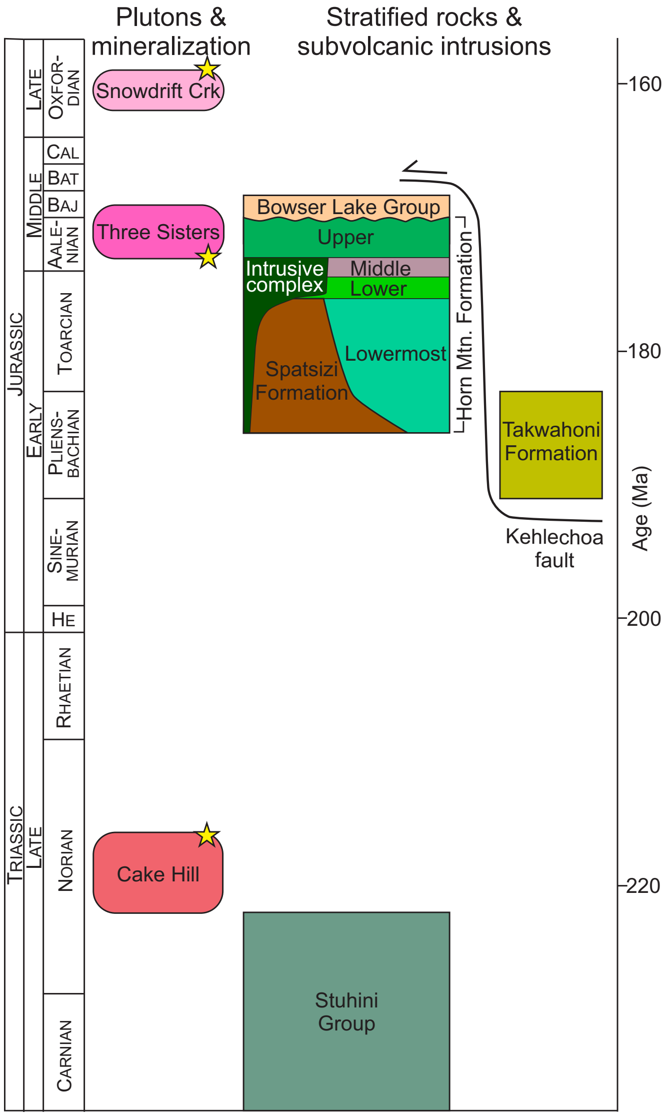


**Fig. 3.** Schematic stratigraphic, plutonic and structural relationships for Triassic to Jurassic rocks in the map area. Main mineralization events indicated by yellow star. Jurassic stage abbreviations: Hettangian (He), Bajocian (Baj), Bathonian (Bat), Callovian (Cal). Chronostratigraphic ages from International Commission on Stratigraphy, version December 2016 (Cohen et al., 2013).

Stuhini Group (Triassic), in the remainder of the field area it rests unconformably on the Cake Hill pluton (Late Triassic). The Spatsizi Formation is up to 1 km thick in the southwestern part of the map area. It thins and pinches out to the southeast, where the Horn Mountain Formation rests unconformably on the Cake Hill pluton. Farther southeast, the stratigraphic level occupied by the unconformity, Spatsizi Formation and lower Horn Mountain Formation is cut by the Three Sisters pluton (Middle Jurassic).

### 3.1.2.1. Spatsizi Formation

A succession of predominantly sedimentary rocks (up to 1 km thick) is exposed in the central and western parts of the map area (Fig. 2). We correlate this sequence with the Spatsizi

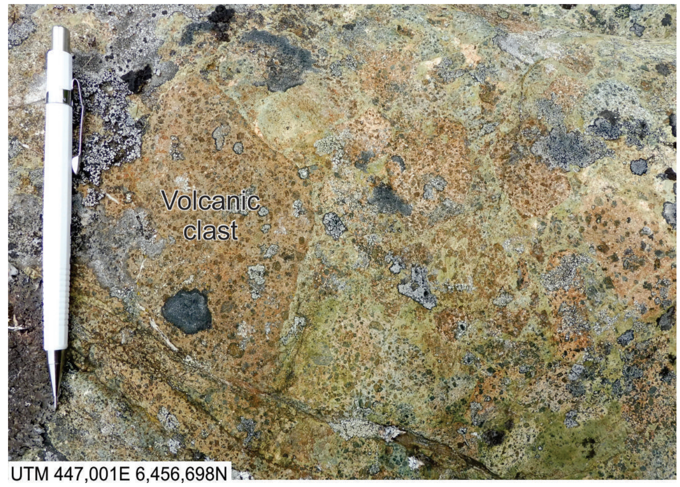


**Fig. 4.** Stuhini Group mafic volcanic unit (TrSTvm). Volcanic breccia with augite-plagioclase-phyric clasts.

Formation, as defined by Thomson et al. (1986) and modified by Evenchick and Thorkelson (2005) and Gagnon et al. (2012). It unconformably overlies the Cake Hill pluton (Late Triassic) in most of the map area, except in the far west where it is inferred to rest unconformably on the Stuhini Group (Triassic). It is conformably overlain by volcanic rocks of the Horn Mountain Formation. We recognize three main Spatsizi Formation units in the study area (Table 1).

In the basal unit, subfeldspathic arenite, clast-supported conglomerate, and quartz-rich feldspathic arenite unconformably overlie the Cake Hill pluton (Table 1). The unit contains abundant hornblende quartz monzonite to quartz monzodiorite clasts similar to the subjacent Cake Hill pluton; locally, volcanic clasts are common. South of Glacial Mountain, the Spatsizi Formation is generally absent between the Cake Hill pluton and Horn Mountain Formation, except for a 800 by 250 m zone of monomictic conglomerate to breccia interbedded with rare siltstone and sandstone (Figs. 2, 5). The conglomerate contains abundant hornblende monzogranite clasts similar in composition and texture to the pluton exposed directly to the south and east (Fig. 2; Section 4.1.). It likely represents the fill of a paleodepression cut into the Cake Hill pluton.

The basal unit fines upward to a unit of argillite, siltstone, and fine-grained sandstone (Fig. 6) with rare to locally common medium- to coarse-grained sandstone, granule conglomerate, and clast-supported volcanic breccia. This middle unit contains two volcanic subunits, coarse platy plagioclase-phyric volcanic breccia northeast of the Tanzilla River (van Straaten and Nelson, 2016), and mafic volcanic breccia southwest of the Tanzilla River, south of Horn Mountain and south of Glacial Mountain.

At the top of the Spatsizi Formation in the centre of the map area, a volcaniclastic unit consists mainly of fine- to coarse-grained volcaniclastic sandstone (Fig. 7) with lesser siltstone and fine tuff laminae. Rare augite-plagioclase-phyric coherent rocks are interpreted as sills. This unit gradationally overlies

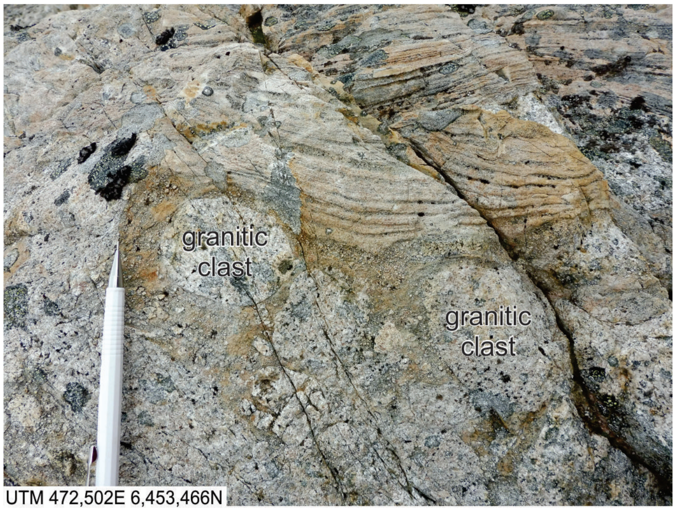


**Fig. 5.** Spatsizi Formation basal sandstone and conglomerate unit (lmJSPcg). Conglomerate with sandstone interbeds; granitic clasts in conglomerate have a similar composition to the immediately underlying Cake Hill pluton.


**Fig. 6.** Spatsizi Formation argillite, siltstone, and sandstone unit (lmJSPs). Interbedded siltstone and fine- to medium-grained sandstone displaying syn-sedimentary deformation.


**Fig. 7.** Spatsizi Formation volcaniclastic sandstone unit (lmJSPsv). Bedded volcaniclastic sandstone.

siliciclastic rocks of the middle unit (van Straaten and Nelson, 2016).

New geochronological data and fossil collections confirm the age and provenance of the Spatsizi Formation in the study area. A detrital zircon sample from the basal sandstone and conglomerate unit yielded a Late Triassic zircon population (Section 7.1.), complementing the results of Iverson et al., (2012) who reported Late Triassic and Early-Middle Jurassic zircon populations from the middle argillite, siltstone and sandstone unit. A tan to grey weathering, fine-grained calcareous sandstone at the base of this middle unit (Fig. 8) contains common bivalves and rare ammonites. Based on preliminary study, T. Poulton (pers. comm., 2016) suggests that ammonites may be as old as late Pliensbachian (*Protogrammoceras*) or as young as late Toarcian (*Pseudogrammoceras*) and that bivalves (*Bositra buchi*) are also late Pliensbachian to Toarcian. Henderson and Perry (1981) reported early Toarcian fossils from the basal unit in the western part of the map area, including bryozoa faunas interpreted to record shallow-marine conditions. Fossils from the same unit in the central part were interpreted as late Toarcian (Anderson, 1983) or, more recently, as early to middle Toarcian (Gabrielse, 1998).

The base of the Spatsizi Formation marks the change from Stuhini arc uplift and erosion to subsidence and sedimentation. The basal unconformity represents one of the few well-documented examples of unroofed Stuhini arc in northern Stikinia. It spans at least 30 m.y., and includes the latest Triassic and Early Jurassic porphyry copper metallogenic epochs farther south (e.g., Galore Creek, Red Chris, KSM; Fig. 1). The overall fining upward of the Spatsizi Formation, from basal conglomerate and sandstone to thick sections of argillite and siltstone suggests basin deepening. Regionally, the Spatsizi Formation is correlated with the predominantly siliciclastic Nilkitkwa Formation east and northeast of Smithers. The north-northwest trend of the Spatsizi and Nilkitkwa formations records Pliensbachian to Toarcian marine sedimentation in a back-arc or intra-arc depression (Hazelton trough; Fig. 1; Tipper and Richards, 1976; Marsden and Thorkelson, 1992; Gagnon et al., 2012).

### 3.1.2.2. Horn Mountain Formation

The Horn Mountain Formation, defined by van Straaten and Nelson (2016), is a volcanic succession (approximately 5.4 km thick) exposed between Gnat Pass and the McBride River (Figs. 2, 3; Table 1). Along its 50 km strike length, this succession displays relatively consistent stratigraphy and lithological

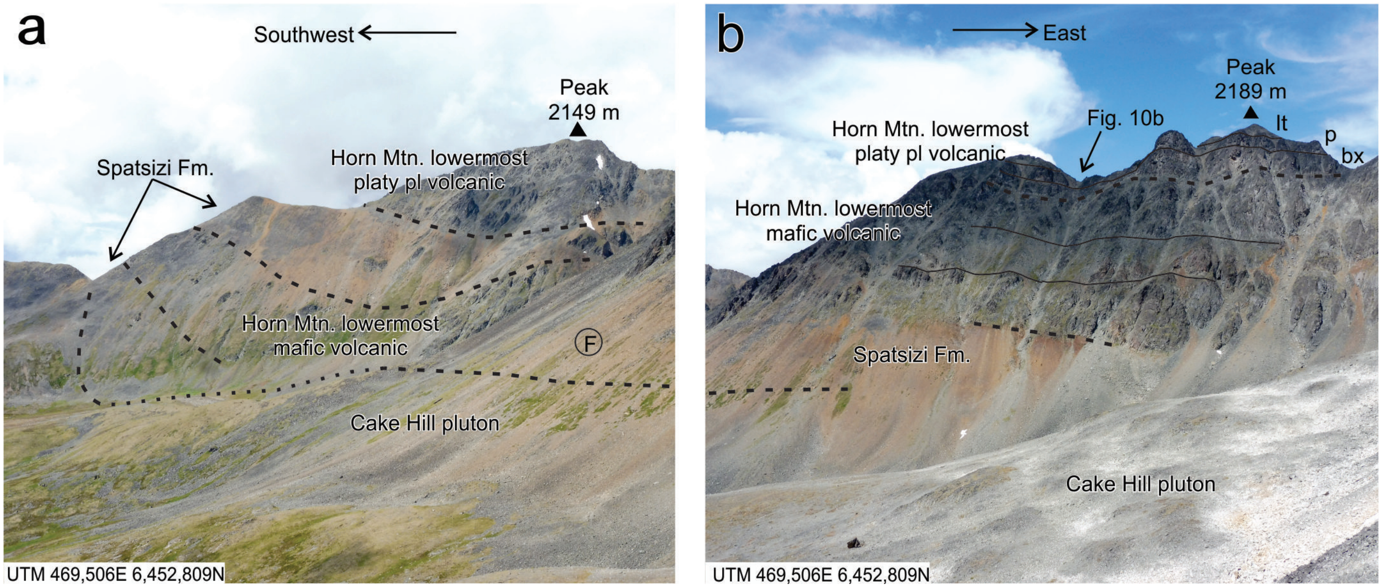


**Fig. 8.** Outcrop character and interfingering relationships between the Spatsizi and Horn Mountain formations. In far left background (a) and foreground (a, b) is Cake Hill quartz monzodiorite (LTrCHqm). **a)** In left background are recessive, orange-brown weathering, well-bedded Spatsizi Formation sedimentary rocks (lmJSPcg, lmJSPs) overlain by resistant, cliff-forming, crudely bedded grey coarse platy plagioclase-phyric volcanic rocks (lmJHMLMv.po) on the right. Within the Spatsizi Formation sedimentary rocks is a tongue of moderately resistant, dark grey mafic volcanic rocks of the Horn Mountain Formation (lmJHMLMvm). **b)** Continuation of a), to the east. On the left, recessive, orange-brown weathering, well-bedded Spatsizi Formation argillite, siltstone, and sandstone unit (lmJSPs) overlain by Horn Mountain Formation. Thick dashed lines represent contacts between units, thin solid lines represent lithologic contacts within units. Three very thick beds are identified in the lowermost mafic volcanic rock unit (lmJHMLMvm); the first and second bed are separated by a several m-thick recessive orange-brown weathering siltstone and sandstone bed. Three very thick beds are identified within the platy plagioclase-phyric volcanic unit (lmJHMLMv.po); they comprise a basal tuff breccia (bx), middle pillow (p) and upper lapilli tuff (lt) bed. F = fossil sample location (late Pliensbachian-Toarcian).

characteristics. In this study we significantly expand the known extent of this unit. Originally subdivided into four informal subdivisions (van Straaten and Nelson, 2016), herein we describe an additional two subdivisions exposed at the base of the formation in the east-central part of the map area.

