Syncollisional late Early to early Late Jurassic volcanism, plutonism, and porphyry-style alteration on the northeastern margin of Stikinia

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Abstract
A previously enigmatic Jurassic volcanic succession on the northeastern margin of Stikinia hosts several early-stage mineral exploration projects, including the Tanzilla porphyry system. Based on new field mapping and preliminary lithogeochemical and geochronological data, we consider these rocks as part of the Hazelton Group and formally define them as the Horn Mountain Formation. The Horn Mountain Formation (ca. 5.4 km thick) consists mainly of green to maroon augite±plagioclase-phyric trachybasalt to trachybasaltic andesite volcanic breccias and lesser plagioclase-phyric to aphyric trachyte to trachyandesite, and is cut by numerous, roughly coeval subvolcanic feeder dikes, sills and stocks. It conformably overlies Toarcian sedimentary rocks of the Spatsizi Formation, which unconformably overlies the Cake Hill pluton (Late Triassic). The Horn Mountain Formation is overlain both conformably and unconformably by Bajocian sedimentary rocks of the Bowser Lake Group. Petrographic observations and major element lithogeochemistry indicate that the volcanic rocks and related subvolcanic intrusions are largely quartz deficient, K-feldspar-rich and alkaline in composition. Regional evaluation indicates that the Horn Mountain Formation extends for least 50 km, and perhaps 110 km, in a west-northwest to east-southeast trending belt that parallels the King Salmon thrust, at the boundary between the Stikine and Cache Creek terranes. A revised structural interpretation extends the Kehlechoa thrust to juxtapose rocks of the Whitehorse trough above Toarcian to Bajocian rocks of the Horn Mountain Formation and Bowser Lake Group. The Snowdrift Creek pluton (early Late Jurassic) stitches the fault and constrains movement to Bajocian-Oxfordian. At the Tanzilla gossan, an advanced argillic lithocap overlies porphyry-style alteration at depth. We report a preliminary 173 Ma U-Pb zircon age for the calc-alkaline plagioclase porphyry that hosts porphyry-style alteration. The alkaline Horn Mountain Formation, calc-alkaline Tanzilla intrusions, Three Sisters plutonic suite, and Snowdrift Creek pluton formed during Stikine-Quesnel arc-arc collision. The protracted late Early to early Late Jurassic syncollisional magmatism represents a potential new metallogenic epoch for the Canadian Cordillera, and is prospective for calc-alkalic to alkalic porphyry- and epithermal-style mineralization.

Keywords: Horn Mountain Formation, Spatsizi Formation, Hazelton Group, Three Sisters plutonic suite, Snowdrift Creek pluton, Takwahoni Formation, Kehlechoa fault, Jurassic, Tanzilla, lithocap, advanced argillic alteration, porphyry copper, Stikinia, arc-arc collision

1. Introduction

This paper focuses on a volcano-sedimentary succession east of Dease Lake (northern Stikinia; Fig. 1) that hosts the Tanzilla porphyry copper prospect. 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). To clarify the age and nature of this volcano-sedimentary sequence and to establish a geological framework for alteration and mineralization at Tanzilla, we conducted one month of 1:20,000-scale mapping and stratigraphic analysis northeast of the Tanzilla River, between Gnat Pass and the Tanzilla River, north of Glacial Lake, and east of the McBride River (Figs. 2, 3). Herein we provide the first detailed description of this previously enigmatic volcanic sequence, supported by preliminary igneous rock geochemistry and geochronology. This work demonstrates that the succession represents an unusual late Early to Middle Jurassic volcanic episode coeval with accretion of the Stikine and Cache Creek terranes. Thus far, similar volcanic successions have not been documented elsewhere in northern Stikinia (Fig. 1). We formally define this unit the Horn Mountain Formation, in the upper part of the Hazelton Group, and suggest it extends for at least 50 km, and perhaps 110 km, along the northeastern margin of Stikinia.

2. Geological setting

The study area is near the northeastern margin of the Stikine terrane (Stikinia, Fig. 1), an island arc complex that was accreted to ancestral North America during the Middle Jurassic (Nelson and Mihalynuk, 1993; Mihalynuk et al., 1994; Nelson et al., 2013). The basement of Stikinia contains carbonate and volcanic rocks of the Stikine assemblage (Devonian to Permian) that are overlain by volcanic and related sedimentary rocks of the Stuhini Group (Triassic) and the Hazelton Group (Early to Middle Jurassic; Marsden and Thorkelson, 1992; Currie and Parrish, 1997). The Canadian Cordilleran tectonic

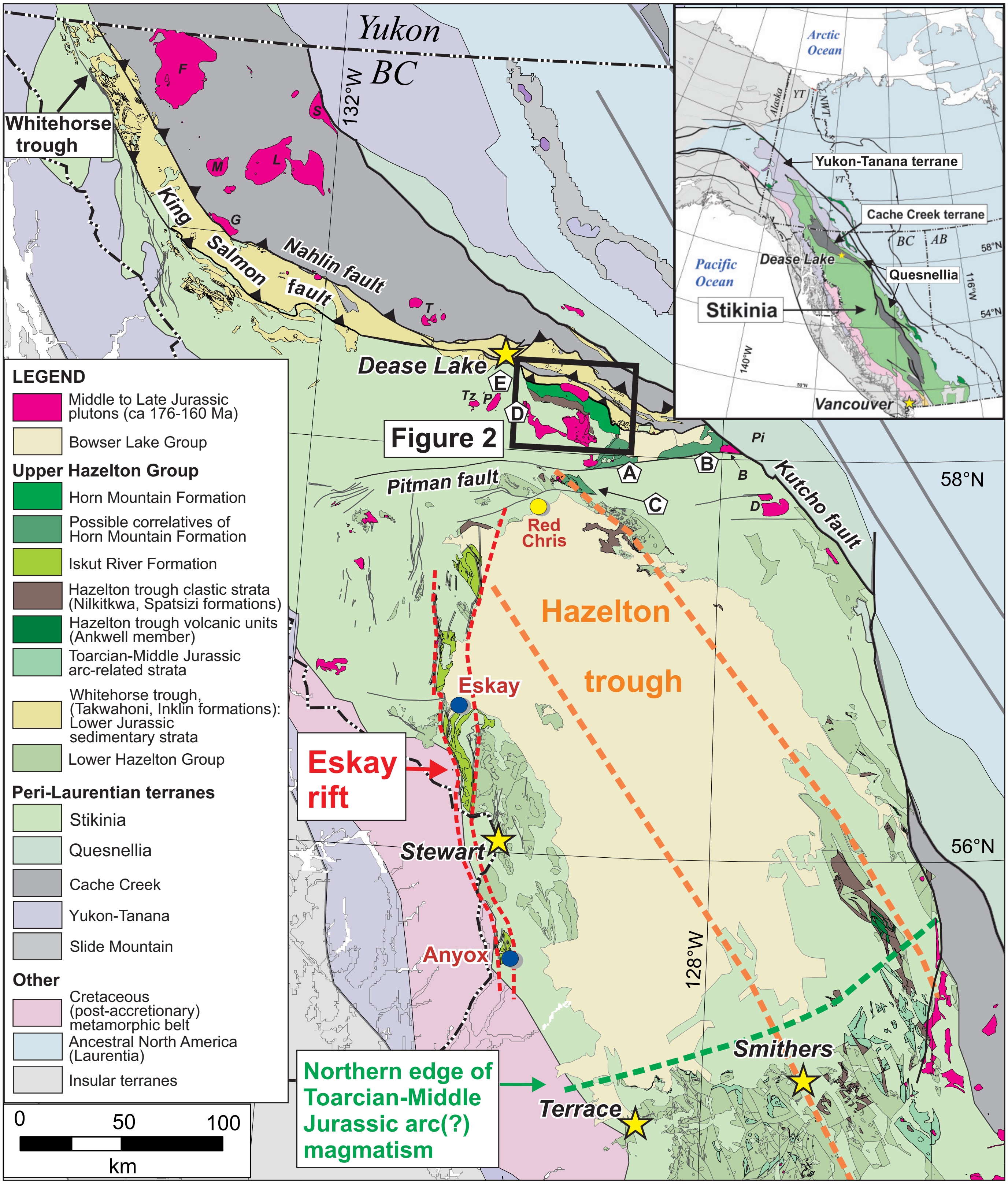


Fig. 1. Geology of northern Stikinia, with emphasis on Middle to Late Jurassic geology and tectonic elements. Boundary of Hazelton trough from Marsden and Thorkelsen (1992); boundary of Eskay rift from Gagnon et al. (2012). Possible correlatives of the Horn Mountain Formation (new volcanic unit proposed herein) are in areas labelled with pentagons 'A' to 'E'. Middle to early Late Jurassic intrusions include F: Fourth of July; S: Slaughterhouse; M: McMaster; L: Llangorse; T: Tachilta Lakes; G: Granite Lake; Tz: Tanzilla; P: Pallen; B: Mt. Blair; D: Mt. Albert Dease; Pi: Pitman.

collage includes the Quesnel terrane (Quesnellia), a volcanic arc with a similar Devonian to Early Jurassic history as Stikinia. The two volcanic arcs are separated by the Cache Creek terrane, an accretionary complex of oceanic crustal rocks, primitive arc ophiolite, pelagic rocks and carbonate rocks (Fig. 1). Combined, Stikinia and Quesnellia host most of the porphyry copper deposits in the Canadian Cordillera (Logan and Mihalynuk, 2014).

The previously enigmatic volcano-sedimentary succession for which we propose the name Horn Mountain Formation (see Section 3.1.2.2.) is exposed in a northwesterly trending belt, about 50 km long and 10 km wide, north and northeast of the Hotailuh batholith (Fig. 2). The succession is on Stikinia, bounded to the north and northeast by the Kehlechoa thrust fault, which separates it from rocks of the Whitehorse trough (Takwahoni Formation) to the north (Fig. 2). The succession is bounded to the west by the Gnat Pass and related faults; its southeastern extent is unknown. Farther northeast, Cache Creek terrane rocks in the hanging wall of the north-dipping King Salmon thrust structurally overlie the Takwahoni Formation (Fig. 2).

The succession unconformably overlies Late Triassic rocks of the Cake Hill pluton, and early workers considered it a part of the Takwahoni Formation (Lower Jurassic) structurally overlain by volcano-sedimentary rocks of the Stuhini Group (Triassic) on an inferred thrust (Hotailuh fault; Anderson, 1983; Gabrielse, 1998). However, recent work by Iverson et al. (2012) demonstrated that rocks previously mapped as part of the Stuhini Group contain Early to Middle Jurassic detrital zircons (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. 3; Iverson et al., 2012; van Straaten et al., 2012).

3. Lithostratigraphic units

Rocks in the study area define two tectonostratigraphic domains. Stratigraphic units in the footwall of (south of) the Kehlechoa fault are part of Stikinia; those in the hanging wall (north) are part of the Whitehorse trough (Fig. 2). Most unit descriptions (Table 1) are based on detailed mapping of an area northeast of the Tanzilla River (Figs. 2, 3). We also examined the areas: 1) between Gnat Pass and the Tanzilla River; 2) east of the McBride River; and 3) north of Glacial Lake. Classifications for igneous rocks (Gillespie and Styles, 1999) and sedimentary rocks (Hallsworth and Knox, 1999) are used throughout the following.

3.1. Stikinia

Uniformly north-dipping stratified rocks are present between the Hotailuh batholith and Kehlechoa fault (Figs. 3, 4). As discussed below, we assign the lower predominantly sedimentary succession to the Spatsizi Formation of Thomson et al. (1986) as modified by Evenchick and Thorkelson (2005) and Gagnon et al. (2012). The Spatsizi Formation is overlain by predominantly volcanic rocks of the Horn Mountain Formation (new name, see below). Both formations belong to the upper part of the Hazelton Group as described by Gagnon et al. (2012). In the detailed study area, the Horn Mountain Formation is unconformably overlain by gently north-dipping sedimentary rocks of the Bowser Lake Group.

3.1.1. Stuhini Group (Triassic)

Stuhini Group volcanic rocks were not mapped as part of this study, but a description is included here to document the similarity to the mafic volcanic rocks now assigned to the Horn Mountain Formation. The nearest unequivocal exposures of Stuhini Group are immediately southwest of the study area near Gnat Pass (Fig. 2). Here, poorly exposed dark green, massive augite- and lesser augite-plagioclase-phyric flows, volcanic breccia, tuffaceous conglomerate, volcaniclastic sandstone and siltstone are cut by Late Triassic intrusions (Table 1; Anderson, 1983; Gabrielse, 1998; van Straaten et al., 2012).

3.1.2. Hazelton Group (Lower to Middle Jurassic)

3.1.2.1. Spatsizi Formation

The Spatsizi Group was originally defined by Thomson et al. (1986) based on investigations in the Spatsizi area, ca. 50 km south of the current study area (Area 'C', Fig. 1). The unit was demoted to formational status by Evenchick and Thorkelson (2005) based on its limited geographic extent and to allow inclusion in the Hazelton Group. Gagnon et al. (2012) further modified the Spatsizi Formation to exclude the uppermost Quock Member, a regionally extensive interbedded siliceous mudstone and tuff unit commonly found immediately below Bowser Lake Group sedimentary rocks. They proposed raising the Quock to formational status. The revised Spatsizi Formation comprises shale with minor siltstone, sandstone, tuffaceous beds, conglomerate and limestone; it is Pliensbachian to Aalenian (Thomson et al., 1986; Evenchick and Thorkelson, 2005; Gagnon et al., 2012).

On a more regional scale, the Spatsizi Formation has been correlated with the predominantly siliciclastic Nilkitkwa Formation described east and northeast of Smithers (Fig. 1). The north-northwest trend of siliciclastic rocks of the Spatsizi and Nilkitkwa formations records Pliensbachian to Toarcian marine sedimentation in a back-arc depression (Hazelton trough; Tipper and Richards, 1976; Marsden and Thorkelson, 1992; Gagnon et al., 2012).

The 0.7-1 km thick lower sedimentary sequence between the Hotailuh batholith and Kehlechoa fault (Figs. 3, 4; Table 1) shares many lithological characteristics with the Spatsizi Formation. Both consist mainly of fine-grained siliciclastic rocks, and the Toarcian and younger age of the lower sedimentary sequence in the study area overlaps with published ages for the Spatsizi Formation elsewhere. As a result, we include the lower sedimentary sequence in the Spatsizi Formation. This sequence consists of three main units (Table 1).

In the basal conglomerate unit, subfeldspathic arenites (>75% quartz grains), conglomerate, and quartz-rich feldspathic arenite unconformably overlie the Cake Hill pluton

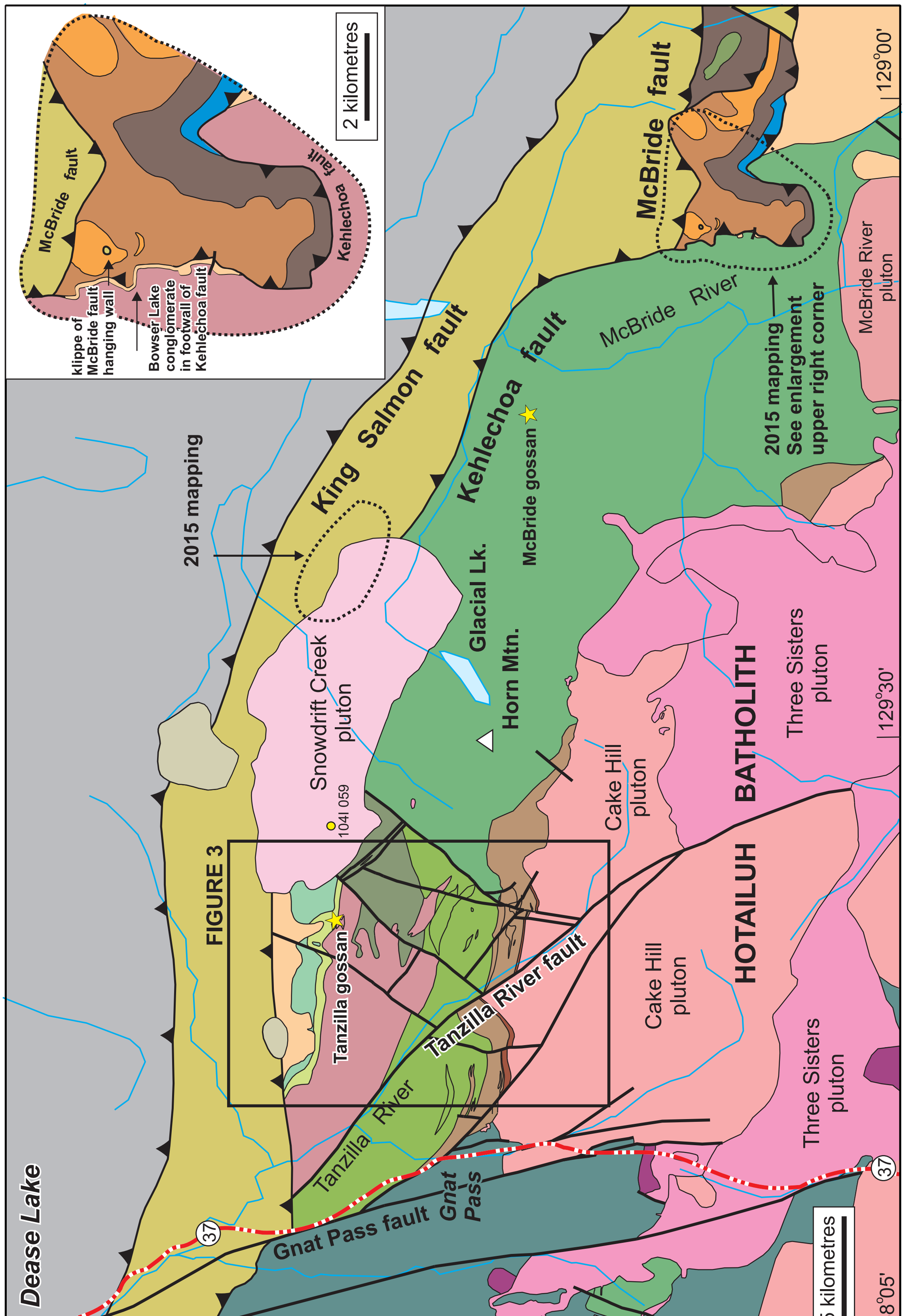


Fig. 2. Regional geology, modified after Gabrielse (1998), Logan et al. (2012b) and van Straaten et al. (2012). See Figure 1 for location. A possible correlative of the Horn Mountain Formation (new volcanic unit proposed herein) is in area 'D'.

LEGEND

Post-accretionary overlap strata

Miocene-Pleistocene Tuya Formation

- Olivine basalt

Syn- to post-accretionary Middle to Late Jurassic plutons

- Snowdrift Creek Pluton ca 160-161 Ma: granodiorite, tonalite
- Three Sisters Pluton ca 170 Ma: diorite, quartz monzonite, granite

Cache Creek terrane

- Undivided: Late Permian-Early Triassic Kutcho arc sequence, Inklin Formation; ultramafite, basalt, chert, argillite, limestone

King Salmon fault

Whitehorse trough

Lower Jurassic Takwahoni Formation

- Toarcian mudstone, minor sandstone and conglomerate
- Toarcian conglomerate
- Pliensbachian greywacke, mudstone, minor conglomerate
- Sinemurian? Toarcian? andesitic volcanics
- Sinemurian conglomerate, sandstone, siltstone, mudstone

Upper Triassic Sinwa Formation

- Upper Norian limestone

Kehlechoa fault

Stikinia

Middle Jurassic (Bajocian)

- Bowser Lake Group

Lower to Middle Jurassic Upper Hazelton Group

Middle Jurassic Horn Mountain Formation

- Upper mafic volcanics
- Upper felsic volcanics

Early to Middle Jurassic Horn Mountain intrusions

- Mafic intrusive complex

Lower to Middle Jurassic Horn Mountain Formation

- Maroon volcanic rocks
- Lower mafic volcanic rocks
- Undivided; also includes cogenetic mafic intrusions