**The lowermost mafic volcanic unit** contains augite-plagioclase-phyric volcanic breccia (Fig. 9a). The unit is only present in the east-centre of the map area. In the east the unit is up to 1 km thick and unconformably overlies the Cake Hill pluton. Immediately southwest of Peak 2189 m it is 310 m thick and conformably overlies a 150 m-thick Spatsizi Formation section (Fig. 8b). In both cases the unit is overlain by the lowermost platy plagioclase-phyric volcanic unit (see below). Two kilometres west of Peak 2189 m the lowermost mafic volcanic unit thins to 65 m, where it forms an apparently conformable tongue within the Spatsizi Formation argillite, siltstone and sandstone unit (Fig. 8a). South of Peak 2189 m very thick (~70 m) internally massive beds of mafic volcanic breccia are locally separated by well-stratified, rusty brown, recessive siltstone and sandstone (Fig. 8b). Here, breccias at the base of the unit and the base of the second very thick bed contain subrounded to subangular 0.5-30 cm clasts of hornblende quartz monzodiorite to quartz monzonite. The clasts have a similar texture and composition as the Cake Hill pluton exposed to the south. One of these plutonic clasts yielded a K-Ar hornblende age of 227 ±14 Ma (Anderson, 1983), within error of ages for the Cake Hill pluton (Table 2). South of Glacial Mountain, the base of the unit contains common hornblende monzogranite clasts, similar to the subjacent hornblende monzogranite intrusion (Figs. 2, 9b; Section 4.1.). A bed of lapilli tuff with aphyric felsic clasts and a bed of pale greenish-grey felsic fine tuff were sampled for U-Pb zircon geochronology (Section 7.1.). The lowermost volcanic units appear to represent relatively low volume volcanic eruptions with rapid lateral facies transitions. The interfingering fine-grained sedimentary rocks indicate that at least some of the volcanic rocks were deposited in a subaqueous setting.

**The lowermost platy plagioclase-phyric volcanic unit,** the second additional unit we recognize (Table 1), forms a distinct 200 to 350 m-thick marker above the lowermost mafic volcanic unit in the centre of the map area (Fig. 8). It consists of medium- to very thickly bedded lapilli tuff, lesser lapillistone, tuff breccia and volcanic breccia (Fig. 10a). On the high ridges of Peak 2189 m, tuff breccia beds are overlain by a 35 m-thick bed of pillows, in turn overlain by lapilli tuff (Figs. 8b, 10b). Volcanic clasts and pillows contain coarse platy plagioclase, amygdules, and local rare augite. A felsic volcanic breccia subunit is exposed at two locations, west and northwest of Peak 2189 m; it contains light-coloured aphyric, plagioclase-phyric and rare flow banded clasts (Table 1). Immediately southwest of Peak 2189 m, the unit directly overlies augite-plagioclase-phyric volcanic breccia of the lowermost mafic volcanic unit


**Fig. 9.** Horn Mountain Formation, lowermost mafic volcanic unit (lmJHMLMvm). **a)** Massive, clast-supported volcanic breccia with augite-plagioclase-phyric clasts. **b)** Granitic and volcanic clasts at base of unit. Granitic clasts have a similar composition to the immediately underlying Cake Hill pluton.

with a sharp but conformable contact (Fig. 8b). Eight hundred and fifty metres west of Peak 2189 m, it conformably overlies 5 m of rusty weathered siltstone and fine-grained sandstone above the lowermost mafic volcanic unit. About 1.5 km west of Peak 2189 m, the unit conformably overlies a 250 m-thick section of Spatsizi Formation granule to pebble conglomerate, sandstone, argillite and clast-supported volcanic breccia above the lowermost mafic volcanic unit (Fig. 8a). North of Peak

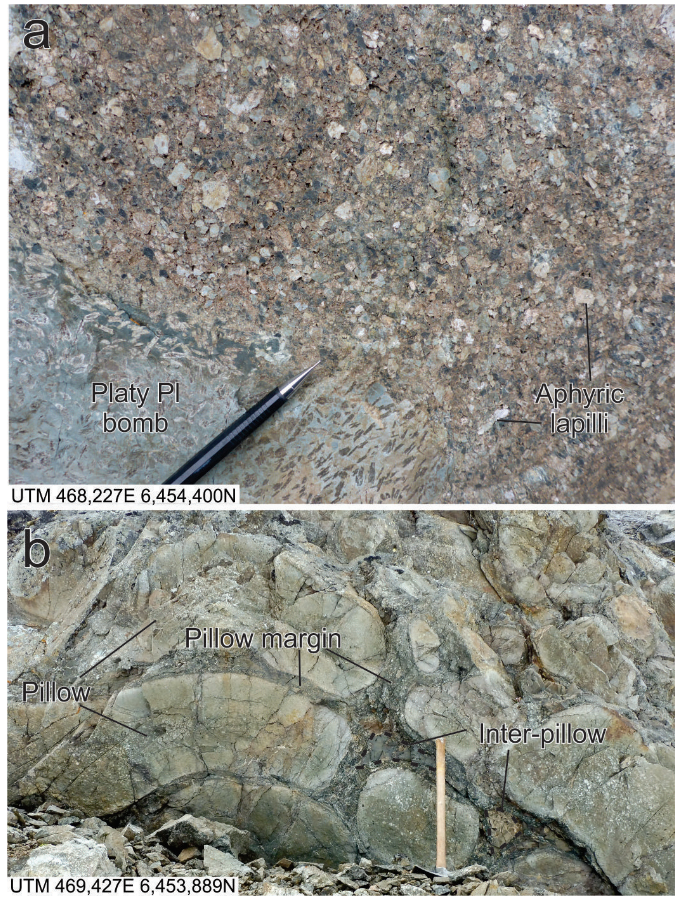


**Fig. 10.** Horn Mountain Formation, lowermost platy plagioclase-phyric volcanic unit (lmJHMLMv.po). **a)** Massive, clast-supported lapilli tuff with angular aphyric to plagioclase-phyric lapilli and platy plagioclase-phyric bomb. **b)** Elongate to circular pillows (in 2D) of coarse platy plagioclase-phyric mafic flow.

2189 m, wavy laminated Spatsizi Formation volcaniclastic siltstones directly overlie the platy plagioclase-phyric volcanic unit with a sharp but conformable contact. In the east, the platy plagioclase-phyric volcanic unit is overlain by the lower mafic volcanic unit (see below). Conformable contacts and interfingering between the platy plagioclase-phyric volcanic unit and Spatsizi Formation sedimentary rocks indicate that the two units are coeval. The platy plagioclase-phyric volcanic subunit in the Spatsizi Formation (Table 1) is likely a lateral facies equivalent of the Horn Mountain lowermost platy plagioclase-phyric volcanic unit.

The pillows at Peak 2189 m suggest subaqueous deposition and the overlying very thick lapilli tuff beds indicate volcanic eruptions with a high fragmentation intensity. A lack of change in lithogeochemistry (B. van Straaten et al., unpublished data), mineralogy, crystal content or vesicularity suggests the shift from effusive to explosive volcanism is unlikely to have resulted from a change in magma composition. The lapilli tuff may have formed by phreatomagmatic eruptions.

**The lower mafic volcanic unit** (Table 1) is 850-1500 m thick and consists predominantly of massive dark green monomictic

**Table 2.** Summary of intrusive units. Mineral abbreviations after Kretz (1983).

| Age | Phase | Description | Timing relationships | Geochronology |
|---|---|---|---|---|
| Late Jurassic | Snowdrift Creek subalkaline | **Snowdrift Creek pluton (LJSCgd).** Medium-grained (3-5 mm) equigranular Bt-bearing Hbl to Hbl-bearing Bt granodiorite. A fine-grained (1-3 mm) equigranular (Hbl-bearing) Bt Qtz diorite at the Joyce showing is interpreted as a satellite stock. Recessive to moderately resistant, medium grey weathering. | Cuts Takwahoni greywacke unit[1], mafic intrusive complex and Horn Mountain upper mafic volcanic unit. At contact, metamorphosed Takwahoni greywacke unit[1], mafic intrusive complex, and Horn Mtn upper mafic volcanic unit. Interpreted to cut Kehlechoa fault. | U-Pb zircon: 160.43 ±0.16 Ma |
| | | **Hornblende diorite (LJdr).** Hbl diorite dikes and possible sills. Contains 1-6 mm (generally acicular) Hbl and equant 1-4 mm Pl. Resistant, light grey to white weathering. | Cuts Takwahoni greywacke unit; Spatsizi argillite, siltstone & sandstone unit; Spatsizi platy Pl-phyric volcanic and volcaniclastic sandstone units[1]; Horn Mtn lower mafic volcanic and middle maroon volcanic units[1]; mafic intrusive complex. Follows faults. | |
| Middle Jurassic | Three Sisters subalkaline | **Potassic phase (MJTSgr).** Bt-bearing Hbl monzogranite with 20% Pl phenocrysts (1-3 mm) set in a fine-grained (0.1-1 mm) sugary groundmass. Moderately resistant, pink to pink-grey weathering. | Dikes cut Horn Mtn lower mafic and middle maroon volcanic units; Three Sisters central phase. Interpreted to cut mafic intrusive complex. | U-Pb zircon: 171 ±1 Ma[4], 169.1 ±0.8 Ma[3], 168.57 ±0.54 Ma[2] |
| | | **Central felsic phase (MJTSqm).** Medium-grained (2-4 mm) equigranular (Bt-bearing) Hbl Qtz monzodiorite, rare granodiorite. Local microdiorite xenoliths. Resistant, medium grey to pink-grey weathering. | Apophyses cut Three Sisters mafic phase. Interpreted to cut Cake Hill pluton and Horn Mtn lower mafic volcanic unit. | U-Pb zircon:, 177.13 ±0.59 Ma[2], 172.75 ±0.87 Ma[2], 169.0 ±1.3 Ma[3] |
| | | **Mafic phase (MJTSqd).** Medium-grained (2-3 mm) equigranular Hbl-Cpx to Cpx-Hbl diorite, rare Qtz diorite. Resistant, dark greenish-grey weathering. | Interpreted to cut Cake Hill pluton and Horn Mountain lowermost mafic volcanic unit. | Ar-Ar Hbl: 171.9 ±1.7 Ma[3] |
| | Tanzilla subalkaline | **Augite quartz diorite (MJqd).** Medium-grained equigranular Aug Qtz diorite (and diorite?)[2]. | Cuts Horn Mountain middle maroon volcanic and upper felsic volcanic units[1]; Aug-bearing Pl porphyry[1]. | |
| | | **Augite-bearing plagioclase porphyry (MJap).** Aug-bearing Pl porphyry dikes and stocks with 40% tabular to equant Pl (1-4 mm), 3-5% equant Aug (<2 mm), minor Mag[2]. | Interpreted to cut Horn Mtn middle maroon volcanic unit, mafic intrusive complex, and Horn Mtn upper felsic volcanic unit[1]. | U-Pb zircon: 173.25 ±0.13 Ma[1] |
| Early-Middle Jurassic | Spatsizi & Horn Mountain alkaline | **Felsic intrusive (EMJf).** Felsic dikes with common dike margin-parallel flow bands and wispy Qtz ribbons. Local m-wide tabular to 100 m-wide bulbous bodies of intrusive breccia containing angular to amoeboid Pl-phyric (20%, 1-2 mm) clasts, aphyric clasts, Aug-Pl-phyric clasts and minor flow-banded autoclasts. | Cuts Horn Mountain lower mafic volcanic unit[1]. Interpreted to cut mafic intrusive complex. | |
| | | **Hornblende monzonite (EMJmz).** Hbl to Hbl-Bt monzonite dikes, Pl-porphyritic; contains minor Mag. | Cuts mafic intrusive complex. | |

**Table 2.** Continued.

| Age | Phase | Description | Timing relationships | Geochronology |
|---|---|---|---|---|
| Early-Middle Jurassic | Spatsizi & Horn Mountain alkaline | **Platy plagioclase porphyry (EMJm.po).** Pl-phyric dikes, sills, and stocks. Coarse Pl plates (0.5-4 cm, 5:4:1 aspect ratio) and locally rare Aug (<2 mm) set in a dark green to dark purple-grey aphanitic groundmass. Locally amygdaloidal. Rare breccia textures. Resistant, dark grey weathering. | Cuts Horn Mountain lower mafic volcanic and middle maroon volcanic units. Cuts mafic intrusive complex, locally with gradational contacts[1]. | |
| | | **Mafic intrusive complex (EMJm).** Aug-Pl-phyric sills, dikes and intrusive bodies. Contains 30% equant Pl (0.5-2 mm), 20% Aug (1-4 mm, locally up to 10 mm) and rare amygdules. Local Aug microdiorite. Resistant, dark grey to green weathering. | Cuts Spatsizi volcaniclastic sandstone unit, Horn Mountain lower mafic volcanic and middle maroon volcanic units. | |
| Triassic-Jurassic | | **Cpx-rich diorite to gabbro (TrJgb).** Medium-grained (1-4 mm) equigranular Cpx-rich diorite to gabbro. Highly magnetic. Resistant, dark grey to black weathering. | Cuts sedimentary rocks assigned to Stuhini Group. Interpreted to cut Horn Mtn maroon volcanic unit. | |
| Late Triassic | Stikine subalkaline | **Gnat Pass porphyry (LTrGP).** Porphyritic hypabyssal intrusive with euhedral-subhedral Pl (2 mm), rare Qtz (2-4 mm) and Hbl[4]. | Cuts Stuhini Group mafic volcanic unit. | U-Pb zircon: 216.5 ±1.4 Ma[3] |
| | | **Cake Hill quartz-rich phase (LTrCHgr).** Medium-grained (3-5 mm) equigranular Hbl monzogranite, often with Qtz eyes (5-7 mm) and tabular Hbl. Correlated with the Cake Hill quartz-rich phase of van Straaten et al. (2012). Moderately resistant, greyish-white weathering. | Interpreted to be unconformably overlain by Spatsizi basal sandstone and conglomerate unit; Horn Mtn lowermost mafic volcanic unit. | U-Pb zircon: 216.2 ±1.2 Ma[3] |
| | | **Cake Hill pluton (LTrCHqm).** Medium-grained (3-4 mm) equigranular (Bt-bearing) Hbl Qtz monzodiorite to Qtz monzonite with local granodiorite and Qtz diorite. Contains accessory Ttn and Mag. Locally foliated. Resistant, pale grey weathering. | Cuts Gnat Lakes intrusive[3]. Unconformably overlain by Spatsizi basal conglomerate unit and Horn Mtn lowermost mafic volcanic unit. Interpreted to cut Stuhini volcanic and sedimentary units. | U-Pb zircon: 221 ±3 Ma[4], 218.2 ±1.3 Ma[3] |
| | Stikine alkaline | **Gnat Lakes intrusive (LTrGLum).** Medium-grained (3-4 mm) equigranular Pl-bearing hornblendite to Cpx Hbl-rich gabbro. Moderately resistant, black weathering. | Interpreted to cut Stuhini volcanic and sedimentary units[3]. | |

Note: [1] van Straaten and Nelson (2016); [2] Takaichi (2013a; b); [3] van Straaten et al. (2012); [4] Anderson and Bevier (1992) volcanic breccia and lapilli tuff (Fig. 11). Volcaniclastic sandstone, augite-plagioclase crystal tuff, and tuff, although rarely observed, are locally common southeast of Glacial Mountain. Minor augite-plagioclase-phyric coherent rocks are interpreted as sills. The unit displays a gradational lower contact with the Spatsizi Formation in the western and central parts of the map area. Farther east, it overlies the lowermost platy plagioclase-phyric volcanic unit; both a gradational and a sharp but conformable contact were observed. The unit is texturally and compositionally similar to the lowermost mafic volcanic unit described above, but can be distinguished by its stratigraphic position, lateral extent, and lack of interbedded fine-grained siliciclastic rocks and plutonic clasts near its base. Based on gradational contacts with underlying sedimentary rocks and lateral transitions to volcaniclastic sandstones (see below), at least some of the volcanic rocks may have been deposited in a submarine setting.