Lower Jurassic (Toarcian) Spatsizi Formation

- Undivided sedimentary and volcaniclastic strata
- Basal conglomerate

Early Jurassic

- McBride River Pluton granodiorite

Late Triassic

- Cake Hill Pluton: quartz monzodiorite, granodiorite, plag(-qtz) porphyry

Late Triassic

- Gnat Lakes ultramafite pyroxenite, hornblendite, gabbro

Triassic

- Stuhini Group, undivided

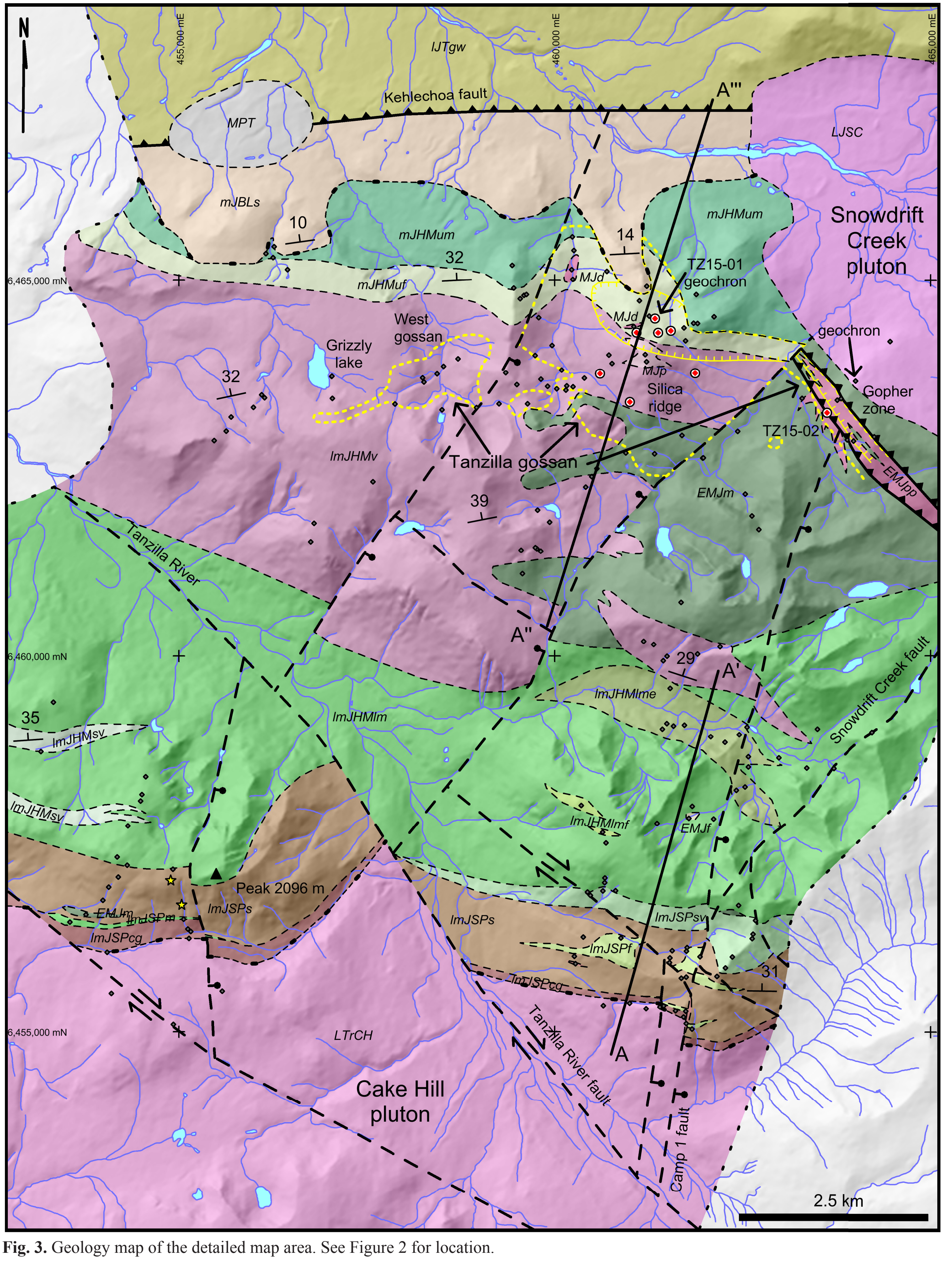
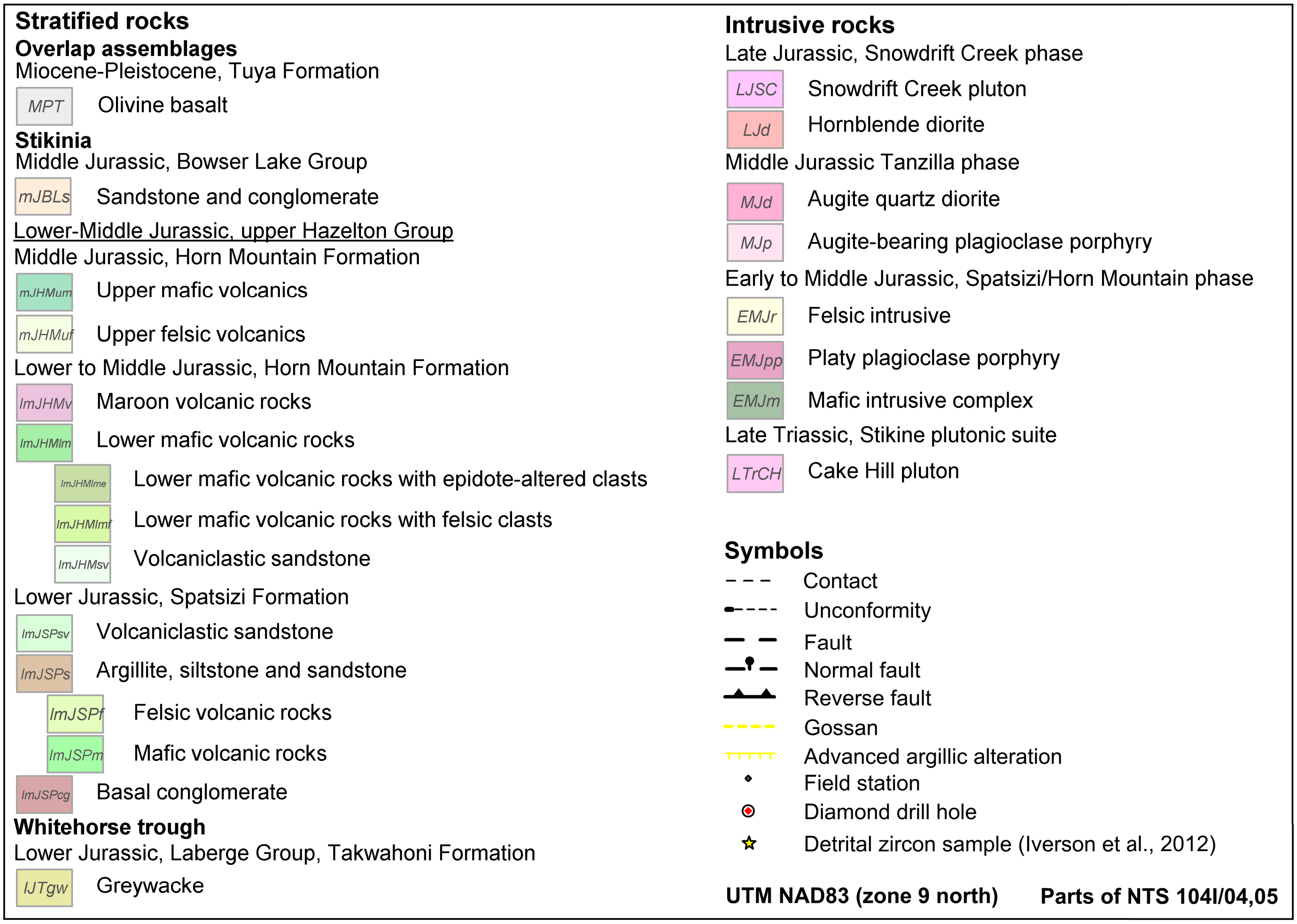


Fig. 3. Geology map of the detailed map area. See Figure 2 for location.



(Late Triassic; Anderson, 1983; Gabrielse, 1998; van Straaten et al., 2012; this study). The conglomerate contains common plutonic clasts of similar composition as the underlying Cake Hill pluton. A calcareous feldspathic arenite bed contains early Toarcian fossils (Henderson and Perry, 1981).

This basal unit fines upward to a unit of argillite, siliceous siltstone, and fine-grained sandstone with minor grey tuff laminae, subordinate mono- to polymictic volcanic breccia intervals, and rare volcaniclastic sandstone (Fig. 5). Detrital zircon samples from this succession yielded Early-Middle Jurassic and Late Triassic age peaks (Iverson et al., 2012). The unit contains two volcanic subunits, felsic coarse platy plagioclase-phyric volcanic breccias northeast of the Tanzilla River (Fig. 6), and a mafic augite-phyric breccia body southwest of the Tanzilla River.

The volcaniclastic unit, at the top of the Spatsizi Formation northeast of Tanzilla River, consists mainly of medium- to coarse-grained volcaniclastic sandstone with lesser siltstone and fine tuff laminae, and subordinate augite-phyric or plagioclase-phyric monomictic volcanic breccia. The contact with the underlying unit is gradational.

3.1.2.2. Horn Mountain Formation (new name)

We propose that the upper, predominantly volcanic succession between the Hotailuh batholith and Kehlechoa fault be called the Horn Mountain Formation, a new formation in the upper part of the Hazelton Group (Figs. 2, 3; Table 1). At its type section (Table 2), the sequence is approximately 5.4 km thick (Fig. 4) and comprises four informal subdivisions. It is middle Toarcian to early Bajocian, based on fossils collected from the underlying Spatsizi Formation and overlying Bowser Lake Group strata. As described below, its base is a transitional contact above the Spatsizi Formation. Its upper contact with Bowser Lake Group conglomerates is unconformable in the detailed map area, and conformable and gradational east of the McBride River. We consider that it extends at least to the first range of mountains east of the McBride River (Fig. 2), based on our work there and on regional mapping by Gabrielse (1998), which included a 684 m-thick stratigraphic section west of the McBride River entirely composed of maroon volcanic rocks (Gabrielse, 1998, p. 126). The Horn Mountain Formation continues along strike for over 50 km.

The Horn Mountain Formation consists of four main units (Figs. 3, 4; Table 1). The lower mafic volcanic unit contains

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

Age	Unit		Description	Position
Miocene-Pleistocene		Tuya Formation	**Olivine basalt (MPT)** (Gabrielse, 1998)	Overlap
Lower Jurassic	Laberge Group	Takwahoni Formation	**Greywacke (lJTgw).** Interbedded feldspathic wacke, siltstone, argillite, rare feldspathic arenite and rare calcareous feldspathic arenite. Contains common (5%) Qtz grains and minor grey mudstone rip-up clasts. Local predominantly monomictic cobble conglomerate with Hbl diorite clasts. Pliensbachian	Whitehorse trough (N panel)
Lower Jurassic	Laberge Group	Takwahoni Formation	**Argillite and siltstone (lJTs**). Black cherty grey argillite and siltstone, well-stratified, some thinly laminated. Contains minor volcaniclastic sandstone with mainly Pl, lesser Qtz and lithic grains. Minor lighter coloured tuff laminae. Recessive, dark grey-black weathering; forms blocky scree. Toarcian **Upper polymictic conglomerate (lJTucg).** Disorganized polymictic cobble-boulder conglomerate. Common rounded to subangular clasts of light grey recrystallized limestone and black mudstone-siltstone intraclasts. Lesser clasts with 40% 0.5-2 cm equant Pl and 15% 2-3 mm Aug crystals. Minor Aug-Pl-phyric and Pl-phyric clasts. Locally common clasts of equigranular (1-2 mm) Hbl diorite. Rare clasts of Qtz-rich very coarse-grained feldspathic arenite to granule conglomerate, and Qtz diorite clasts with 15% 3-4 mm Qtz eyes. Conglomerate commonly as m- to 100 m-scale blocks and lenses in disrupted bedded to laminated black argillite to dark grey siltstone and feldspathic wacke. Resistant, dark grey weathering. Conglomerate weathers in positive relief relative to enclosing finer grained rocks. Toarcian **Lower polymictic conglomerate (lJTlcg).** Polymictic conglomerate with clasts of limestone (up to 1 m), feldspar porphyry, granitic rock, chert, and argillite. Transitions laterally to black to dark grey shale-tuff beds. Overlain by green andesitic to coarse basaltic breccia, minor tuff, and rare pebble conglomerate (Gabrielse, 1998). Sinemurian	Whitehorse trough (SE panel)
Upper Triassic		Sinwa Fm	**Limestone (uTrS).** Massive limestone with smooth-shelled pelecypods and poorly preserved corals (Gabrielse, 1998). Moderately resistant, white to light grey weathering. Upper Norian	
Middle Jurassic	Bowser Lake Group		**Undivided (mJBL).** Shale, siltstone, tuffaceous shale, feldspathic wacke, breccia, and thick-bedded chert clast-bearing pebble to cobble conglomerate with clasts of green and red radiolarian chert, limestone with fusulinids, aphanitic to porphyritic volcanic rocks and cream-weathering volcanic rocks (Gabrielse, 1998) **Sandstone and conglomerate (mJBLs).** Interbedded calcareous (locally fossiliferous) sandstone, cross-bedded sandstone, and polymictic conglomerate containing mafic volcanic, Pl-phyric, hypabyssal, and pyritic clasts. Moderately resistant, brownish weathering **Chert clast-bearing conglomerate (mJBLcg).** Laminated to medium bedded granule to pebble conglomerate and sandstone. Clasts include abundant rounded 1-2 cm green chert, lesser maroon chert, and limestone. Locally up to 2% very fine-grained greenstone (?). Common Qtz grains. Minor light green laminated to medium bedded tuff and sandstone. Moderately recessive, greenish-grey weathering. Bajocian	Stikinia
Middle Jurassic	upper Hazelton Group	Horn Mountain Formation	**Upper mafic volcanic rocks (mJHMum); >650 m thick.** Aug-Pl-phyric volcanic breccias and flows. Breccia locally contains minor felsic clasts. Includes two thin polymictic conglomerate to breccia beds with Pl-phyric and grey siliceous clasts. Resistant, dark grey weathering **Upper felsic volcanic rocks (mJHMuf); 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 Pl±Aug±Hbl-phyric clasts. Common bomb sags. Includes rare pebble conglomerate with well-rounded clasts, and calcareous sandstone (locally fossiliferous)	

Table 1. Continued.

Age	Unit		Description	Position
Lower-Middle Jurassic	upper Hazelton Group	Horn Mountain Formation	**Middle maroon volcanic rocks (lmJHMv); ≤3000 m thick.** Maroon, pinkish to rare green volcanic breccias and flows, minor pyroclastic rocks; upper volcaniclastic subunit. Maroon breccias are generally massive (locally medium to very thickly bedded ± graded) and contain varicoloured 0.5-5 cm Aug-Pl-phyric clasts, common maroon glassy (felsic?) clasts, local Aug microdiorite clasts, Pl-phyric clasts, rare flow-banded clasts, and very rare platy Pl-phyric clasts. Aug-Pl-phyric flows (pink; rarely green) and rare glassy felsic (?) flows (blood-red to maroon) transition to monomictic autoclastic breccias. Pyroclastic rocks include reddish-maroon laminated to medium bedded tuffs, crystal tuffs, and lapillistone, and at least one welded lapilli-tuff bed with sub-cm fiamme and lithic fragments. Resistant to moderately resistant, dark grey to maroon weathering, moderately to crudely stratified unit in outcrop, except east of the McBride River where it is distinctly thickly bedded. Upper subunit of recessive well-stratified maroon volcaniclastic sandstones and tuffs	Stikinia
			Lower mafic volcanic rocks (lmJHMlm); >1500 m thick. Massive monomictic volcanic breccia with Aug±Pl-phyric 5-10 cm clasts in a sand- to granule crystal matrix or cement; predominantly clast-supported. Rare tuffaceous sandstone interbeds. Very resistant; dark grey to green hackly weathering	
			Lower mafic volcanic rocks with felsic clasts (lmJHMlmf); 0-75 m thick. Similar to middle maroon volcanic rocks, but contains flow-banded Pl-phyric clasts, epidote-altered clasts, and fine-grained to aphyric off-white felsic clasts	
			Lower mafic volcanic rocks with epidote-altered clasts (lmJHMlme); 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	
			Lower volcaniclastic sandstone (lmJHMsv); 0-150 m thick. Laminated to thickly bedded volcaniclastic sandstone and siltstone. Recessive, brown weathering	
		Spatsizi Formation	**Volcaniclastic sandstone (lmJSPsv); 0-300 m thick.** Medium- to coarse-grained volcaniclastic sandstone with lesser siltstone and fine tuff laminae; subordinate horizons of Aug-phyric or (non-platy) Pl-phyric monomictic volcanic breccia. Well-stratified in outcrop, including prominent resistant horizon up to 100 m thick. Common soft-sediment deformation structures. Resistant, medium-dark brown weathering.	
			Argillite, siltstone and sandstone (lmJSPs); 560 m thick. Argillite, siliceous siltstone, and fine-grained sandstone with minor grey tuff laminae. Subordinate monomictic to polymictic volcanic breccia with Aug-Pl-phyric, Pl-phyric and platy Pl-phyric clasts; rare volcaniclastic sandstone. Mostly recessive, rusty orange-brown weathering. Yielded Early to Middle Jurassic detrital zircon populations (Iverson et al., 2012)	
			Felsic volcanic rocks (lmJSPf); 0-75 m thick. Monomictic clast-supported volcanic breccia with medium grey coarse platy Pl-phyric and pale grey aphyric, common vesicular felsic clasts. Resistant, medium grey weathering	
			Mafic volcanic rocks (lmJSPm); 0-60 m thick. Very thickly bedded Aug±Pl-phyric volcanic breccia. Resistant, dark grey-green weathering	
			Basal conglomerate (lmJSPcg); 140 m thick. Polymictic conglomerate containing aphyric felsic clasts, Aug-phyric clasts, plutonic clasts similar to subjacent Cake Hill pluton, and Qtz clasts. Qtz-rich feldspathic arenite, rare fossiliferous calcareous sandstone and siltstone. Subfeldspathic arenite (likely grus) unconformably overlies the Cake Hill pluton. Recessive, brown weathering. Contains Early Toarcian fossils (Henderson and Perry, 1981)	
Triassic	Stuhini Group		**Basaltic volcanic rocks (TrST).** Massive Aug- and lesser Aug-Pl-phyric flows, volcanic breccia, tuffaceous conglomerate, volcaniclastic sandstone and siltstone (Anderson, 1983; Gabrielse, 1998; van Straaten et al., 2012)	