The mafic volcanic rocks grade westward into a volcaniclastic sandstone subunit at Gnat Pass (Fig. 2, Table 1). Resistant volcanic breccias near Peak 2096 m transition to intervals of alternating resistant volcanic breccia and recessive volcaniclastic sandstone on its western slopes. In the Gnat Pass area, limited outcrop shows both volcanic breccia and volcaniclastic sandstone. Along Tsenaglode Creek, rocks currently considered part of the volcaniclastic subunit consist of lithic arenite and pebbly granular conglomerate interbedded with laminated siltstone. The conglomerate contains angular-subrounded dark grey very fine-grained (volcanic?) and rare grey siliceous clasts in a feldspar-rich matrix with up to 2% quartz. These rocks are cut by platy plagioclase-augite- and plagioclase-phyric mafic intrusions.


**Fig. 11.** Horn Mountain Formation, lower mafic volcanic unit (lmJHMLvm). Massive, monomictic, clast-supported tuff breccia with augite-plagioclase-phyric volcanic clasts.

**The middle maroon volcanic unit** overlies the lower mafic volcanic unit everywhere but in the centre of the map area, where it is obscured by the mafic intrusive complex (Fig. 2). The lower contact of the unit is not exposed. The unit is up to 3 km thick and contains interlayered flows, volcanic breccia, tuff and lapilli tuff (Figs. 12, 13). Flows and clasts are predominantly augite-plagioclase-phyric. Interlayering of flows, tuff, and volcanic breccia is common and well-illustrated in exposures north of the McBride mineral occurrence (Fig. 12). The uppermost part of this unit in the Tanzilla area and immediately north of the Wolf showing contains well-stratified volcaniclastic sandstone and tuff. Rare welded lapilli tuff beds are developed at several locations. At one locale, a poorly sorted pyroclastic breccia with concave downward-shaped gas cavities above larger clasts grades upward into welded lapilli tuff (Figs. 12d, e), suggesting deposition as a hot, gas-rich pyroclastic density current.

The middle maroon volcanic unit formed in a predominantly subaerial environment as indicated by massive lava flows, local welded tuff and rare pyroclastic flow deposits. During formation of this unit, volcanic deposition rates outpaced subsidence rates, leading to the formation of a large subaerial volcanic edifice. Volcaniclastic sandstone and tuff in the upper part of the unit may indicate the end of widespread volcanism. The middle maroon volcanic unit is cut by a 173 Ma augite-bearing plagioclase porphyry (Table 2) which, when combined with the ca. 176 Ma detrital zircon peak from the top of the Spatsizi Formation (Iverson et al., 2012), suggests that the 4.5 km thick section of the lower and middle volcanic units were deposited within an 3 m.y. interval.

**The upper felsic volcanic unit** overlies the middle maroon volcanic unit in the Tanzilla area, (Table 1). Silica-altered plagioclase-phyric, possibly flow banded volcanic rocks 6 km east of Glacial Lake are tentatively assigned to this unit, and may include strong texturally destructive quartz-sericite-clay±lazulite altered rocks at the new Straight-across mineral occurrence (Section 6.2.3.3.). Contact relationships with the underlying unit were not observed. Bomb sags indicate subaerial deposition, and minor conglomerate beds and rare fossiliferous sandstone suggest local erosion within this unit.

**The upper mafic volcanic unit** caps the upper felsic volcanic unit, middle maroon volcanic unit and mafic intrusive complex (Fig. 2). The unit consists mostly of augite-plagioclase-phyric coherent rocks interpreted as flows and minor volcanic breccia, lapilli tuff, and tuff. Mafic coherent rocks and rare volcanic breccia north of the Gopher zone mineral occurrence, previously assigned to the mafic intrusive complex (van Straaten and Nelson, 2016), are reinterpreted here as the upper mafic volcanic unit. Barresi (2008) described drill core from the Mo showing with similar massive to well-bedded lapilli-tuff and crystal tuff containing plagioclase and augite crystals, providing further support for a mafic extrusive unit between the Gopher zone and Straight-up mineral occurrences. Given

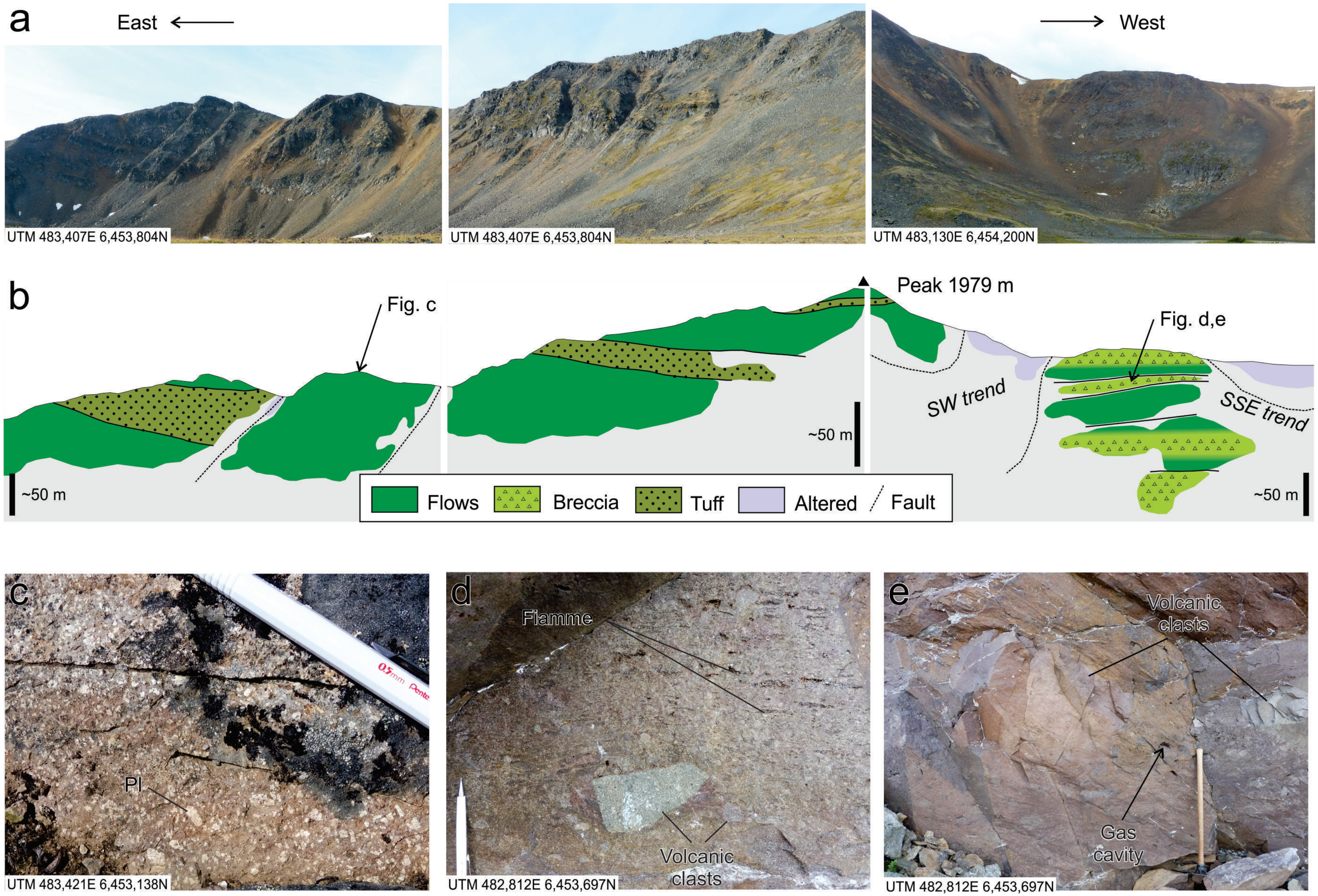


**Fig. 12.** Horn Mountain Formation, middle maroon volcanic unit (lmJHMMv) immediately north of the McBride mineral occurrence. **a)** Panorama of locally altered interlayered flows, volcanic breccia, and tuff. **b)** Diagram of rock types in a). **c)** Maroon plagioclase-phyric coherent rock interpreted as a volcanic flow. Relatively coarse plagioclase laths (4-6 mm, ~1:2.3 aspect ratio) characterize many flows of the unit near the McBride mineral occurrence. **d)** Maroon polymictic welded lapilli tuff with fiamme. **e)** Very poorly sorted maroon tuff breccia with concave-down gas cavities immediately above volcanic clasts.


**Fig. 13.** Horn Mountain Formation. Maroon polymictic tuff breccia in middle maroon volcanic unit (lmJHMMv). Clasts are typically sub-angular, varicoloured, and (augite)-plagioclase-phyric to aphyric.

the abundance of coherent mafic rocks, the unit is difficult to distinguish from the mafic intrusive complex (cf. Tables 1, 2). On the ridge west of Tanzilla, the contact with rocks of the underlying upper felsic volcanic unit is gradational. Contact relationships in all other areas are obscured by alteration and/or shearing. At Tanzilla, the unit overlies strongly quartz-sericite-clay altered rocks interpreted as the upper felsic volcanic unit. In the centre of the map area the unit overlies a northwest-dipping zone (at least 275 m wide) of generally strongly quartz-sericite-clay altered and variably sheared rocks (Fig. 14, Section 5.1.). Locally recognizable textures suggest a platy plagioclase-phyric porphyry protolith (Fig. 2). A down-dropped fault block west of Glacial Lake contains a gently north-dipping sequence of augite-plagioclase-phyric flows, and rare platy plagioclase-phyric flows, platy plagioclase-phyric volcanic breccia, and tuff with coarse platy plagioclase crystals; it is assigned to the upper mafic volcanic unit. Here, the succession overlies platy plagioclase-phyric coherent rocks interpreted as sills; the


**Fig. 14.** Horn Mountain Formation upper mafic volcanic unit (mJHMUvm) overlies strongly altered platy plagioclase porphyry (EMJm.po). Horn Mountain upper mafic volcanic unit is dark grey and moderately resistant. Gossans of the Straight-up mineral occurrence are visible underneath. View to the north-northeast.

intervening contact was not observed. A detrital zircon sample from a polymictic breccia in the upper mafic volcanic unit at Tanzilla yielded a Middle Jurassic maximum depositional age (Section 7.1.).

### 3.1.3. Bowser Lake Group

Gently north-dipping sedimentary rocks assigned to the Bowser Lake Group unconformably overlie Horn Mountain Formation upper volcanic rocks in the northwestern part of the map area (Figs. 2, 3); east of the map area, the Bowser Lake Group is in conformable contact with the middle maroon volcanic unit (van Straaten and Nelson, 2016). The section at Tanzilla contains an ammonite of probable Toarcian age (T. Poulton, pers. comm., 2015), which is at odds with a Middle Jurassic (Bajocian) maximum depositional age indicated by U-Pb analysis of detrital zircons from the same location (Section 7.1.), and middle Bajocian fossils collected east of the map area (Gabrielse, 1998). Regionally, deposition of Cache Creek-derived chert clast-bearing conglomerate in the Bowser basin records the onset of erosion from the Stikinia – Cache Creek tectonic welt (Evenchick et al., 2007).

## 3.2. Whitehorse trough

### 3.2.1. Takwahoni Formation (Early Jurassic)

Sedimentary rocks of the Takwahoni Formation (Laberge Group; Table 1) are exposed in a 5 km-wide belt between the Kehlechoa and King Salmon thrust faults (Figs. 2, 3). The most common lithology is interbedded quartz-bearing (5-15%) feldspathic arenite, feldspathic wacke and lesser siltstone (Fig. 15). Several fossil collections date this succession as (early) Pliensbachian (Gabrielse, 1998). Local basement to the Whitehorse trough strata is not exposed.

A recessive siltstone unit was observed in the northeastern part of the map area (Figs. 2, 16; Table 1). It is generally interbedded with minor fine- to medium-grained feldspathic arenite and feldspathic wacke. The contact between the north-dipping, right-way-up siltstone sequence and underlying sandstone unit is covered. The presence of the siltstone unit in the two eastern fault panels is inferred from regional aeromagnetic data (Aeroquest Airborne, 2012).

Regionally, the Whitehorse trough records progressive erosion of the Stuhini volcanic arc to plutonic levels, accompanied by input from Pliensbachian lower Hazelton arc volcanism to the south; it has been interpreted as a forearc basin (Johannson et al., 1997; Mihalynuk et al., 2004) or, more recently, a synorogenic basin (Colpron et al., 2015).

## 3.3. Overlap unit

### 3.3.1. Tuya Formation (Miocene to Pleistocene)

Gabrielse (1998) mapped several exposures of olivine basalt in the area. The volcanic centres are all on or near major faults (Fig. 2), and show a characteristic dipole signature on the regional aeromagnetic survey (Aeroquest Airborne, 2012).

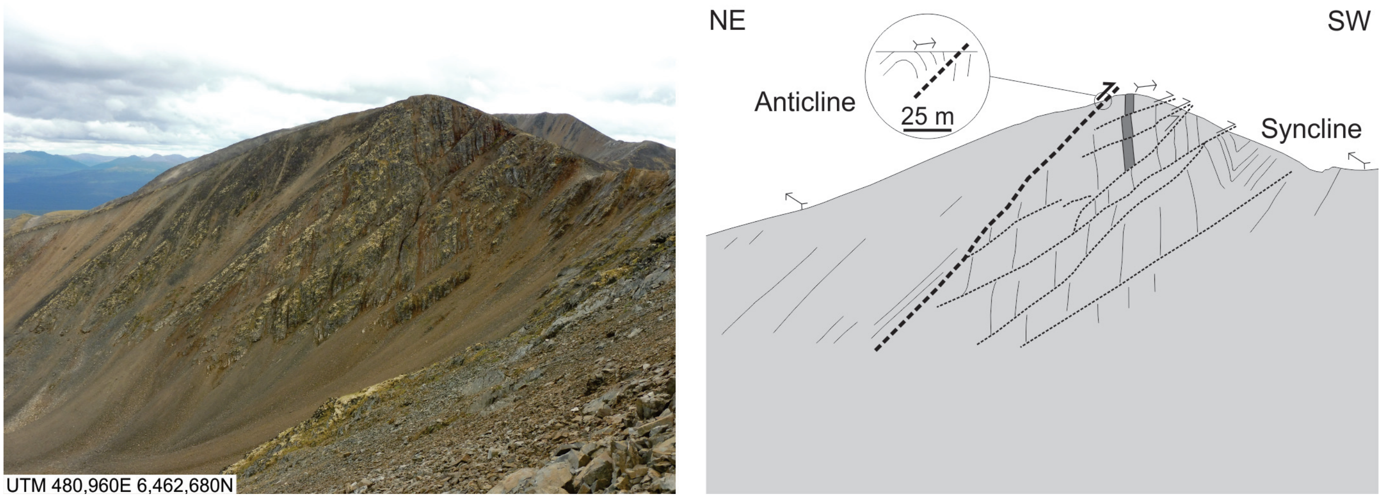


**Fig. 15.** Fault propagation fold within interbedded sandstone and siltstone (Takwahoni Formation, sandstone unit, lJTgw). Arrows show tops; view to the southeast.