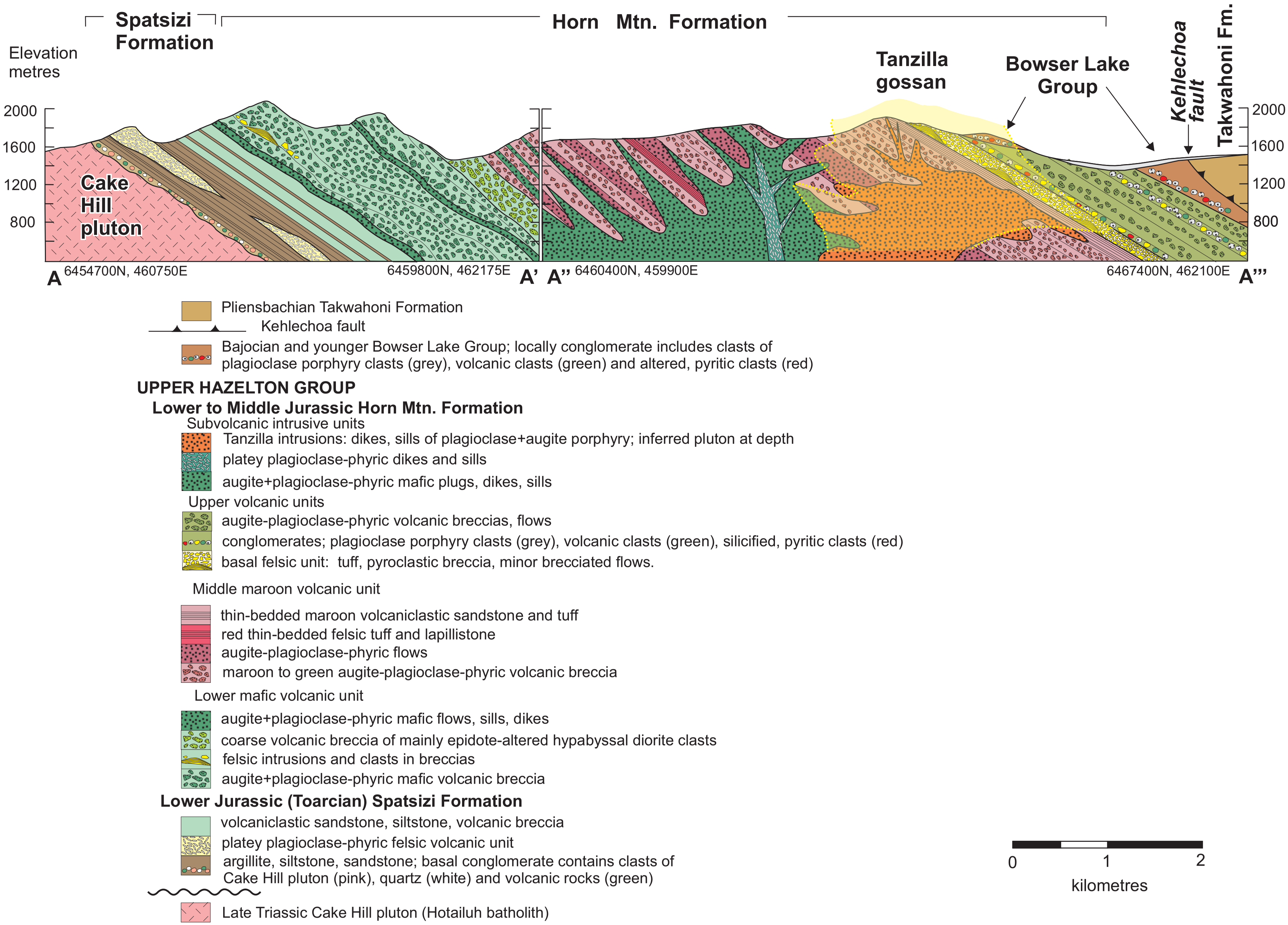


Fig. 4. South (A) to north (A''') cross-section northeast of the Tanzilla River. See Figure 3 for location.

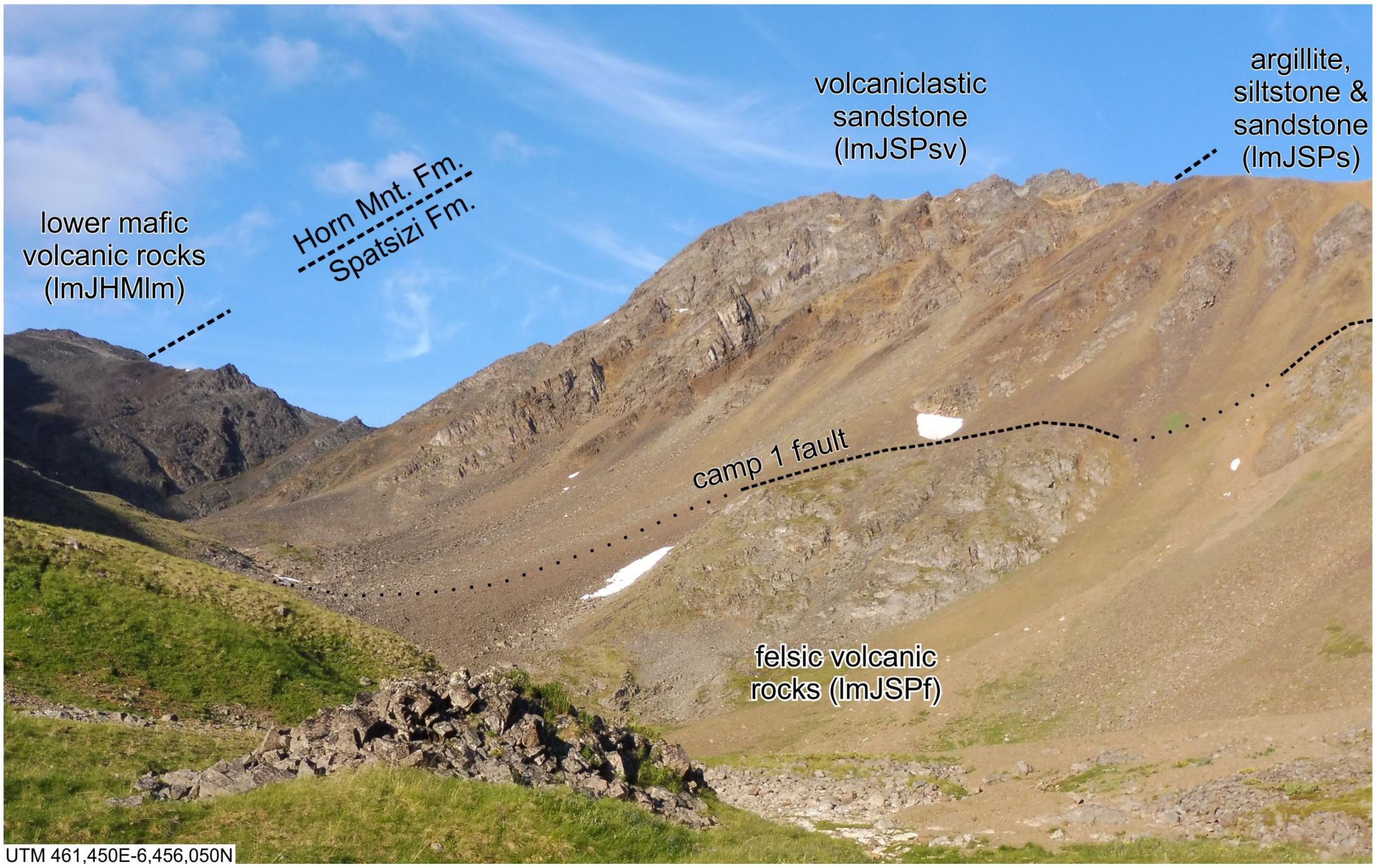


Fig. 5. Outcrop character of Spatsizi and lower Horn Mountain formations. In middle foreground is a ridge-forming felsic platy plagioclase porphyritic volcanic breccia (lmJSPf), part of the argillite, siltstone, and sandstone unit. Behind are recessive, orange-brown weathering rocks of the argillite, siltstone, and sandstone unit (lmJSPs,) and resistant rocks of the volcaniclastic sandstone unit (lmJSPsv). The section is capped by the lower mafic volcanic unit of the Horn Mountain Formation (lmJHMlm). View to the east.

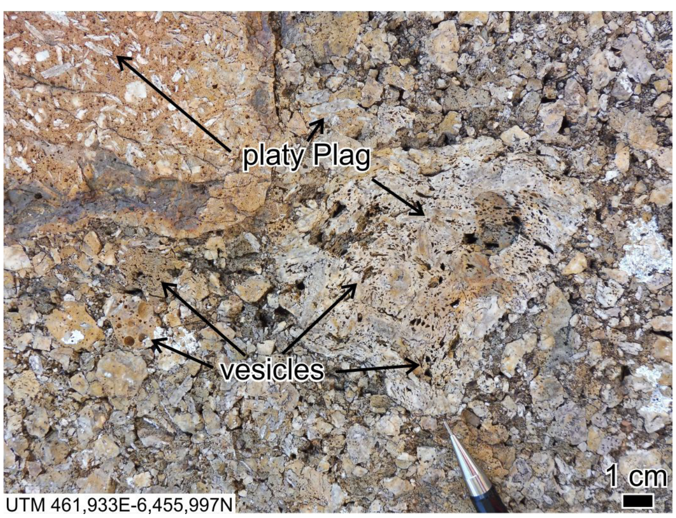


Fig. 6. Spatsizi Formation. Vesicular coarse platy plagioclase-phyric volcanic breccia subunit (lmJSPf) in the argillite, siltstone, and sandstone unit.

generally massive mafic augite±plagioclase-phyric clast-supported volcanic breccias (Fig. 7). It has a minimum thickness of 1.5 km. Its basal contact is considered gradational based on: 1) the common occurrence of augite-phyric volcanic breccia layers and augite-phyric sills in underlying Spatsizi Formation; and 2) a gradual increase in the size and proportion of volcanic debris upsection in the Spatsizi Formation. Two volumetrically minor but distinctive subunits are part of the lower mafic unit northeast of the Tanzilla River; one subunit contains common felsic clasts (Fig. 8), the other contains abundant augite microdiorite and epidote-altered clasts. Southwest of the Tanzilla River, the lower mafic volcanic unit interfingers with a volcaniclastic sandstone subunit.

The middle maroon volcanic rock unit, with an approximate maximum thickness of 3 km, overlies the lower unit of mafic volcanic rocks. The unit contains mainly maroon volcanic breccias, autobreccias, and flows, and includes minor laminated felsic tuffs to bedded lapillistone, and at least one welded lapilli tuff bed. The volcanic breccias and flows are predominantly augite-plagioclase-phyric, suggesting a mafic composition. However, maroon glassy clasts of presumed felsic composition are widespread (although volumetrically minor), and rare blood red to maroon glassy flows and autobreccias of inferred felsic composition were observed in the central part of the detailed map area, suggesting a significant felsic volcanic component. A subaerial origin is suggested by the presence of welded tuff and coherent flows and autobreccias. The contact between this

Table 2. Definition of the Horn Mountain Formation.

Horn Mountain Formation	
Category, rank	Lithostratigraphic unit with the rank of formation.
Name	Named for Horn Mountain, a prominent peak 7.5 km east of the type section.
Description of unit	Resistant dark green weathering massive augite±plagioclase-phyric trachybasalt to basaltic trachyandesite volcanic breccias. Generally overlain by crudely stratified maroon to dark green weathering volcanic breccias with augite±plagioclase-phyric trachybasalt to basaltic trachyandesite clasts and volumetrically lesser plagioclase-phyric and aphyric felsic clasts; rare maroon to red laminated to medium bedded tuff, lapillistone and volcaniclastic sandstone. At the type section, the maroon volcanic rocks are overlain by well-stratified tuff and plagioclase-phyric to aphyric trachyte to trachyandesite volcanic breccia. The volcanic succession is cut by texturally variable augite±plagioclase-phyric trachybasalt to basaltic trachyandesite plugs, sills and dikes. Areas of high intrusion densities (75-99%) cover up to several square kilometres. The intrusions are likely coeval with the lower and middle Horn Mountain volcanic rocks based on similar texture, mineralogy and lithogeochemistry, and a lack of crosscutting relationship with the upper Horn Mountain Formation. In regional studies, these intrusions could be included in the formation.
Geometry, thickness	The unit extends for at least ~50 km in a west to east-southeast trending belt north and northeast of the Hotailuh batholith. The unit is approximately 5.4 km thick at the type section.
Lower contact	Conformable and gradational contact above volcaniclastic sandstone of the Spatsizi Formation. Lower boundary defined where augite±plagioclase-phyric volcanic breccias and related volcanic rocks are more abundant (>50%) than volcaniclastic sandstone and related sedimentary strata (UTM 462,670E-6,456,520N).
Upper contact	At the type section the contact between strongly altered Horn Mountain volcanic rocks and Bowser Lake sedimentary rocks is covered for 100 m, but assumed to be unconformable (UTM 461,130E-6,464,820N). An unconformable contact between upper Horn Mountain mafic volcanic rocks and Bowser Lake conglomerates and sandstones is exposed at a reference section north of Grizzly lake (UTM 456,155E-6,465,355N). At a reference section east of the McBride River, we interpret the contact with overlying chert clast-bearing conglomerates of the Bowser Lake Group as conformable (UTM 493,040E-6,447,048N). Here, the boundary is defined where these conglomerates and related sedimentary strata are more abundant (>50%) than Horn Mountain volcanic rocks.
Age	Late Early Jurassic (Toarcian) to Middle Jurassic (Bajocian), possibly younger.

Coordinates are in UTM NAD 83 (zone 9 north)

unit and the lower mafic volcanic unit is separated by a covered interval of 55 m. In the eastern part of the detailed map area, the unit is cut by abundant (up to 75%) augite-plagioclase-phyric sills, and grades into the mafic intrusive complex discussed in Section 4.2. The uppermost part of this unit contains well-stratified volcaniclastic sandstones and tuffs. The middle maroon volcanic unit was also mapped east of the McBride River (Fig. 2), where it comprises predominantly thickly bedded maroon volcanic breccias with plagioclase-phyric, plagioclase-augite-phyric, aphyric and rare flow-banded clasts, and local flows (Fig. 9).

The upper felsic volcanic unit (about 235 metres thick) overlies the middle maroon volcanic unit. The unit consists mainly of aphanitic and plagioclase-phyric clasts of presumed felsic composition, and lesser plagioclase±augite±hornblende-phyric clasts. Common bomb sags are distributed along a strike length of 3.5 km, suggesting a subaerial pyroclastic origin. On the ridge two kilometres west of Silica ridge (see Fig. 3) the upper felsic volcanic unit contains a bed of pebble conglomerate and (locally fossiliferous) calcareous sandstone, suggesting local erosion and marine deposition.

The upper felsic volcanic unit is capped by the upper mafic volcanic unit, which is up to 650 metres thick. This unit is made up of augite-plagioclase-phyric volcanic breccias and flows, locally containing minor felsic clasts. The contact with the underlying felsic volcanic unit is gradational. On the northeastern spur of Silica ridge, a polymictic conglomerate to breccia contains plagioclase-phyric felsic clasts and grey siliceous clasts in a weakly altered matrix. The siliceous clasts appear to represent strongly silicified rock types derived from the underlying Silica ridge gossan (see Section 6).

The Horn Mountain Formation postdates widespread arc volcanism recorded in the 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 mainly consists 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

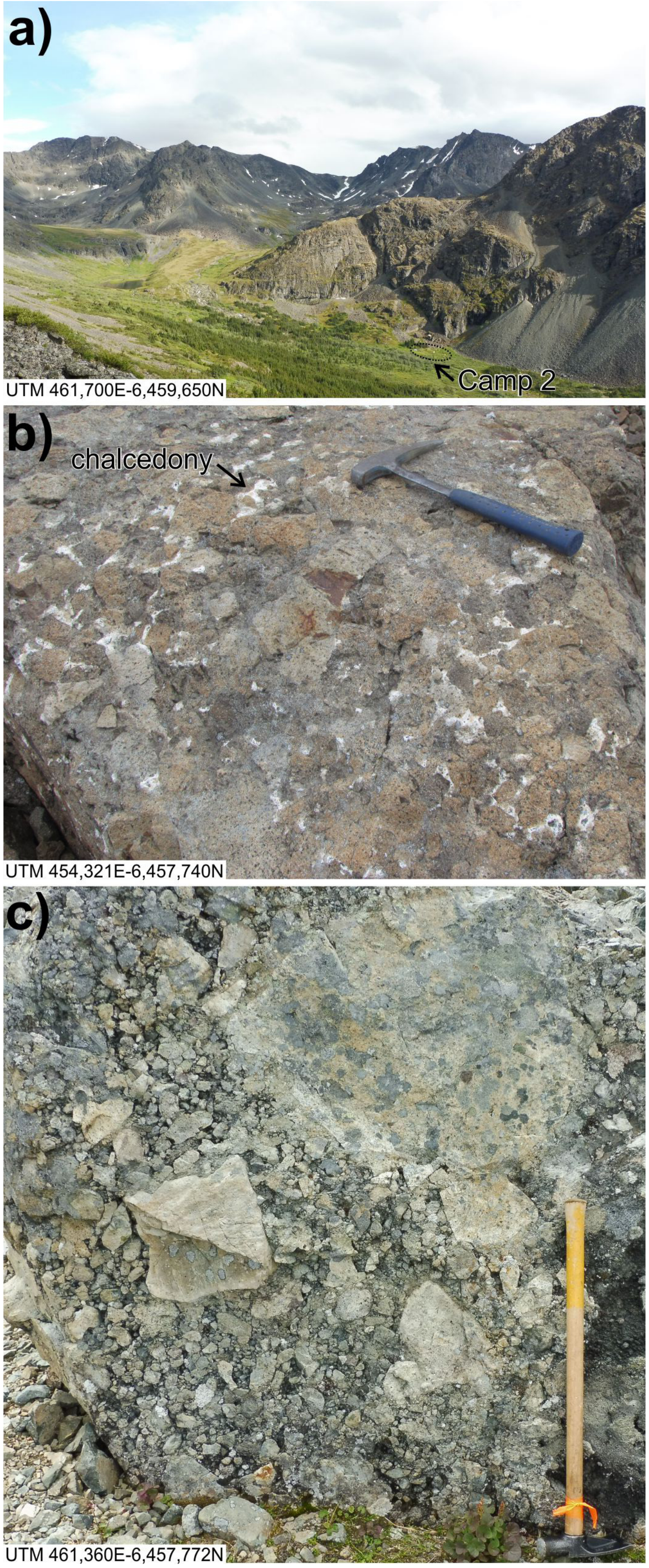


Fig. 7. Horn Mountain Formation, features of the lower mafic volcanic unit (lmJHMlm). **a)** resistant hackly weathering nature of this unit (looking southeast); **b)** chalcedony-cemented augite-phyric volcanic breccia; **c)** clast-supported augite-phyric volcanic breccia.

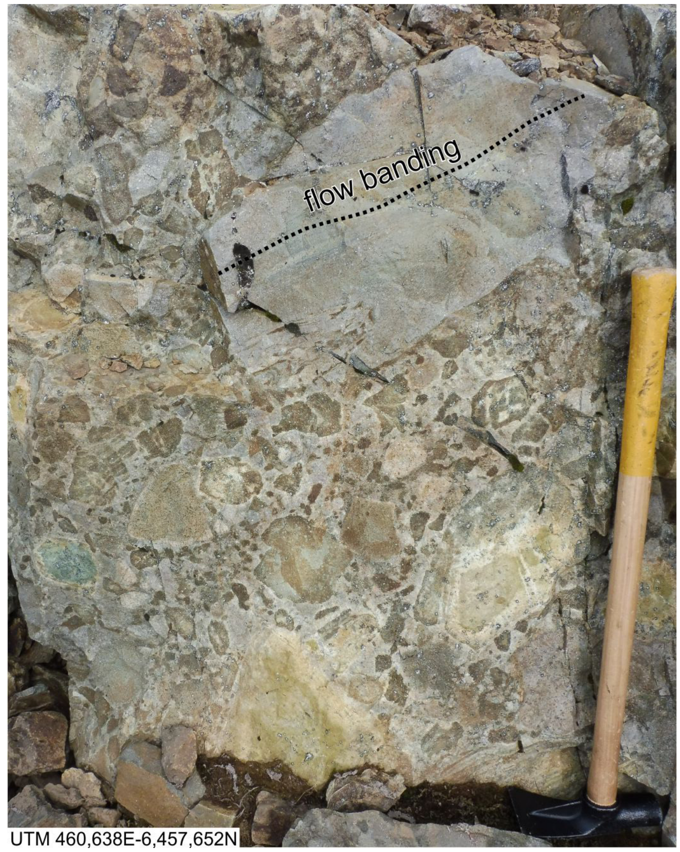


Fig. 8. Horn Mountain Formation, plagioclase-phyric and flow-banded clasts in felsic volcanic breccia subunit (lmJHMlmf). Note chilled margins and reaction rims on smaller clasts.

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., 2015b). 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 (see Section 5), and lithogeochemistry (see Section 7). 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.

3.1.3. Bowser Lake Group (Middle Jurassic)

Sedimentary rocks of the Bowser Lake Group (Table 1) outcrop northeast of the Tanzilla River and east of the McBride River (Fig. 2). Northeast of the Tanzilla River, at Silica ridge (Fig. 3), basal Bowser Lake Group rocks overlie the Hazelton Group. This basal unit comprises interbedded calcareous (locally fossiliferous, including dm-scale ammonites) sandstone, cross-bedded sandstone, and polymictic conglomerate containing