**Fig. 16.** Takwahoni Formation; recessive, orange-brown weathering, and well stratified siltstone unit (lJTs). View to the northeast.

## 4. Intrusive units

### 4.1. Late Triassic intrusions

The margin of the Cake Hill pluton, part of the 2275 km$^2$ composite Hotailuh batholith (van Straaten et al., 2012), is exposed in the southern part of the map area (Fig. 2). The main phase comprises hornblende quartz monzodiorite to quartz monzonite with accessory titanite and magnetite. Generally massive, it is locally foliated in the western part of the map area near Gnat Pass (Table 2). At its western contact, the Cake Hill pluton cuts Triassic Stuhini mafic volcanic rocks (van Straaten et al., 2012). Results from two U-Pb zircon samples indicate a ca. 221-218 Ma age (Anderson and Bevier, 1992; van Straaten et al., 2012). The northern margin of the pluton is unconformably overlain by Hazelton Group volcano-sedimentary rocks (Figs. 2, 8).

A small (~4 km$^2$) intrusive body of medium-grained (3-5 mm) equigranular hornblende monzogranite is exposed in the southeast of the map area (Fig. 2). It can be distinguished from the main phase of the Cake Hill pluton by a higher abundance of K-feldspar and quartz, and 5-7 mm quartz eyes (Fig. 17; Table 2). Contact relationships with the Hazelton Group to the north are equivocal. However, the presence of texturally-similar hornblende monzogranite clasts in basal Hazelton Group suggests an unconformity. Based on textural similarities and a probable pre-Early Jurassic age, the intrusion is correlated with the Cake Hill quartz-rich phase (Late Triassic) of van Straaten et al. (2012). The locally abundant hornblende monzogranite clasts suggest the quartz-rich phase may be (or may have been) more extensive than currently recognized.

The Gnat Pass porphyry consists of numerous small (<0.2 km$^2$) plagioclase±quartz±hornblende porphyritic intrusions in the northwest of the map area (Fig. 2; Table 2). These rocks host K-feldspar-tourmaline alteration and local chalcopyrite-

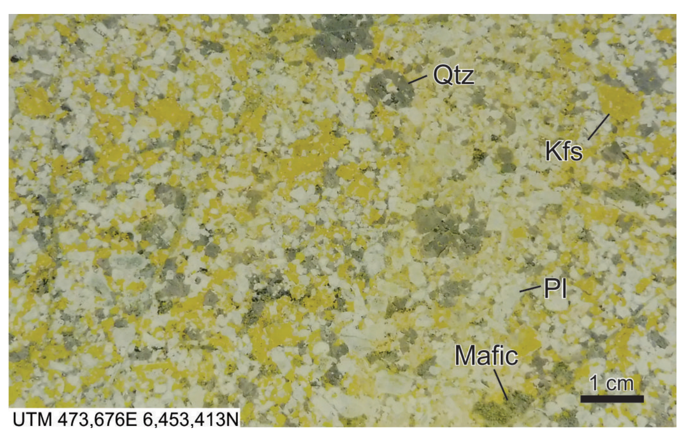


**Fig. 17.** Cake Hill pluton, quartz-rich phase (LTrCHgr). Medium-grained, equigranular, massive hornblende monzogranite. Slab is stained for K-feldspar.

pyrite mineralization at the Gnat Pass developed prospect and Moss showing (Section 6.1.).

A clinopyroxene-rich diorite to gabbro body of uncertain age was mapped in two areas in the western part of the map area (Fig. 2; Table 2). It is highly magnetic and has a concomitant high aeromagnetic response (Aeroquest Airborne, 2012). The unit intrudes sedimentary rocks tentatively assigned to the Stuhini Group (Fig. 2). A narrow (~100 m wide) diorite-gabbro body in the Horn Mountain middle maroon volcanic unit is assigned to this unit; contacts are not exposed. A similar pyroxenite, hornblende gabbro to monzodiorite unit (Triassic to Jurassic) was mapped ~30 km west of the map area by Logan et al. (2012a; b).

#### 4.2. Early to Middle Jurassic subvolcanic intrusions

The mafic intrusive complex forms two bodies (37 km$^2$ and 26 km$^2$) in the central and eastern part of the map area (Fig. 2). It consists of augite-plagioclase-phyric mafic coherent rocks (Fig. 18; Table 2) and minor microdiorite. Rare volcanic breccia is interpreted as Horn Mountain Formation wall rock. The complex consists of irregular intrusive bodies, sills, and dikes that cut the Spatsizi volcaniclastic unit, and Horn Mountain lower mafic volcanic and middle maroon volcanic units (Fig. 2). The intrusions are likely coeval with high-volume volcanism during formation of the lower and middle Horn Mountain volcanic units based on their textural, mineralogical, and lithogeochemical similarities and because they cross-cut only the lower and middle Horn Mountain units (van Straaten and Nelson, 2016; this study). This implies that the contact between the mafic intrusive complex and the Horn Mountain upper mafic volcanic unit is either a local unconformity or a fault. The central location of the complex in the volcanic belt indicates a possible feeder relationship.

Dikes and sills of coarse platy plagioclase porphyry commonly cut the mafic intrusive complex and Horn Mountain lower mafic and middle maroon units (Fig. 2; Table 2). A south-dipping zone of generally strongly quartz-sericite-clay altered and variably sheared rocks is structurally below the Horn Mountain upper mafic volcanic unit northwest of Glacial Lake (Sections 5.1., 6.2.). Locally recognizable textures at the southern end of the 275 m-wide zone suggest a platy plagioclase porphyry protolith (Fig. 2). In a down-dropped fault block west of Glacial Lake, platy plagioclase-phyric coherent rocks that underlie the upper mafic volcanic unit are interpreted as sills.

Near the Joyce showing, rare pale-grey plagioclase-phyric felsic dikes and a felsic breccia body are at the contact between a quartz diorite intrusion (Late Jurassic, see below) and the mafic intrusive complex (Figs. 2, 19). The breccia body contains (augite)-plagioclase-phyric and aphyric clasts in a pale grey flow-banded coherent groundmass (Table 2). Similar felsic dikes and a felsic intrusive breccia body cut the Horn


**Fig. 18.** Mafic intrusive complex, massive augite-plagioclase-phyric coherent rock (EMJm).

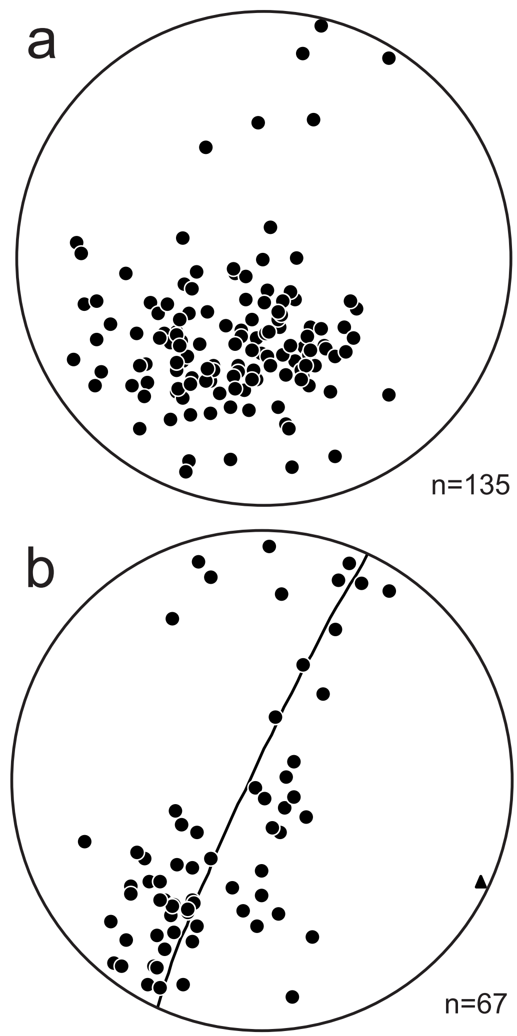


**Fig. 19.** Stereonet plots with poles to bedding for **a)** southern structural domain (upper part of Hazelton Group, Stikinia), and **b)** northern structural domain (Takwahoni Formation, Whitehorse trough). Great circle in b) shows cylindical best fit, triangle represents corresponding fold axis. Lower hemisphere equal area projections.

Mountain lower mafic volcanic unit 5.5 km west of the Joyce showing (van Straaten and Nelson, 2016).

Several metre-wide monzonite dikes near the McBride mineral occurrence contain plagioclase, hornblende, and biotite crystals in a very fine-grained, pink groundmass. These dikes display alteration and porphyry-style veining internally and along their margins (Section 6.2.1.2.). Texturally and mineralogically similar dikes were observed east of Tanzilla (van Straaten and Nelson, 2016). They may represent alkaline intrusions (Early-Middle Jurassic) coeval with the Horn Mountain volcanic rocks, or subalkaline intrusions (Middle Jurassic) related to the potassic phase of the Three Sisters pluton.

### 4.3. Middle Jurassic intrusions

The Three Sisters pluton in the southeast of the map area consists of a main central felsic phase and marginal mafic and potassic phases (Fig. 2; Table 2). Crosscutting relationships (van Straaten et al., 2012; this study) and geochronological data (Table 2) suggest an evolutionary path from mafic towards more evolved compositions between ca. 173 and 169 Ma.

The mafic phase is a small (<2 km$^2$) hornblende-clinopyroxene diorite intrusion in the southeast of the map area. It is highly magnetic and has a high aeromagnetic response (Aeroquest Airborne, 2012).

Small (<0.2 km$^2$) intrusive bodies of (augite-bearing) plagioclase porphyry at the Tanzilla prospect and Straight-across mineral occurrences are generally surrounded by highly altered rocks interpreted as the Horn Mountain middle maroon volcanic unit. These intrusions are interpreted to be coeval with porphyry-style alteration at the Tanzilla prospect, and a U-Pb zircon age of 173.25 ±0.13 Ma indicates that the intrusions are coeval with the mafic phase of the Three Sisters pluton.

The central felsic phase consists of hornblende quartz monzodiorite to biotite-bearing hornblende quartz monzodiorite. Part of this body was previously mapped as the Cake Hill pluton (Gabrielse, 1998). It is re-interpreted here as Three Sisters central felsic phase based on Middle Jurassic U-Pb zircon ages (Takaichi 2013a; b; see Section 7.2). Local minor biotite, presence of common diorite xenoliths, and the lack of accessory titanite confirm this assignment. Apophyses of the central felsic phase cut the mafic phase, and diorite xenoliths similar to the mafic phase are common in the central felsic phase (Table 2). Fluidal-shaped mafic domains and mafic domains with chilled margins in central felsic phase rocks (van Straaten et al., 2012) suggest the central felsic and mafic phases are roughly coeval.

The potassic phase comprises biotite-bearing hornblende monzogranite. It occurs immediately east of the central phase, and as a ~700 m wide apophysis cutting the mafic intrusive complex, Horn Mountain lower mafic and Horn Mountain middle maroon volcanic unit (Fig. 2; Table 2). Pale pink hornblende-plagioclase-phyric dikes correlated with the potassic phase cut Horn Mountain lower mafic and middle maroon volcanic rocks, and appear to cut the central felsic phase.

The Three Sisters pluton is part of a Middle Jurassic quartz-bearing calc-alkaline plutonic belt that trends northwest to east-southeast for at least 300-400 km, spanning the Cache Creek and Stikine terranes (Fig. 1; van Straaten et al., 2012). In the far northwest of this belt, the Fourth of July batholith (ca. 171 Ma) cuts deformed rocks of the Cache Creek terrane (Mihalynuk et al., 1992). These plutons extend into the Yukon, where they are referred to as the Bryde suite (ca. 172-168 Ma; Colpron et al., 2016a; b).

### 4.4. Late Jurassic intrusions

The Snowdrift Creek pluton is a mostly recessive 96 km$^2$ hornblende-bearing biotite granodiorite body (Table 2; Fig. 2). Apophyses of the pluton cut Takwahoni sandstone and augite-plagioclase-phyric coherent rocks interpreted as the Horn Mountain upper mafic volcanic unit. Moderate to intense biotite hornfels, with up to 25% very fine-grained (0.02-0.2 mm) black biotite replacement, occurs up to one kilometre away from the southern margin of the pluton. It affects the Horn Mountain upper mafic volcanic rocks, mafic intrusive complex, platy plagioclase porphyry and augite-bearing plagioclase porphyry. Along the northeastern margin of the pluton, fine-grained brown biotite hornfels extends at least several hundred metres into Takwahoni sandstone. We interpret that the Snowdrift Creek pluton cuts the Kehlechoa fault, the thrust that places sedimentary rocks of the Whitehorse trough structurally above Stikinia (Fig. 2).

A ~5 km$^2$ intrusive body of fine-grained hornblende-bearing biotite quartz diorite cuts the mafic intrusive complex at the Joyce showing (Fig. 2). Based on its composition, texture and crosscutting relationships we consider it a satellite stock of the Snowdrift Creek pluton. A small (0.1 km$^2$) hornblende quartz monzodiorite intrusion crops out 2 km south of the Snowdrift Creek pluton and a small granodiorite body is interpreted from drill logs from the Mo prospect (Barresi, 2008; Fig. 2).

Hornblende diorite dikes and sills correlated with the Snowdrift Creek pluton occur throughout the map area. They cut the Takwahoni Formation and most units in the upper part of the Hazelton Group (Table 2).

The Snowdrift Creek pluton yielded a U-Pb zircon age of 160.43 ±0.16 Ma. Plutons of this age are rare in the northern Canadian Cordillera. However, recent studies in the Yukon suggest that the McGregor pluton is of roughly similar age (ca. 163-160 Ma, Colpron et al., 2016a; b).

## 5. Structure

The map area can be divided into southern and northern structural domains, separated by the Kehlechoa thrust fault (Fig. 2). In the southern domain, the Spatsizi and Horn Mountain formations define a moderately NNE-dipping homocline that is cut by northeast-striking normal faults and northwest-striking dextral and normal faults. In the northern domain, sedimentary rocks of the Whitehorse trough in the hanging wall of the Kehlechoa thrust are deformed by southvergent folds and thrusts that are offset by NNE-striking tear faults. In the western part of the map area between Gnat Pass and Dease Lake, both domains are cut by NNW-striking faults that were active from the Late Triassic to late Middle Jurassic.

**5.1. Southern structural domain**

Bedding in the Spatsizi and Horn Mountain formations defines a generally NNE-dipping homocline (Fig. 19a). Local east-dipping bedding coincides with the eastern margin of the Cake Hill pluton, and may reflect heterogeneous strain around the margins of a rigid body. Rare steeply south-dipping bedding in the Horn Mountain lower mafic volcanic unit west of Highway 37 (Fig. 19a) may represent open upright folds with east-trending hinge lines, similar to those in the northern structural domain (see below).

Several northeast-striking faults cut the Spatsizi and Horn Mountain formations with apparent right- and left-lateral offset. They are interpreted as normal faults with both east-side and west-side down movement (Fig. 2). These faults are truncated to the north by the Snowdrift Creek pluton and the Kehlechoa fault.