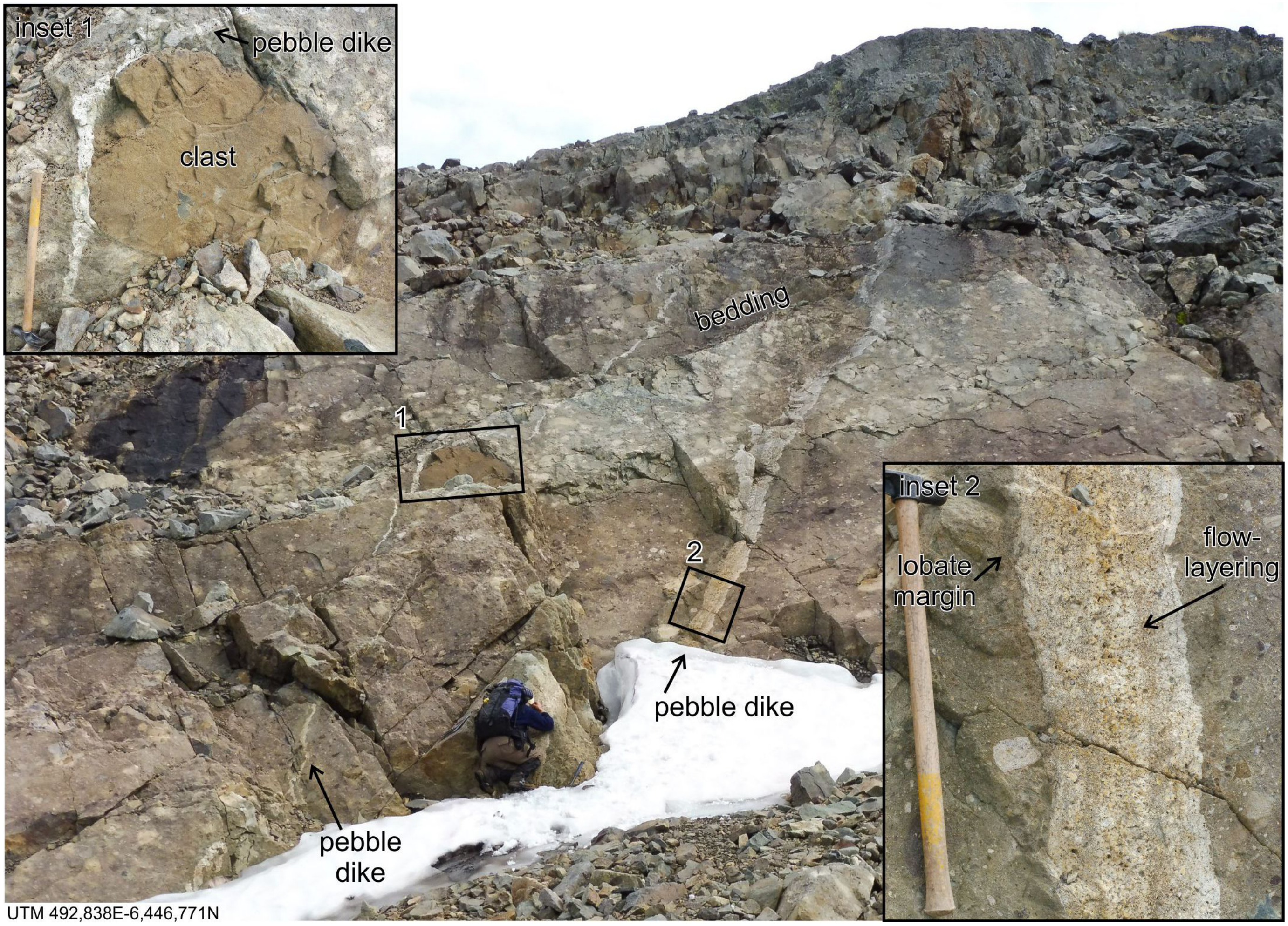


Fig. 9. Horn River Formation, maroon volcanic unit east of the McBride River. Thickly bedded maroon augite-plagioclase-phyric volcanic breccia (lmJHMv) cut by white chert clast-bearing pebble dikes, injected from postulated underlying Bowser Lake Group sediments. **Inset 1)** Close-up of thin pebble dike following large volcanic clast margin. **Inset 2)** Close-up of flow-layered pebble dike with irregular, locally lobate to flame-like, margins.

mafic clasts, plagioclase-phyric clasts and pyrite-altered clasts that appear to have been derived from erosion of Stikinia units. The unit is locally epidote-chlorite-pyrite altered and overlies strongly altered rocks (see Section 6). North of Grizzly lake, a basal pebble to cobble conglomerate directly overlies a mafic flow of the Horn Mountain upper mafic volcanic unit. At both locations, the base of the sedimentary unit and bedding within it dip shallowly to the north, suggesting a 10-15° discordance with the underlying volcanic rocks.

East of the McBride River, chert clast-bearing pebble to granule conglomerate and sandstone of the Bowser Lake Group are interpreted to interfinger with the maroon volcanic unit of the Horn Mountain Formation. The conglomerate contains abundant 1-2 cm green and lesser maroonish-red rounded chert clasts, local limestone clasts, and common quartz grains. In contrast to the Silica ridge section, the McBride River section appears to record an influx of exotic Cache Creek-derived chert clasts. A middle Bajocian age is suggested based on fossils collected from similar Bowser Lake Group units seven kilometres to the south-southeast (Gabrielse, 1998). Steeply east-northeast dipping chert clast-bearing pebble dikes, with dike wall-parallel flow layering, cut the uppermost maroon volcanic rocks (Fig. 9). The dikes display irregular, locally lobate to flame-like, contacts and commonly follow (rather than cut across) volcanic clast boundaries, suggesting that underlying Bowser Lake Group sediments injected into semiconsolidated maroon volcanic deposits. A scree-filled gully 10-15 metres east of the pebble dikes marks the contact between the maroon volcanic rocks and chert clast-bearing conglomerates, likely representing a steeply dipping north-trending minor fault. The lowermost chert clast-bearing conglomerate two metres east of the gully contains maroon volcanic clasts with similar shapes and textures as those in the maroon volcanic unit (Fig. 10). Based on these observations we interpret that the contact between the maroon volcanic rocks and chert clast-bearing conglomerates is conformable, and that the two lithologies interfinger. North to north-northeast trending faults and pebble dikes likely formed while the units were still

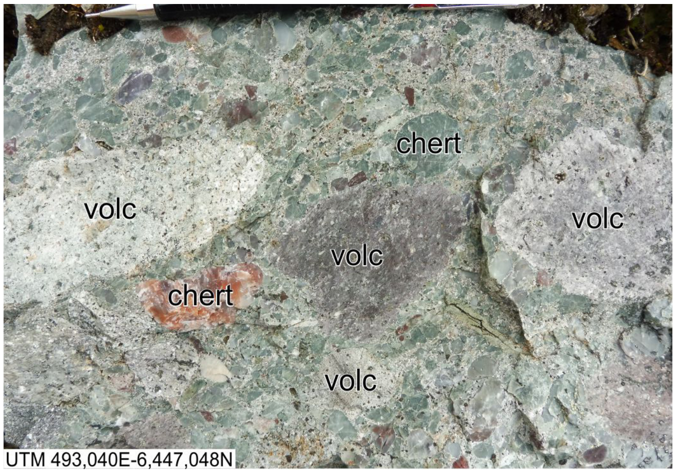


Fig. 10. Base of the Bowser Lake Group east of the McBride River (mJBLcg). Chert clast-bearing pebble conglomerate with green, lesser grey and reddish chert clasts, and maroon to grey volcanic clasts with similar shapes and textures as the underlying maroon volcanic unit.

poorly consolidated. Interbedded maroon volcanic rocks and chert clast-bearing conglomerates are described regionally in two areas to the southeast (see Section 9.1.).

3.2. Whitehorse trough

Between the Kehlechoa and King Salmon thrust faults, sedimentary rocks of the Takwahoni Formation (Laberge Group; Table 1) form a belt at least 90 km long and up to 10 km wide (Fig. 2). The belt represents one of the most southeasterly exposures of the Whitehorse trough (Fig. 1). It was previously interpreted to sit depositionally on undivided Triassic-Jurassic volcanic rocks (Gabrielse, 1998; now assigned to the Horn Mountain Formation), and is re-interpreted here as a sequence above the revised Kehlechoa thrust fault (see Section 5). Feldspathic wackes with Pliensbachian fossils (Gabrielse, 1998) predominate in a northern thrust panel (Fig. 2). A separate thrust panel between the McBride and Kehlechoa faults (east of the McBride River) contains Upper Triassic carbonate rocks overlain by a Lower Jurassic (Sinemurian to Toarcian) sedimentary succession (Fig. 2).

3.2.1. Northern thrust panel

A distinct unit of the Takwahoni Formation was observed north of Glacial Lake (north of the Kehlechoa fault) and east of the McBride River (north of the McBride fault; Fig. 2). The most common lithology at both locations is well-stratified, commonly quartz-bearing (5%), feldspathic wacke, siltstone, and argillite (Fig. 11). East of the McBride River, local monomictic cobble conglomerate with hornblende diorite clasts were observed close to the McBride fault. Numerous fossil collections date this succession as Pliensbachian (Gabrielse, 1998).

3.2.2. Southeastern thrust panel

East of the McBride River, a thrust panel between the McBride and Kehlechoa faults comprises a section of Upper Triassic limestone (Sinwa Formation) and Lower Jurassic sedimentary rocks of the Takwahoni Formation (Fig. 2). Sinwa Formation limestones, with late Norian conodont ages (Gabrielse, 1998), are unconformably overlain by a polymictic conglomerate unit with Sinemurian ammonites (lower polymictic conglomerate, Table 1; Gabrielse, 1998). According to Gabrielse (1998), the conglomerate contains limestone, feldspar porphyry, granitic, chert and argillite clasts. It interfingers with dark, fine-grained siliciclastic strata that also contain Sinemurian ammonites. These units were not investigated as part of this study.

The Sinemurian strata are overlain by laminated black argillite, siltstone and lesser volcaniclastic sandstone (argillite and siltstone unit, Table 1), which surrounds several ca. 1 km lenses of distinctive coarse conglomerate (Fig. 2; upper polymictic conglomerate, Table 1). Although separate, all of the polymictic conglomerate lenses contain similar clast populations (Table 1; Fig. 12). Coarse equant plagioclase-

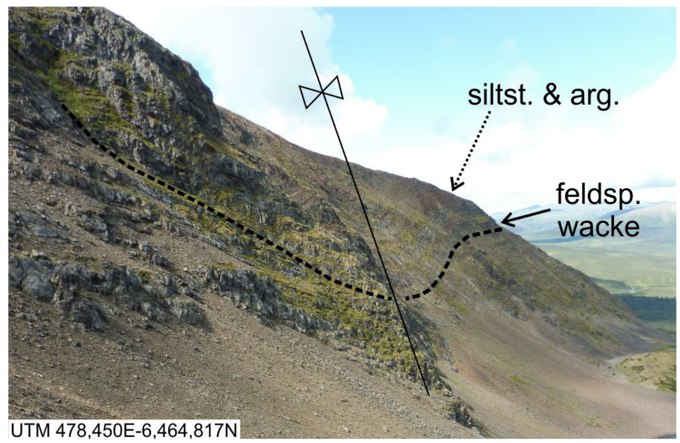


Fig. 11. Syncline in alternating Takwahoni siltstone, argillite (brown) and feldspathic wackes (medium grey), looking west-northwest down the fold axis; in hanging wall of Kehlechoa fault north of Glacial Lake (lJTgw).