Northwest-striking faults cut the Spatsizi and Horn Mountain formations. The regional-scale (10-20 km) northwest-striking Tanzilla River fault and a fault south of Peak 2096 m display an apparent dextral offset and cut the northeast-striking faults. Short (<4 km) northwest-striking dextral and north-side down normal faults are cut by the northeast-striking faults. A steeply north-dipping fault 3 km south-southwest of Glacial Lake juxtaposes a hanging wall of Horn Mountain Formation lowermost mafic volcanic rocks with a footwall of Cake Hill quartz monzonite. A normal sense is inferred based on the juxtaposition of younger over older rocks. In the hanging wall of an inferred north-side down, northwest-striking normal fault immediately west of Glacial Lake, moderately to gently north-dipping Horn Mountain Formation upper mafic volcanic flows lie above a footwall of moderately to steeply north-dipping Horn Mountain middle maroon volcanic rocks (Fig. 2). This fault is defined by a 2 m-wide zone of steeply north-dipping quartz-clay schist. The lack of foliation development in other northwest-striking faults suggests the foliation may have formed as a result of subsequent reverse movement, similar to the shear zone at the Straight-up mineral occurrence (see below).

At the Gopher zone and Straight-up mineral occurrences (Fig. 2), well-developed foliation generally dips moderately to steeply to the northeast, or steeply to the southwest. It is best developed in a zone (at least 275 m wide) of strongly quartz-sericite-clay-pyrite altered rocks (see Section 6.2.). This zone likely extends for 12 km along strike, from the Gopher zone to the Straight-up mineral occurrence, based on 1) subcrop and float of altered and/or foliated rocks at the Mo east mineral occurrence, and 2) similar chargeability anomalies along the Gopher zone and Mo east occurrences (Andrzejewski and Bui, 2012). Although kinematic indicators were not observed and the structure does not appear to duplicate or omit stratigraphy, a reverse shear sense is inferred based on a roughly similar orientation as regional-scale thrust faults and its crosscutting relationship with respect to the alteration system at Tanzilla. It likely formed along a zone of weakness created by earlier hydrothermal alteration. The shear zone has a similar orientation to both bedding and normal faults in the map area, as such it may represent 1) a decollement surface developed within altered rocks below an unconformity at the base of the upper mafic volcanic unit, and/or 2) a southwest-verging thrust fault reactivating a northeast-side down normal fault, which previously focussed hydrothermal fluids and resultant advanced argillic alteration. The shear zone appears to be offset across two northeast-striking left-lateral tear faults (Fig. 2).

Local biotite schists form steeply NNE-dipping metre-wide domains of limited lateral continuity in the Horn Mountain upper mafic volcanic unit. At two locations, fabrics in the schists are cut by pink felsic dikelets (2 cm wide) attributed to the Snowdrift Creek pluton.

**5.2. Northern structural domain**

Two regional SSW-vergent thrust faults define the boundaries of the northern structural domain (Fig. 2). In the north, the King Salmon fault places rocks of the Cache Creek terrane over the Takwahoni Formation (Whitehorse trough; Gabrielse, 1998). To the south, the Kehlechoa fault places Takwahoni Formation rocks over younger Horn Mountain Formation and Bowser Lake Group (Stikinia) rocks. The Kehlechoa fault is inferred from 1) the juxtaposition of Pliensbachian Takwahoni Formation over younger, Toarcian-Bajocian Bowser Lake Group and Horn Mountain Formation; 2) the presence of folds and internal imbrication in the hanging wall; and 3) a well-defined aeromagnetic lineament (Aeroquest Airborne, 2012). The absence of internal imbrication and folding in the homoclinal footwall sequence suggests the Kehlechoa fault is the foreland thrust of the Cache Creek-Stikinia orogenic welt. Geochronological data (see Section 7) indicate that the fault moved between ca. 170 and 160 Ma.

Bedding in the Takwahoni Formation is predominantly right-way-up and moderately north- to northeast-dipping (Fig. 2). The folds are open to tight, with subhorizontal fold axes (Fig. 19b), and have wavelengths of up to 1 km. Folds, small-scale thrusts and a 100s of metre-scale fault propagation fold (Fig. 15) verge to the south-southwest. Rare axial planar cleavage in fine-grained units dips moderately to steeply north to north-northeast and locally, steeply south. The orientation and vergence of structural elements in the northern structural domain are similar to the Kehlechoa and King Salmon faults, and agree with results from other studies in the region (Gabrielse, 1998; Logan et al., 2012a).

Northeast-striking faults, with apparent right-lateral and left-lateral slip cut the Takwahoni Formation in the northeast part of the map area (Fig. 2). They terminate a thrust fault and km-scale fold patterns, and offset the Takwahoni siltstone unit.

### 5.3. NNW-trending faults between Gnat Pass and Dease Lake

Regional-scale NNW-trending faults cut the southern and northern structural domains in the western part of the map area. A NNW-striking fault is inferred to cut across Tsenaglode Creek in the westernmost part of the map area (Fig. 2). The base of the Takwahoni Formation shows a 6 km right-lateral offset along the northern segment of this fault. West of the fault, the basal contact of the Takwahoni Formation is inferred as depositional on top of Stuhini Group (Logan et al., 2012a; b). East of this fault, the Takwahoni Formation occupies the hanging wall of a thrust fault above the Horn Mountain Formation. Our mapping extends the Horn Mountain Formation to at least the lower reaches of Tsenaglode Creek. Here, the NNW-trending fault is interpreted to juxtapose Stuhini Group and Horn Mountain Formation (Fig. 2). On the west side of the inferred fault, the age of volcano-sedimentary rocks is uncertain; following mapping by Logan et al. (2012b) farther west we tentatively assign this succession to the Stuhini Group. The southernmost 6 km of the fault manifests as a well-defined aeromagnetic lineament; the remainder of the fault lacks a clear aeromagnetic expression (Aeroquest Airborne, 2012).

Along Highway 37 (Fig. 2), the Gnat Pass structure is defined by a zone of foliated rocks up to 1 km wide at the contact of the Stuhini Group and Cake Hill pluton (Late Triassic). These rocks are interpreted as a syn-intrusion east-side-up reverse shear zone (van Straaten et al., 2012). East-west continuity of Spatsizi and Horn Mountain units, and the Gnat Pass to Moss alteration system (see Section 6.1.) suggest minimal, if any, strike-slip movement. The structure is inferred to extend northward and merge with an adjacent fault to the east.

A northwest-striking fault passes ~1-2 km east of Gnat Pass (Fig. 2). The northern segment of the fault is defined by an aeromagnetic lineament. Based on the 1.7 km apparent right-lateral offset of an east-west aeromagnetic lineament ascribed to the Kehlechoa fault, it is interpreted as a tear fault. In the south, this fault shows a relatively well-constrained 2 km apparent right-lateral offset of the Spatsizi basal sandstone and conglomerate unit, and appears to structurally juxtapose altered rocks of the Gnat Pass developed prospect against Spatsizi basal sandstone and conglomerate. We interpret this segment of the fault as an Early Jurassic growth fault, based on 1) abrupt thickening of the Spatsizi Formation across the fault (Fig. 2), 2) abundant small-scale syn-sedimentary faults and soft-sediment deformation in the Spatsizi Formation (Fig. 6), and 3) an up-section decrease in displacement of contacts in the overlying Horn Mountain Formation.

## 6. Mineral occurrences

Mineral occurrences in the map area (Fig. 20) can be subdivided according to age of formation, age of host rocks, mineralization characteristics, and alteration style. Late Triassic porphyry-style copper mineralization occurs at the Gnat Pass developed prospect and nearby Moss showing. The Horn Mountain Formation hosts aerially extensive gossans at Tanzilla and McBride and epithermal veins with elevated copper values near Glacial Lake. A trend of argillic to advanced argillic altered rocks (at least 17 km long) is exposed at high stratigraphic levels of the Horn Mountain Formation. Molybdenum mineralization is present locally in the Snowdrift Creek pluton and its immediate wall rocks, and in a satellite stock to the south.

Preliminary assay data from ten altered and/or mineralized rock samples collected in 2016 are presented in Table 3. Samples were jaw crushed and pulverized at the British Columbia Geological Survey, and analyzed at Bureau Veritas in Vancouver. The samples were dissolved using an aqua regia digestion before being analyzed by ICP-ES/MS. Results of external standards and duplicates were monitored to ensure analytical reproducibility and accuracy. Detailed methods and complete results will be reported elsewhere.

### 6.1. Mineral occurrences in Triassic rocks

The two porphyry copper mineral occurrences in the southwestern part of the map area are hosted in Stuhini Group mafic volcanic rocks and Gnat Pass plagioclase porphyry.

#### 6.1.1. Gnat Pass (MINFILE 104I 001)

Drilling at the Gnat Pass porphyry copper developed prospect (Fig. 20) in the 1960s defined a non NI 43-101-compliant resource of 30 million tonnes grading 0.389% copper (Lytton Minerals Ltd., 1972, reported in MINFILE 104I 001; British Columbia Geological Survey, 2016). Limited diamond drilling was carried out in 1989 and 2012 (Smith and Garagan, 1990; Roberts et al., 2013). Chalcopyrite is in black tourmaline veins and disseminations, and is commonly accompanied by pink K-feldspar alteration (van Straaten et al., 2012; Roberts et al., 2013). Mineralization is mainly in the Gnat Pass plagioclase porphyry, but is also in Stuhini Group mafic volcanic rocks adjacent to the porphyry. Sheeted subvertical, northwest-striking black tourmaline±chalcopyrite±magnetite veins were observed near Gnat Pass. A NNW-trending fault juxtaposes altered Stuhini Group and unaltered Spatsizi Formation rocks (Figs. 2, 20). A northeast-trending fault bounds the Gnat Pass deposit to the south. Surface mapping and drilling indicates that it separates altered Stuhini Group and Gnat Pass porphyry in the hanging wall from Spatsizi basal sandstone and conglomerate overlying the Cake Hill pluton in the footwall (Bowen, 2013; Roberts et al., 2013).

#### 6.1.2. Moss (MINFILE 104I 029)

The Moss porphyry copper showing is 2.3 km west-northwest of the Gnat Pass developed prospect (Fig. 20). Geologic, geochemical, and geophysical surveys, trenching, and percussion drilling were conducted in conjunction with work on the Gnat Pass developed prospect in the late 1960s to early 1970s. Chalcopyrite is in a northwest-trending zone of tourmaline veins and breccias with pink K-feldspar alteration (Bowen, 2013). Results from trenching returned 122 metres at 0.10% copper (Lytton Minerals Ltd., 1969). Recent

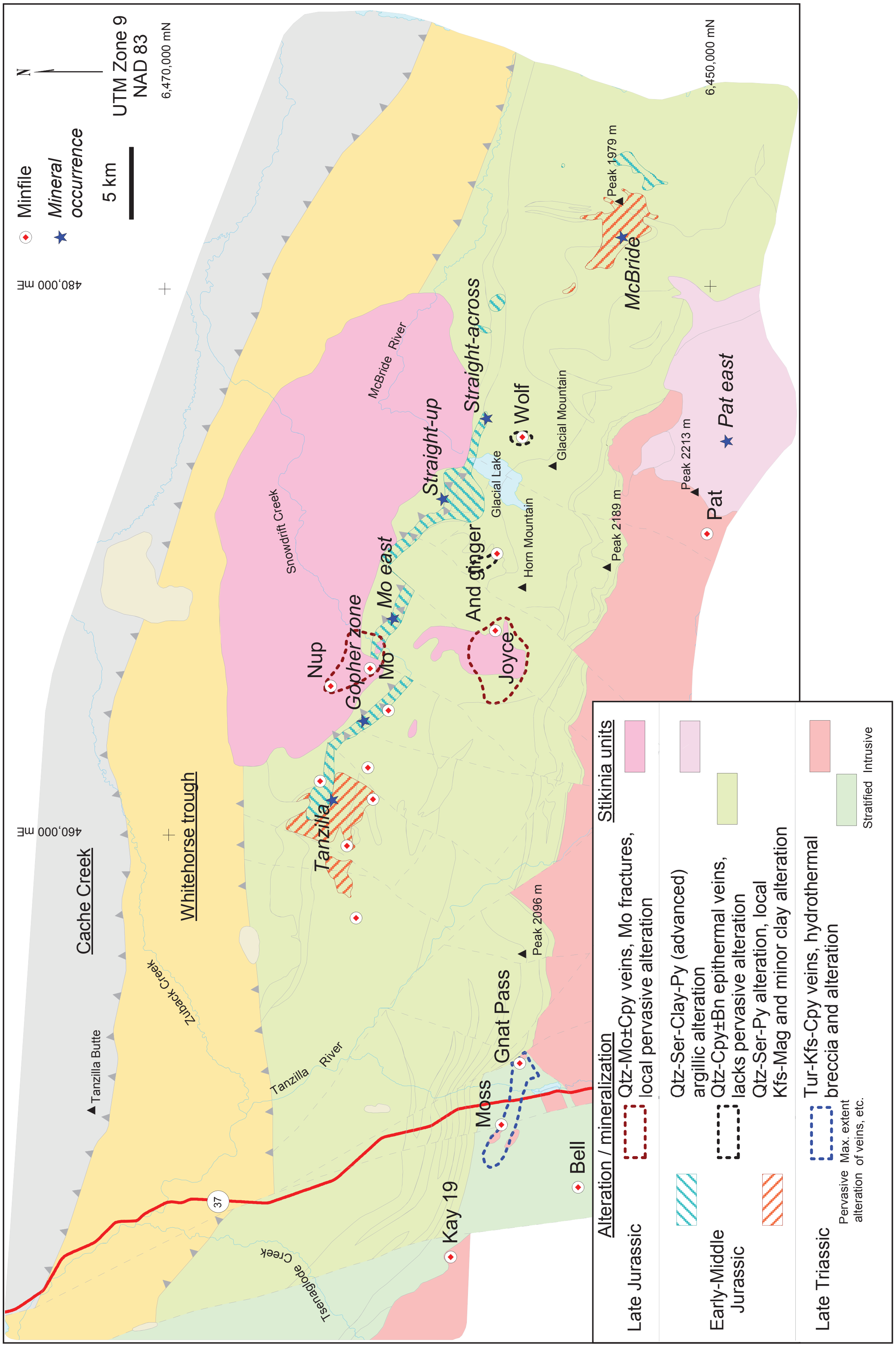


**Fig. 20.** Simplified geologic map highlighting mineral occurrences, and generalized extent of characteristic alteration and mineralization domains. For detailed geology and legend see Figure 2.

**Table 3.** Assay results and coordinates of mineralized and altered rock samples.

| Sample | Mineral Occur. | Easting | Northing | Mo | Cu | Pb | Zn | Ag | Ni | Co | Mn | Fe | As | Au | Cd | Sb | Bi | W | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | unit | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | % | ppm | ppb | ppm | ppm | ppm | ppm | % |
| | | | DL | 0.1 | 0.1 | 0.1 | 1 | 0.1 | 0.1 | 0.1 | 1 | 0.01 | 0.5 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.05 |
| 16BvS-10-76 | Mo E | 467598 | 6461887 | 116.7 | 107.4 | 49.8 | 174 | 2.4 | 14.7 | 25 | 1668 | 6.73 | 4.4 | 2.6 | 0.2 | 0.1 | 11.5 | 0.2 | 3.46 |
| 16BvS-10-77 | Mo E | 468022 | 6461904 | 1.5 | 178.5 | 6.3 | 54 | 0.1 | 12.9 | 25.8 | 483 | 4.84 | 1.2 | 1.7 | 0.1 | 0.2 | 1.2 | <0.1 | 4.47 |
| 16BvS-21-158 | Straight-across | 475168 | 6458269 | 1.4 | 90.9 | 3.6 | 44 | <0.1 | 8.3 | 29.2 | 396 | 5.87 | 1 | 2.4 | <0.1 | <0.1 | 0.1 | <0.1 | 0.94 |
| 16RGI-8-49 | 4 km NW HM | 467982 | 6458411 | 0.3 | 103 | 5.6 | 65 | 0.1 | 18 | 18.1 | 1942 | 3.9 | 1 | 3 | 0.1 | 0.2 | <0.1 | <0.1 | <0.05 |
| 16RGI-8-50 | 3 km NW HM | 467974 | 6458205 | 0.5 | 62.9 | 2.7 | 104 | <0.1 | 25.5 | 35.2 | 943 | 4.86 | 1.6 | <0.5 | 0.1 | <0.1 | 0.3 | 0.1 | 0.44 |
| 16RGI-9-57 | 2 km N HM | 470024 | 6457741 | 1.4 | 13.2 | 4.7 | 67 | <0.1 | 8.8 | 8.4 | 579 | 3.79 | 1 | 7.4 | <0.1 | 0.2 | 0.4 | 0.2 | 0.89 |
| 16RGI-21-136 | 13 km SE GL | 447899 | 6454093 | 1.2 | 25.3 | 9.4 | 67 | <0.1 | 7.2 | 6.6 | 766 | 7.09 | 2.7 | 5.5 | <0.1 | 0.2 | 0.3 | <0.1 | 0.9 |
| 16RGI-23-144 | 11 km SE GL | 478722 | 6454864 | 2.9 | 84.8 | 2.1 | 74 | 0.1 | 5.1 | 21.4 | 1165 | 4.22 | 2.4 | 6 | <0.1 | 0.3 | 0.2 | 0.2 | 0.25 |
| 16RGI-27-172 | Pat E | 474279 | 6449454 | 18.8 | 3524 | 6.8 | 54 | 0.8 | 3.7 | 22.2 | 895 | 3.98 | 5 | 82.2 | <0.1 | 0.1 | 49 | 0.1 | 0.27 |
| 16RGI-41-268 | 4 km SE GL | 476727 | 6455044 | 6.2 | 89.6 | 8.6 | 16 | 0.1 | 22.9 | 37.3 | 140 | 5.58 | 27.4 | 2.1 | <0.1 | 0.3 | <0.1 | <0.1 | 5.35 |
| *External standards and duplicates* | | | | | | | | | | | | | | | | | | | |
| 16RGI-41-268dup | | | | 6.7 | 89.7 | 9 | 16 | 0.1 | 23.4 | 38.2 | 135 | 5.41 | 28.8 | 1.9 | <0.1 | 0.4 | 0.1 | <0.1 | 5.51 |
| USGS GXR-1 | | | | 18.1 | 1221 | 693 | 750 | 32.4 | 40.2 | 8.3 | 922 | 24.43 | 414.2 | 3795 | 3 | 86.7 | 1546.6 | >100 | 0.22 |
| Expected* | | | | 18 | 1110 | 730 | 760 | 31 | 41 | 8.2 | 880 | 25 | 427 | 3300 | 3.3 | 122 | 1380 | 164 | 0.26 |
| BCGS Till 2013 STD | | | | 0.9 | 172.1 | 215.3 | 366 | 1.9 | 219.7 | 51.7 | 1611 | 7.42 | 66.6 | 20.7 | 0.9 | 9.1 | 0.3 | <0.1 | <0.05 |
| Expected** | | | | 0.81 | 170 | 240 | 410 | 2.24 | 250 | 60 | 1780 | 8.94 | 70 | 31 | 1.04 | 16.4 | 0.21 | 2.3 | <0.01 |

Coordinates in NAD83, Zone 9 north

Aqua regia digestion followed by ICP-ES/MS analysis

Abbreviations: DL-detection limit, GL-Glacial Lake, HM-Horn Mountain, N-north, E-east, S-south, W-west

* USGS GXR-1 expected values from Gladney and Roelandts (1990)

** BCGS Till 2013 expected values from A. Rukhlov, pers. comm. (2016)

trench grab samples returned up to 2.1% copper and 0.7 g/t gold (Andrzejewski and Bui, 2012). Similar to the Gnat Pass developed prospect, the Moss showing is spatially coincident with Gnat Pass porphyry intrusions (Figs. 2, 20; Bowen, 2013). Including the Gnat Pass developed prospect, tourmaline and/or K-feldspar alteration and chalcopyrite mineralization extend for 4.3 km along a west-northwest trend (Fig. 20; van Straaten et al., 2012; Bowen, 2013). The tourmaline vein and breccia zones at the Moss showing and sheeted tourmaline veins at Gnat Creek suggest a strong structural control.

### 6.2. Mineral occurrences in Early to Middle Jurassic rocks

Early to Middle Jurassic rocks in the map area host porphyry-style occurrences, local epithermal-style veins, and a laterally extensive argillic to advanced argillic alteration zone.

#### 6.2.1. Porphyry-style occurrences

##### 6.2.1.1. Tanzilla (MINFILE 104I 142)

The Tanzilla occurrence is in a zone of quartz-sericite-clay±pyrite alteration measuring at least 5 by 2 km (Fig. 20). The altered area includes the Gopher zone (see Section 6.2.3.1.) and other MINFILE occurrences (Fig. 20). Recent work includes geophysical surveys, a terraspec alteration mineral study, and diamond drilling (Luckman et al., 2013; Barresi et al., 2014). In addition to phyllic, argillic and intermediate argillic alteration, the terraspec-aided field study identified an advanced argillic alteration assemblage of alunite, pyrophyllite and topaz (Luckman et al., 2013). Diamond drilling in 2014 and 2015 tested for porphyry-style alteration and mineralization below the strongly advanced argillic altered lithocap exposed at the surface (Barresi et al., 2014). Drill holes intersected advanced argillic alteration overlying porphyry-style alteration with local anomalous copper and molybdenum concentrations (Barresi et al., 2014; Kaizen Discovery Inc., 2015; van Straaten and Nelson, 2016). An augite-bearing plagioclase porphyry (173 Ma; Section 7.4.) was affected by pervasive quartz-sericite-pyrite and potassic alteration. van Straaten and Nelson (2016) interpreted this porphyry as syn-mineral because it hosts porphyry-style alteration and veining, and lacks the advanced argillic alteration of adjacent volcanic rocks. The alteration system at Tanzilla is cut by unaltered hornblende diorite dikes, correlated with the Snowdrift Creek pluton (Table 2).

##### 6.2.1.2. McBride

The first recorded exploration activities near the McBride occurrence (Fig. 20) were by Teck Resources Limited (2011 to 2014) and included geophysical surveys, stream-sediment, soil and rock sampling, and geologic mapping (Takaichi and Johnson, 2012; Takaichi, 2013a; Jutras et al., 2014). The occurrence is in interlayered augite-plagioclase-phyric flows, tuffs, and volcanic breccias of the Horn Mountain middle maroon unit (Figs. 2, 12). A gossan (~1.5 by 1.5 km) immediately west of Peak 1979 m shows abundant float, subcrop, and local outcrop of moderately to strongly quartz-sericite-pyrite altered rocks, and local cm-scale quartz-pyrite veins. A magnetite breccia (75 by 100 m) described by Jutras et al. (2014) in the western part of this gossan is in a probable intrusive rock containing plagioclase phenocrysts set in a pink, very fine-grained K-feldspar-rich groundmass. The K-feldspar, likely in part hydrothermal, is accompanied by common magnetite-pyrite alteration, and magnetite, biotite, and rare quartz-magnetite veinlets. Rock samples from this location returned up to 0.07% copper and 0.25 g/t gold (Jutras et al., 2014). The close spatial relationship of potassic alteration and hydrothermal veins with monzonite intrusions (EMJmz, Table 2) suggest they may be cogenetic. Several narrow (<50-100 m) alteration zones extend north-northwest to northeast from the gossanous zone (Figs. 12a, 20) and are likely related to pre-existing faults. A zone of weak to moderate quartz-sericite-pyrite alteration extends along the creek west of Peak 1979 m for at least 1 km (Fig. 20). The zone contains several northwest- to north-trending pink hornblende-biotite monzonite dikes (EMJmz; Table 2) with rare quartz-pyrite veins and local magnetite veinlets in the adjacent mafic intrusive. Farther east, on the hillside above the McBride River, a northeast-trending zone, 1.8 km long by 0.3 km wide, with variable alteration characteristics is exposed. Hydrothermal mineral assemblages vary from quartz-sericite-clay-pyrite to quartz-clay-pyrite and massive grey silica-pyrite. Medium grey massive silica-pyrite altered rock is exposed at an isolated outcrop 2.4 km north-northeast of Peak 1979 m (Fig. 20). The local potassic alteration and porphyry-style veining within a broader quartz-sericite-pyrite altered zone may represent the upper levels of a porphyry system (Jutras et al., 2014). The eastern and north-northeastern exposures appear to display more distal argillic to advanced argillic alteration assemblages.

#### 6.2.2. Epithermal-style mineral occurrences

Several small copper-bearing veins in the centre and south-centre of the map area generally lack significant alteration envelopes and are likely relatively low-temperature, shallow epithermal in origin.

##### 6.2.2.1. And Ginger (MINFILE 104I 140)

The And Ginger copper-silver showing, 2 km west of Glacial Lake, was discovered in 2008 during geologic mapping and prospecting near the Joyce property (Barresi, 2009; Fig. 20). The showing includes quartz-calcite-epidote-chlorite-bornite±chalcopyrite veins and pods hosted in sea green aphanitic rhyolite dikes and mafic volcanic rocks (Barresi, 2009). Grab samples returned up to 3% copper and 69 g/t silver (Barresi, 2009). Nearby we observed similar chalcopyrite- and malachite-bearing quartz veins that show open-space vein-fill textures and lack significant alteration envelopes.

##### 6.2.2.2. Wolf (MINFILE 104I 056)

The Wolf copper showing is 1 km southeast of Glacial Lake (Fig. 20). Prospecting and geologic mapping identified a restricted (45 by 45 m) zone of copper mineralization (Noel, 1972). Abundant cm- to rarely 0.5 m-wide quartz-chlorite-carbonate-chalcopyrite-bornite veins locally have slickenfibres developed along their surfaces. Mineralization is along the margin of, and locally within, a NNE-NE-trending, steeply dipping hornblende diorite dike that is up to 12 m wide. The dike is equigranular, medium grained (3-4 mm), and contains 15% euhedral hornblende and 85% euhedral, concentrically zoned plagioclase. It cuts augite-plagioclase-phyric flows of the Horn Mountain middle maroon volcanic unit and is considered part of the Snowdrift Creek suite. The veining and mineralization at Wolf are comparable to And ginger, but contrast strongly to those at occurrences in Late Jurassic rocks (see below).

#### 6.2.2.3. Pat East

Subcrop and float of a brecciated malachite-stained quartz vein was observed in a 5-10 m wide northwest-trending recessive zone with common disseminated pyrite in central felsic phase quartz monzodiorite of the Three Sisters pluton. An assay sample returned 0.35% copper and anomalous molybdenum and gold (Table 3). The vein is 3 km east-southeast of the Pat copper-molybdenum showing (MINFILE 104I 043; Fig. 20).

### 6.2.3. Argillic to advanced argillic alteration zones

A 17 km-long zone of quartz-sericite-clay-pyrite alteration extends across the central part of the map area (Fig. 20). It includes alteration at Tanzilla, the Gopher zone, Mo east, Straight-up and the newly discovered Straight-across occurrence. At Tanzilla and the Gopher zone, terraspec analyses confirmed advanced argillic alteration assemblages (Luckman et al., 2013). Based on textural and mineralogical similarities, we postulate that advanced argillic alteration extends across the entire zone. Similar alteration may be present east and northeast of the McBride occurrence, 10 km east of the Straight-across occurrence.

#### 6.2.3.1. Gopher zone (MINFILE 104I 141)

The Gopher zone mineral occurrence, 2.5 km east-southeast of Tanzilla, trends northwest and is at least 275 m wide. It consists of strongly sheared silicified rocks and quartz-sericite-clay schist, and commonly contains blue lazulite (an anhydrous phosphate mineral). A terraspec-aided field study identified an advanced argillic alteration assemblage of pyrophyllite±topaz (Luckman et al., 2013). Texturally destructive alteration generally prevents protolith identification, but near the southern end of the zone is coarse platy plagioclase porphyry.

#### 6.2.3.2. Mo East

A broad saddle on the ridge east of the Snowdrift Creek valley shows a pronounced chargeability high on an induced polarization survey (Andrzejewski and Bui, 2012). Although exposure is generally poor, rare subcrop and float indicate massive to strongly foliated quartz-sericite-clay altered rocks. Abundant iron oxide coated fractures, iron oxide lined cavities, and only rare disseminated pyrite, suggest extensive surface leaching of pyritiferous rocks. A sample of coarse platy plagioclase-phyric coherent rock with disseminated pyrite and a quartz-pyrite±molybdenite vein, returned 117 ppm molybdenum (Table 3).

#### 6.2.3.3. Straight-up

The Straight-up mineral occurrence consists of extensive gossans on the ridges northwest of Glacial Lake (Figs. 14, 20). This occurrence was first described by Barresi (2009), who reported highly variable alteration intensity, alteration minerals, and planar fabric development. Alteration minerals include quartz, clay, chlorite, sericite, pyrite, hematite and rare kaolinite, andalusite, lazulite and titanite. Barresi (2009) described the rocks as being highly leached, and reported that samples failed to yield significant base or precious metal concentrations. He considered alteration mineralogy, strong apparent leaching, and high aluminum concentrations consistent with strong acidic alteration. We confirmed the presence of quartz-sericite-clay altered rocks, commonly with a well-developed foliation. At the north end of the zone protoliths were not identifiable due to strong texturally destructive alteration; at the south end, the protolith is variably altered and sheared platy plagioclase porphyry. The valleys to the southwest and east contain ferricrete deposits and, together with the abundant iron oxide coated fractures and vugs, indicate extensive pyrite leaching.

#### 6.2.3.4. Straight-across

We mapped massive grey silica±sericite altered rocks containing minor blue lazulite, 1.5 km east-southeast of the outlet of Glacial Lake and herein name the occurrence 'Straight-across' (Fig. 20). It displays similar argillic to advanced argillic alteration as Tanzilla, Gopher zone, Mo east and Straight-up. Leached cavities are common, except in rare areas where abundant (<5-10%) disseminated pyrite is preserved. A sample did not return significant base or precious metal concentrations (Table 3). The southern part of the occurrence, and an isolated outcrop 300 m to the east, consist of biotite hornfelsed and locally quartz-pyrite altered augite-bearing plagioclase porphyry, similar to the syn-mineral porphyry at Tanzilla. The area surrounding the Straight-across occurrence is covered by thick overburden.

## 6.3. Mineral occurrences in Late Jurassic rocks

### 6.3.1. Mo and Nup (MINFILE 104I 146, 104I 059)

The Mo and Nup mineral occurrences are in the overburden-filled Snowdrift Creek valley (Fig. 20). Anomalous molybdenum and copper in stream-sediment, soil, and rock samples were identified by Stevenson (1973a; b), Ball and Ashton (1982), Graham (1982), and Bradford (2008). Drilling by Paget Moly Corporation in 2008 intersected volcanic tuff, platy plagioclase porphyritic intrusion, and biotite granodiorite of the Snowdrift Creek pluton (Barresi, 2008). Anomalous molybdenum values were intersected in several drill holes, generally coincident with widely spaced molybdenite and trace chalcopyrite in quartz veins with pink K-feldspar envelopes (Barresi, 2008). Most likely, this mineralization is a molybdenum (copper) porphyry system genetically related to the Snowdrift Creek pluton.

### 6.3.2. Joyce (MINFILE 104I 049)

The Joyce showing is 2 km northwest of Horn Mountain (Fig. 20). In the late 1960s low-grade molybdenum-copper mineralization was identified by prospecting, geologic mapping, induced polarization surveys and trenching (Woolverton, 1967). Diamond-drill holes intersected variable chlorite-sericite, clay, and silica alteration accompanied by molybdenite, but mineralization was not deemed economic (James and Westervelt, 1970). Recent rock geochemical analyses confirmed elevated molybdenum and copper (Barresi, 2009). We observed molybdenite, pyrite, and rare chalcopyrite in quartz veins, fracture coatings, and as disseminations in altered wall rock. Mineralization is hosted in a biotite quartz diorite intrusion interpreted as a satellite stock of the Snowdrift Creek pluton (Fig. 20). Historical trenches in areas of overburden contain gossanous and yellow clay altered rocks; gossanous exposures extend ~1 km east and west of the showing.

## 7. Geochronology

U-Pb zircon and Ar-Ar mica analyses were carried out at the Pacific Centre for Isotopic and Geochemical Research (University of British Columbia). Re-Os molybdenite analyses were carried out at the Canadian Centre for Isotopic Microanalysis (University of Alberta). Preliminary results are presented in Table 4; detailed methods and final results will be reported elsewhere. Preliminary maximum depositional ages are calculated for LA-ICP-MS detrital zircon analyses using the weighted mean age of the youngest zircon population (excluding outliers). Future work will use methods of Ludwig (2012), and Dickinson and Gehrels (2009) to further constrain maximum depositional ages.

Takaichi (2013a; b) reported U-Pb zircon results from three Middle Jurassic intrusive rock samples; herein we also provide detailed field descriptions from the sample sites to accompany the geochronological data.

### 7.1. Lower to middle Jurassic stratified units

We sampled the Spatsizi Formation basal sandstone and conglomerate unit northwest of the Tanzilla River (Fig. 2). The sample (15BvS-03-14) returned a unimodal detrital zircon peak at 214.8 ±1.5 Ma (Fig. 21a), which overlaps with ages for the youngest phases of the Stikine plutonic suite (Table 2).

A sample of felsic lapilli tuff from the Horn Mountain lowermost mafic volcanic breccia unit (Fig. 2; Table 4) yielded a preliminary age age of 215.5 ±1.4 Ma (R. Friedman, pers. comm., 2016), which overlaps with ages from the youngest phases of the Stikine plutonic suite. Based on the presence of Early Jurassic fossils and zircon populations (Table 1) along strike we interpret the Late Triassic zircons as detrital.

A bed of polymictic conglomerate in a section of mafic volcanic breccias and flows of the Horn Mountain upper mafic volcanic unit was sampled in 2014 (sample 14MT-03-04). The conglomerate is quartz-sericite-chorite altered, locally foliated, and contains white plagioclase-phyric clasts, dark grey augite-

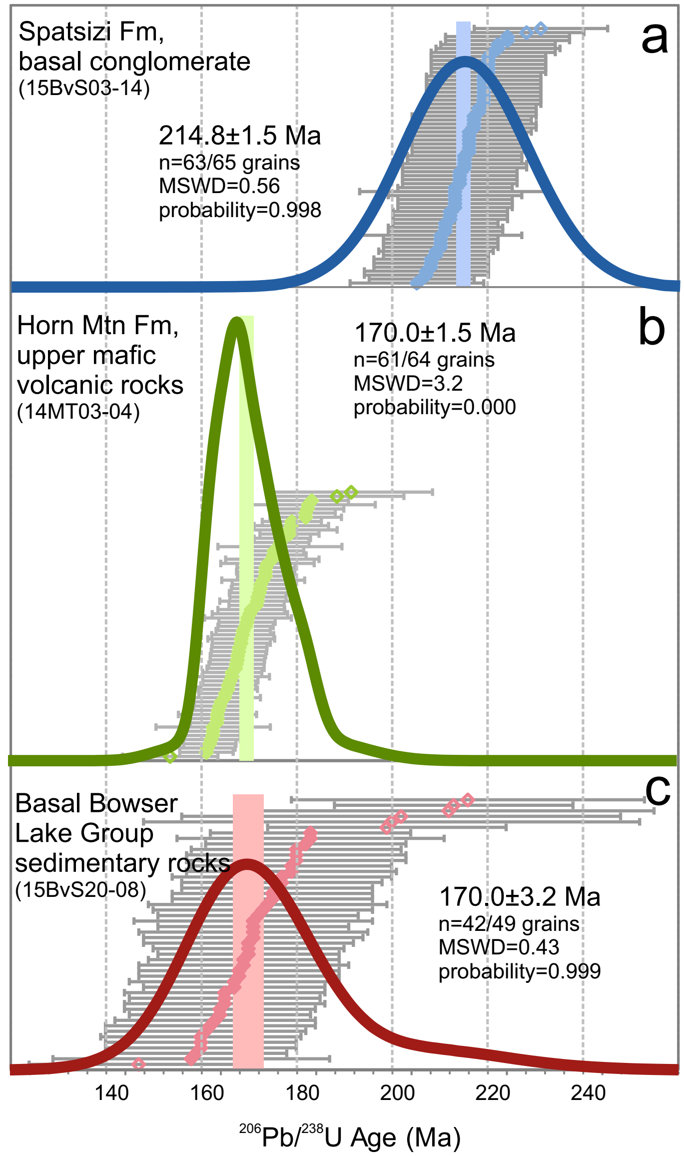


**Fig. 21.** Detrital zircon $^{206}Pb/^{238}U$ age distribution plots, probability curves, and preliminary maximum depositional ages for: **a)** Spatsizi Formation basal sandstone and conglomerate unit (lmJSPcg); **b)** Horn Mountain Formation upper mafic volcanic unit (mJHMUvm); and **c)** Bowser Lake Group sandstone and conglomerate unit (mJBLs). The $^{206}Pb/^{238}U$ ages are marked with coloured diamonds (open symbols are outliers excluded from age calculation) with two standard deviation analytical error represented by grey bars. The probability distribution is plotted with bold coloured lines and the mean age listed on the plots is represented by the coloured vertical line.

phyric mafic clasts, and cream-coloured silicified clasts. The latter clast type is likely derived from the Tanzilla alteration system. The sample returned an apparent unimodal detrital zircon peak with a preliminary maximum depositional age of 170.0 ±1.5 Ma (Fig. 21b). The preliminary maximum depositional age has a larger Mean Square Weighted Deviation (MSWD = 3.2) than expected for such a population (target MSWD = 1.37). This indicates that the scatter is greater than expected based on the precision of individual measurements,

**Table 4.** Geochronology results, sample descriptions and coordinates.

| | Sample no. | Unit | UTM | Type | Description | Population | Statistics | Age (Ma) |
|---|---|---|---|---|---|---|---|---|
| 1 | 14MT-03-04 *(lmJHMUvm)* | Horn Mnt Fm upper mafic volcanic | 461,900E 6,464,420N | U-Pb Zrn LA-ICP-MS | Polymictic conglomerate with white (felsic/silicified) clasts and Aug-Pl-phyric clasts | 61/64 analyses | MSWD=3.2 p=0.000 | 170.0 ±1.5 (MDA) |
| 2 | 15BvS-02-04 *(lmJSPv.po)* | Spatsizi Fm platy Pl-phyric volcanic | 461,753E 6,456,072N | - | Monomictic volcanic breccia with pale grey coarse platy Pl-phyric clasts | - | - | No Zrn |
| 3 | 15BvS-03-14 *(lmJSPcg)* | Spatsizi Fm sandstone and conglomerate | 461,607E 6,455,278N | U-Pb Zrn LA-ICP-MS | Polymictic conglomerate with plutonic clasts and pale aphyric volcanic clasts | 63/65 analyses | MSWD=0.56 p=0.998 | 214.8 ±1.5 (MDA) |
| 4 | 15BvS-14-05 *(LJSCgd)* | Snowdrift Creek pluton | 464,005E 6,463,656N | U-Pb Zrn CA-TIMS | Medium-grained equigranular Hbl-Bt tonalite | 4/4 grains | MSWD=1.02 p=0.38 | 160.43 ±0.16 |
| 5 | 15BvS-20-07 *(MJqd)* | Aug Qtz diorite | 461,054E 6,464,384N | Ar-Ar white mica | Intensely Qtz-Ser altered rock with coarse white mica | 4/14 steps 39.4% $^{39}Ar$ | MSWD=1.01 p=0.39 | 135.83 ±0.44 |
| | | | | | | 5/14 steps 16% $^{39}Ar$ | MSWD=0.97 p=0.42 | 144.6 ±1.9 |
| 6 | 15BvS-20-08 *(mJBLs)* | Bowser Lk Gp sandstone and conglomerate | 461,225E 6,464,919N | U-Pb Zrn LA-ICP-MS | Polymictic conglomerate and sandstone | 42/49 analyses | MSWD=0.43 p=0.999 | 170.0 ±3.2 (MDA) |
| 7 | TZ15-01 352.26-373.43m *(MJap)* | (Aug) Pl porphyry | 461,335E 6,464,490N | U-Pb Zrn CA-TIMS | Syn-hydrothermal Pl porphyry with 25% 1-3 mm Pl, locally 1-2 mm equant mafic grains visible. Chl-Ser-Py altered | 5/5 grains | MSWD=0.94 p=0.44 | 173.25 ±0.13 |
| 7 | TZ15-01 488.65-489.00m *(MJap)* | (Aug) Pl porphyry | 461,335E 6,464,490N | Re-Os Mo | Anh-Py-Mo vein in Qtz-Ser-Py altered Pl porphyry | - | - | Ages did not replicate |
| 8 | 16BvS-15-111a *(lmJHMLMvm)* | Horn Mnt Fm lowermost mafic volcanic | 468,732E 6,454,418N | U-Pb Zrn LA-ICP-MS | Felsic lapilli tuff with abundant aphyric to Pl-phyric clasts | 20/20 analyses | MSWD=0.80 p=0.71 | 215.5 ±1.4 (MDA) |

Sample numbers 1-8 correspond to labels in Fig. 2. UTM coordinates in NAD 83, zone 9 north. Mineral abbreviations after Kretz (1983); Ser = sericite; MDA = maximum depositional age. Age for TZ15-01 488.65-489.00 m reported in van Straaten and Nelson (2016).

suggesting that 1) all grains are not of the same true age, or 2) uncertainty is underestimated. The peak on the probability curve for this sample is ca. 168 Ma, suggesting that the maximum depositional age for this sample is at least as young as ca. 168 Ma.

A conglomerate near the base of the Bowser Lake Group north of Tanzilla (sample 15BvS-20-08) contains abundant clasts of plagioclase porphyry, some of which are pyritic. Analytical results show a unimodal detrital zircon peak with a preliminary maximum depositional age of 170.0 ±3.2 Ma (Fig. 21c).

### 7.2. Middle Jurassic intrusive units

Below we present field descriptions from three U-Pb LA-ICP-MS zircon geochronological sample locations reported by Takaichi (2013a; b).

Takaichi (2013a; b) described sample CNJ-0059 as a monzonite with propylitic chlorite alteration and reported an age of 172.75 ±0.07 Ma. The sample site exposes an unaltered equigranular medium-grained (2-4 mm) biotite-bearing hornblende quartz monzonite with microdiorite xenoliths that we consider part of the Three Sisters pluton central felsic phase.

Sample CNJ-0043, which was described as an unaltered syenite, yielded an age of 177.13 ±0.59 Ma (Takaichi, 2013a; b). At the sample site is an equigranular medium-grained (2-4 mm) biotite-bearing hornblende quartz monzodiorite with local weak epidote and chlorite alteration that we also consider part of the Three Sisters pluton central felsic phase. The reported age is unusually old for the Three Sisters plutonic suite, which has a typical age range of ca. 173-169 Ma (Table 2).

Takaichi (2013a; b) described sample CNJ-0054 as a monzonite with propylitic epidote alteration, and reported an age of 168.57 ±0.54 Ma. The lithology at the sample site is a biotite-bearing hornblende monzogranite with plagioclase, hornblende and biotite phenocrysts set in a fine-grained sugary groundmass that we include in the potassic phase of the Three Sisters pluton.

### 7.3. Late Jurassic intrusive units

A sample of medium-grained equigranular hornblende-biotite tonalite from the southwestern part of the Snowdrift Creek pluton returned a preliminary age of 160.43 ±0.16 Ma (Fig. 22).

### 7.4. Tanzilla alteration and mineralization

We attempted to establish the timing of alteration and mineralization at the Tanzilla prospect using U-Pb, Re-Os, and Ar-Ar geochronology. A syn-mineral augite-bearing plagioclase porphyry at Tanzilla (sample TZ15-01 352.26-373.43 m) returned a U-Pb zircon age of 173.25 ±0.13 Ma (Table 4; see van Straaten and Nelson; 2016).

We collected a sample of anhydrite-pyrite-molybdenite vein in quartz-sericite-pyrite altered plagioclase porphyry from drill hole TZ15-01 for Re-Os analysis (sample TZ15-01 488.65-489.00 m, Table 4; van Straaten and Nelson, 2016).

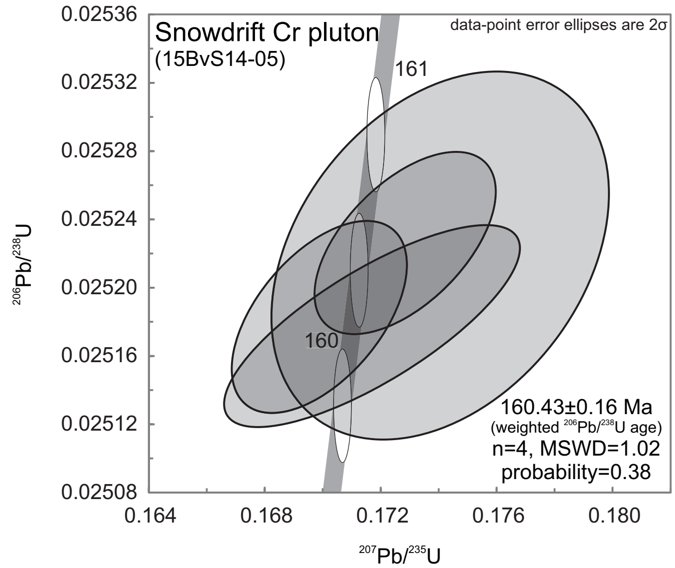


**Fig. 22.** Uranium-lead zircon concordia diagram showing chemical abrasion thermal ionization mass spectrometry results from the Snowdrift Creek pluton.

The analytical results did not properly replicate, and no final age could be calculated (R. Creaser, pers. comm., 2016). This indicates a heterogeneous molybdenite separate, which could have resulted from more than one molybdenite crystallization event.

A strongly quartz-sericite altered rock with coarse white mica was submitted for Ar-Ar analysis. The sample was collected 375 m northwest of the peak at Tanzilla, in a large advanced argillic alteration zone. The sample did not yield a robust plateau age (Fig. 23), suggesting that the rock has been disturbed. A

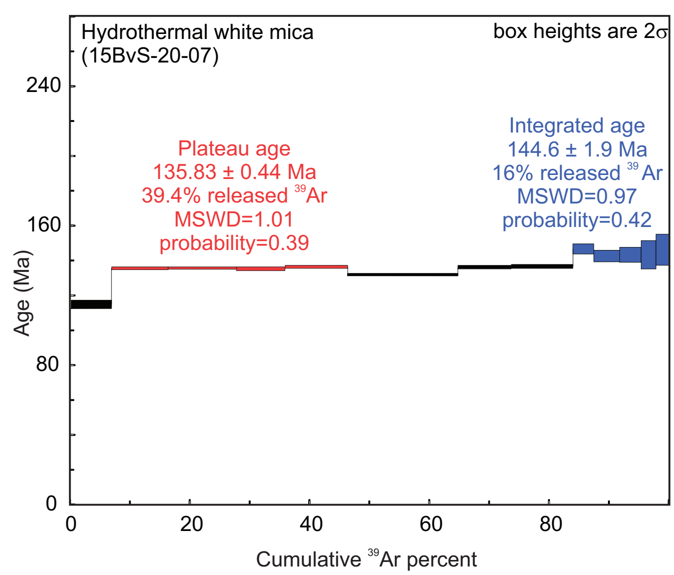


**Fig. 23.** White mica argon-argon step-heating spectrum from strongly quartz-sericite altered rocks at Tanzilla. This sample did not yield a robust plateau age. Weighted mean ages for younger and older steps are identified in red and blue, respectively.

preliminary plateau age of the younger steps (135.83 ±0.44 Ma) probably indicates the disturbance. An integrated age of the last five steps (144.60 ±1.9 Ma) only comprises 16% of the total $^{39}$Ar released, but may be related to the original age. These ages do not correlate with known Middle Jurassic (ca. 177-169 Ma), Late Jurassic (ca. 160-152 Ma) and Upper Cretaceous to Paleocene (ca. 65-63 Ma) intrusive ages in the region (see Table 2 and references therein). The closest age determinations are K-Ar cooling ages for the Snowdrift Creek pluton, which range from 160.8 ±2.5 Ma (hornblende), 157.8 ±2.4 Ma (biotite; Gabrielse, 1998), to 147 ±5 Ma (biotite; Stevens et al., 1982). We tentatively interpret that the disturbed ages represent resetting due to intrusion of the nearby Snowdrift Creek pluton, possibly followed by slow cooling.

## 8. Discussion

### 8.1. Regional extent and significance of the Horn Mountain Formation

The Horn Mountain Formation postdates widespread arc volcanism recorded in lower part of the Hazelton Group. Volcanic rocks are rare in the upper part of the Hazelton Group. In northern Stikinia, the upper part of the Hazelton Group consists mainly of Pliensbachian and younger sedimentary rocks assigned to the Nilkitkwa and Smithers formations in the south and the Spatsizi Formation in the north; both are succeeded by the Quock Formation (Gagnon et al., 2012). Volcanic rocks are mainly in a narrow, north-south oriented belt of tholeiitic pillow basalts, sedimentary rocks, and minor rhyolites assigned to the Iskut River Formation (Gagnon et al., 2012; Barresi et al., 2015a). This Middle Jurassic (Aalenian to Bajocian) succession is interpreted to have formed in a series of sub-basins that define the Eskay rift (Fig. 1). The Iskut River Formation contrasts markedly with the Horn Mountain Formation in lithology, depositional style, structural setting and lithogeochemistry (van Straaten and Nelson, 2016). The Horn Mountain Formation represents a unique volcanic sequence in the upper part of the Hazelton Group. It is coeval with accretion of the Stikine and Cache Creek terranes, and so far, similar volcanic successions have not been documented elsewhere in northern Stikinia. Evaluation of the regional literature indicates that the Horn Mountain Formation may continue for up to 110 km, as a west-northwest to east-southeast trending belt along and near the northeastern margin of Stikinia (Fig. 1; van Straaten and Nelson, 2016).

### 8.2. Alteration and mineralization

At least three magmatic-hydrothermal events are recognized in the map area. The first event was responsible for porphyry copper mineralization in the Gnat Pass and Moss area (Fig. 20). The occurrences are in, or immediately adjacent to, plagioclase porphyry intrusions (Late Triassic; Table 2). Porphyry-style tourmaline-K-feldspar alteration and chalcopyrite mineralization extends for 4.3 km in a west-northwest direction. The WNW-trending hydrothermal veins and breccia zones, east-west elongate Cake Hill pluton, and north-trending Gnat Pass reverse shear zone are compatible with north-south extension. The 1.2 billion tonne Schaft Creek porphyry copper deposit (Fig. 1; Scott et al., 2008; Farah et al., 2013) shares several characteristics with the Gnat Pass and Moss porphyry occurrences. Both have a Late Triassic age, contain copper and minor molybdenum and gold, host appreciable tourmaline, are located immediately adjacent to a several thousand square kilometre Late Triassic pluton, and show veins and hydrothermal breccia zones that trend parallel to the long axis of the adjacent batholith.

Several alteration zones in Horn Mountain volcanic rocks are attributed to a Middle Jurassic magmatic-hydrothermal event, including porphyry-style alteration at Tanzilla and McBride (Fig. 20). At Tanzilla, advanced argillic alteration overlies intermediate argillic, argillic and phyllic assemblages. In deep drilling, rare potassic mineral assemblages and anomalous copper and molybdenum values were intersected. The McBride mineral occurrence displays widespread surface quartz-sericite-pyrite alteration with local potassic alteration. The zone of advanced argillic alteration at Tanzilla is at the contact between the middle maroon volcanic and upper felsic volcanic unit (van Straaten and Nelson, 2016). This year's mapping found that the zone of advanced argillic alteration extends for at least 17 km from Tanzilla to the new Straight-across mineral occurrence (Fig. 20). The Gopher zone, Mo east to Straight-up segment of the alteration zone is variably sheared, and – where identifiable – the protolith is a coarse platy plagioclase porphyry. We tentatively interpret the Gopher, Mo east, Straight-up and Straight-across zones to be formed by fluid channelling along a local unconformity or fault zone. The advanced argillic lithocap formed by acidic fluids related to possible porphyry-fertile intrusions at depth. In addition to porphyry-style and advanced argillic alteration zones, epithermal veins are found at the And ginger and Wolf showings. They may have been cogenetic with the porphyry occurrences.

Before studies in the Tanzilla and McBride area, no Middle Jurassic porphyry-style mineral occurrences had been documented in the Canadian Cordillera. Based on mapping and geochronological studies at Tanzilla, van Straaten and Nelson (2016) proposed that this magmatic event represents a potential new metallogenic epoch prospective for porphyry- and epithermal-style mineralization. Notably, copper-gold mineralization hosted in the Teslin Crossing pluton at Mars (65 km northeast of Whitehorse, Yukon; New Dimension Resources Ltd., 2012) has recently been reported to be Middle Jurassic (Colpron et al., 2016a); it may provide further support for a Middle Jurassic porphyry-style metallogenic epoch in the Canadian Cordillera.

A third magmatic-hydrothermal event is represented in the Snowdrift Creek pluton (Late Jurassic) and an interpreted satellite stock. These include the Nup, Mo and Joyce showings (Fig. 20); all are characterized by quartz-molybdenite±chalcopyrite veins and molybdenite-coated fractures associated with variable alteration styles.

### 8.3. Tectonic evolution and origin of the Horn Mountain Formation

During the Mesozoic, three main phases of magmatic arc development took place in Stikinia, punctuated by collisional events. The Stuhini arc (Late Triassic) was succeeded by the latest Triassic to Early Jurassic main-stage Hazelton arc. The youngest, Toarcian to Late Jurassic, arc is represented by widespread volcanic rocks in southern and central Stikinia (Fig. 1).

During the Late Triassic, voluminous magmatism was predominant along the northern to eastern margin (current reference frame) of Stikinia, resulting in eruption of Stuhini Group augite-phyric mafic volcanic rocks and intrusion of the Stikine plutonic suite (Woodsworth et al., 1991). The arc likely formed as a result of subduction below the northern to eastern margins of Stikinia (Nelson and Mihalynuk, 1993; Mihalynuk et al., 1994; Colpron et al., 2015). Profound plate rearrangement at the end of the Triassic is marked by the cessation of volcanism on the northern margin of Stikinia, followed by arc uplift and erosion. At this time, the northern end (present coordinates) of Stikinia collided with far northern Quesnellia and the Yukon-Tanana terrane, with strata of the Whitehorse trough deposited across all three terranes and adjacent parts of the Cache Creek terrane (Johannson et al., 1997; Mihalynuk et al., 2004; Colpron et al., 2015).

Reconfigured subduction in the latest Triassic to Early Jurassic created two belts of arc-related lower Hazelton Group volcanic rocks in north-central Stikinia south of the Pitman fault. The volcanic arcs are interpreted to have formed by opposing subduction on either side of the Stikinia microplate, creating a western and eastern volcanic belt separated by a central belt of predominantly sedimentary rocks interpreted as the Hazelton trough (Fig. 1; Marsden and Thorkelson, 1992). Volcanism waned in the Pliensbachian and ended in the late Toarcian (Alldrick, 1993; Brown et al., 1996; Barresi et al., 2015b) as Stikinia accreted with neighbouring terranes to the east and west (Nelson et al., 2013). A final episode of arc-related volcanism in Toarcian-Callovian time created a belt of volcanic and intrusive rocks in central and southern Stikinia (Fig. 1; Tipper and Richards, 1976; Diakow and Webster, 1994; MacIntyre et al., 2001). The Horn Mountain Formation rocks are coeval with the youngest arc succession, but the formation is near the northeastern margin of the terrane, close to the Cache Creek-Stikinia suture.

Timing of the Cache Creek-Stikinia collision is constrained as late Early to Middle Jurassic. The youngest Cache Creek cherts that have been overprinted by blueschist-facies, sodic amphibole-bearing metamorphic assemblages are Pliensbachian to Toarcian (Mihalynuk et al., 2004). Argon-argon cooling ages on phengite in blueschist mineral assemblages indicate that the central part of the orogenic welt was exhumed by 173.7 ±0.8 Ma (Aalenian; Mihalynuk et al., 2004). Deposition of Cache Creek-derived chert clast-bearing conglomerate in the Bowser Basin started in the early Bajocian (Ricketts et al., 1992). Thus, the Cache Creek accretionary complex became the site of a southwest-vergent tectonic welt that began to shed debris into the Bowser foreland basin in the early Bajocian (ca. 169 Ma).

The Horn Mountain Formation volcanic rocks and their local correlatives were probably not the products of normal subduction-related arc magmatism for several reasons. First, subduction was not taking place below northern Stikinia at the time of collision. Subduction below the northern margin of Stikinia ceased in the Late Triassic, followed by slab breakoff soon thereafter (Logan and Mihalynuk, 2014). Subduction below the western and eastern margins of Stikinia waned in the Pliensbachian and ended in the Toarcian. Second, the Horn Mountain Formation rocks are younger than any known volcanic successions of arc affinity in northern Stikinia. In the north, rocks of the upper part of the Hazelton Group are either mainly sedimentary (Spatsizi and Quock formations), or of bimodal volcanic-sedimentary character (Iskut River Formation in the Eskay rift). Third, the Horn Mountain volcanic succession is in the foreland adjacent to the Stikinia-Cache Creek collisional boundary (King Salmon fault), and was erupted between ca. 176 and 169 Ma, during collision. They interfinger with synorogenic clastic strata of the Bowser Lake Group (van Straaten and Nelson, 2016), and are intruded by a 173-160 Ma belt of plutons that cut the Stikinia-Cache Creek suture zone. Lithogeochemical data show that the Middle Jurassic calc-alkaline plutons (Mihalynuk et al., 1992; van Straaten et al., 2012) and Horn Mountain Formation (Logan and Iverson, 2013; B. van Straaten et al., unpublished data) are of volcanic arc chemistry. We put forward the preliminary hypothesis that the Horn Mountain Formation formed by re-melting of subduction-modified lithosphere due to collision between the Stikine and Quesnel terranes. Similar to typical subduction-related arc volcanism, postsubduction (syncollisional) arc-like volcanism has been shown to produce porphyry- and epithermal-style mineral deposits (Richards, 2009).

## 9. Conclusions

The Horn Mountain Formation, a previously poorly understood volcanic succession on the northeastern margin of Stikinia, hosts several early-stage porphyry copper exploration projects. Geological mapping and preliminary geochronology indicate that the oldest rocks in the field area are mafic volcanic rocks of the Stuhini Group (Triassic), cut by the Cake Hill pluton (Late Triassic). An at least 50 km-long regional unconformity cuts into the Cake Hill pluton. It represents one of the few well-documented examples of unroofed Stuhini arc in northern Stikinia.

The erosional surface is overlain by a moderately north-northeast dipping volcano-sedimentary succession assigned to the upper part of the Hazelton Group. It includes a lower (up to 1 km-thick) sedimentary sequence grouped with the Spatsizi Formation, and an upper (up to 5.4 km-thick) volcanic sequence assigned to the Horn Mountain Formation. The volcanic rocks are unusual within northern Stikinia as they postdate widespread arc volcanism of the lower part of the Hazelton Group, are coeval with deposition of predominantly sedimentary rocks of the upper part of the Hazelton Group, and are concurrent with accretion of the Stikine and Cache Creek terranes. Sedimentary rocks of the Spatsizi Formation (late Pliensbachian to Toarcian) grade laterally and vertically to mafic volcanic breccia and rare pillows of the lower part of the Horn Mountain Formation. They were, at least in part, deposited in a subaqueous environment. Overlying interlayered flows, volcanic breccia and tuff of the middle maroon volcanic unit represent increasingly higher volume volcanism that led to formation of a subaerial volcanic edifice. Lower and middle units are cut by cogenetic feeder dikes and intrusions. During an erosional hiatus in volcanism the volcanic units were cut and hydrothermally altered by a 173 Ma (Aalenian) porphyry intrusion. An upper mafic volcanic unit (Bajocian) caps the succession. The Horn Mountain Formation is unconformably overlain by Bowser Lake Group conglomerates (Bajocian) and cut by the Three Sisters pluton (ca. 173-169 Ma)

The Horn Mountain Formation hosts two early-stage porphyry projects. At Tanzilla, an advanced argillic lithocap overlies porphyry-style alteration at depth. At the McBride mineral occurrence widespread quartz-sericite-pyrite and local potassic alteration is associated with elevated copper and gold. Our field studies have extended the advanced argillic alteration at Tanzilla for at least 17 km along strike. It is interpreted as a lithocap formed by acidic hydrothermal fluid flow along an unconformity or fault in the upper part of the Horn Mountain Formation.

The Kehlechoa thrust fault places siliciclastic rocks of the Whitehorse trough (Takwahoni Formation, Pliensbachian) above the Horn Mountain Formation and Bowser Lake Group. The hanging wall panel is internally folded and imbricated. Regionally, the sedimentary rocks record unroofing of the Stuhini arc. The Snowdrift Creek pluton (Late Jurassic) cuts the Kehlechoa fault, and constrains movement on the foreland thrust of the Stikine-Quesnel accretionary welt to ca. 170-160 Ma.

The Horn Mountain Formation and Three Sisters plutonic suite are coeval with accretion of the Stikine and Quesnel island arcs. The syncollisional Middle Jurassic magmatic event represents a potential new metallogenic epoch for the Canadian Cordillera and is prospective for porphyry- and epithermal-style mineralization.

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