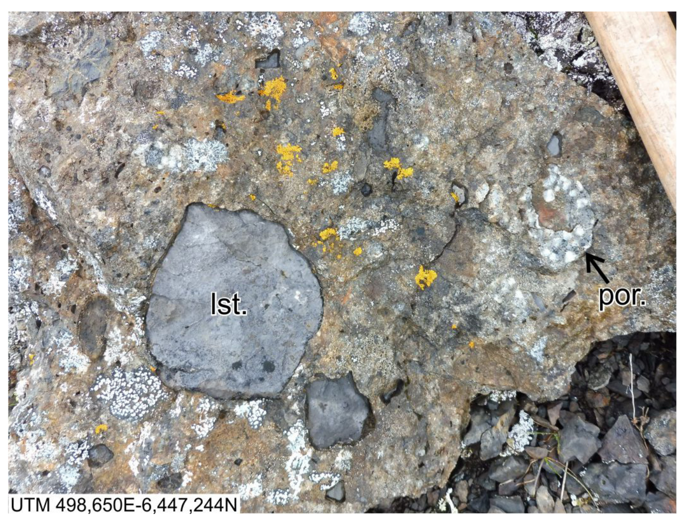


Fig. 12. Takwahoni Formation (Toarcian) polymictic conglomerate (lJTucg) with grey limestone clasts ('lst.') and distinctive coarse equant plagioclase porphyritic clasts ('por.'); east of the McBride River.

phyric clasts (Fig. 12) are a minor but recurring component, distinct from any other clast or igneous unit observed in this study. The conglomerate commonly forms metre to decimetre-scale blocks in disrupted bedded to laminated black argillite, dark grey siltstone, and feldspathic wacke. The irregularity of bedding in the fine-grained sedimentary rocks is likely due to soft-sediment deformation and subsequent tectonic deformation. Toarcian fossils were recovered from both rock units (Gabrielse, 1998).

3.3. Overlap units

3.3.1. Tuya Formation (Miocene to Pleistocene)

Regional aeromagnetic data (Aeroquest Airborne, 2012) show a distinct semi-circular break in a lineament interpreted herein as the Kehlechoa fault (see Section 5). This break might represent a Tuya Formation olivine basalt volcanic centre. Local exposures of olivine basalt have been documented in the region (Fig. 2; Gabrielse, 1998). Alternatively, the aeromagnetic anomaly might represent a post-kinematic intrusive body.

4. Intrusive units

Twelve intrusive units outcrop in the study area including two plutonic phases and a variety of hypabyssal to subvolcanic stocks, sills, and dikes (Table 3). Based on field, petrographic, and preliminary lithogeochemical and geochronological data (see Sections 7, 8) we divide the units into five phases: 1) the Cake Hill pluton (Late Triassic); 2) Early to Middle Jurassic subvolcanic intrusions; 3) Middle Jurassic dikes and stocks coeval with mineralization at Tanzilla; 4) rare dikes correlated with the Three Sisters plutonic suite (Middle Jurassic); and 5) the Snowdrift Creek pluton and associated dikes (Late Jurassic).

4.1. Cake Hill pluton (Late Triassic)

In the southeastern part of the detailed study area, the Cake Hill pluton, which is part of the extensive (2275 km^2) Hotailuh batholith, consists of hornblende quartz monzodiorite and granodiorite. The rocks have lower magnetic susceptibility values (5.9 ±4.0 x 10^3 SI units, average and one standard deviation of 10 measurements at one location) and a lower aeromagnetic response than the rest of the pluton (Aeroquest Airborne, 2012; van Straaten et al., 2012).

4.2. Early to Middle Jurassic subvolcanic intrusions

A mafic intrusive complex extends across an area of at least four by four kilometres in the northeastern part of the detailed map area (Fig. 3). It is made up of texturally variable augite-phyric basalts, augite microdiorite, microdiorite and rare volcanic breccia. Rocks of this complex texturally and compositionally resemble augite-phyric volcanic breccias of the Horn Mountain Formation, and form sills within it (Fig. 4). The complex likely represents a subvolcanic centre that fed Horn Mountain volcanism.

The augite-phyric mafic intrusive complex is cut by coarse platy plagioclase porphyry dikes and stocks that are only found in the northeastern part of the detailed map area. At one location, the porphyry contains diffusely bounded, lobate and flame-like projections of augite microdiorite (Fig. 13) and the microdiorite contains strings of coarse platy plagioclase crystals, suggesting magma mixing between these two phases.

A few felsic dikes and one intrusive felsic breccia occur within the lower mafic volcanic unit of the Horn Mountain Formation. They might represent subvolcanic feeders to the rare felsic volcanic breccias within this unit. Strongly silicified (and locally clay altered) cream to white flow-banded dikes with common ribbon quartz are found higher up in the stratigraphic sequence; they may represent feeder dikes of the Horn Mountain upper felsic volcanic unit.

4.3. Tanzilla intrusions (Middle Jurassic)

Abundant chlorite-epidote-altered plagioclase and augite-plagioclase porphyry dikes and stocks (Fig. 14) cut the Silica

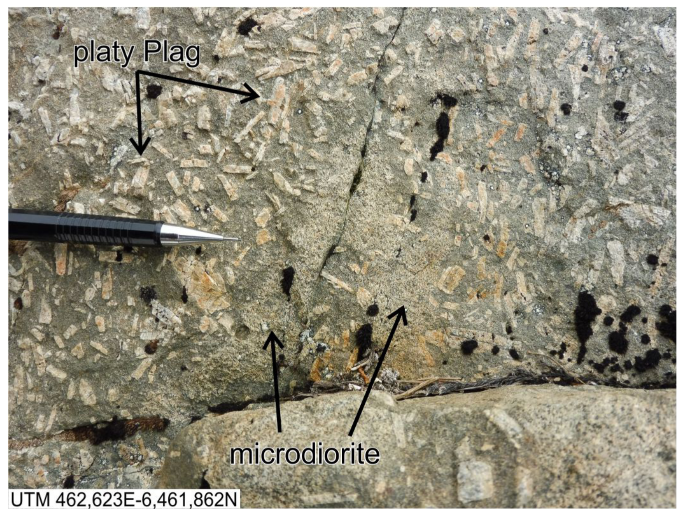


Fig. 13. Coarse platy plagioclase porphyry (EMJpp) with irregular microdiorite (EMJm) projections displaying diffuse boundaries, likely indicating magma mixing.

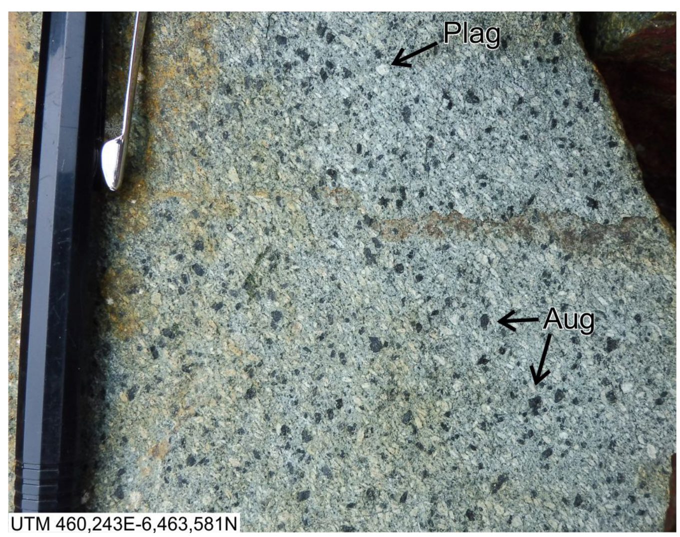


Fig. 14. Tanzilla phase (Middle Jurassic); augite-bearing plagioclase porphyry (MJp).

Table 3. Summary of intrusive units. Mineral abbreviations after Kretz (1983).

Age	Phase	Description	Timing relationships
Late Jurassic	Snowdrift Creek subalkaline	**Snowdrift Creek pluton (LJSC).** Medium-grained (3-4 mm) equigranular Bt-bearing Hbl to Hbl-bearing Bt granodiorite; rare Qtz diorite and tonalite (this study; Gabrielse, 1998). Contains mafic restite xenoliths, trace Mag, Ttn. Recessive to moderately resistant, grey weathering. Preliminary U-Pb zircon age of 160-161 Ma (R. Friedman, pers. comm., 2015)	Cuts Takwahoni greywacke unit, mafic intrusive complex. Interpreted to cut Horn Mountain Formation and Kehlechoa fault
		Hornblende diorite (LJd). Hbl diorite dikes and possible sills. Contains 1-6 mm (generally acicular) Hbl, equant 1-4 mm Pl, rare 2-3 mm Aug, local vesicles, very rare Kfs xenocrysts and Qtz eyes. Resistant, light grey to white weathering	Cuts Spatsizi argillite, siltstone & sandstone unit; Spatsizi felsic volcanic and volcaniclastic sandstone units; Horn Mountain lower mafic volcanic and middle maroon volcanic units. Post-hydrothermal. Follows faults
Middle Jurassic	Three Sisters subalkaline	**Feldspar porphyry (MJfp).** Fsp porphyry dikes with equant to stubby 2-4 mm Fsp phenocrysts set in very fine-grained groundmass. Resistant, commonly orange-pink weathering. Correlated with the Three Sisters – Tees Creek phase of van Straaten et al. (2012)	Cuts Horn Mountain lower mafic volcanic and middle maroon volcanic units; mafic intrusive complex
		Hornblende-bearing syenogranite (MJsg). Hbl-bearing syenogranite dikes (2% Hbl, 3% Mag) with white Pl phenocrysts (3 mm) set in sugary fine- to very fine-grained Qtz-Kfs-rich groundmass. Only observed at one location. Correlated with the Three Sisters – potassic phase of van Straaten et al. (2012)	Cuts Horn Mountain lower mafic volcanic unit
	Tanzilla subalkaline	**Augite quartz diorite (MJd).** Medium-grained equigranular Aug Qtz diorite (and diorite?)	Cuts Horn Mountain middle maroon volcanic and upper felsic volcanic units; Pl porphyry (MJp). Syn-hydrothermal
		Augite-bearing plagioclase porphyry (MJp). Aug-bearing Pl porphyry dikes and stocks with tabular to equant 1-4 mm Pl, 3-5% Aug, minor Mag. Preliminary U-Pb zircon age of 173.25±0.13 Ma (this study)	Interpreted to cut Horn Mountain middle maroon volcanic and upper felsic volcanic units. Syn-hydrothermal
Early-Middle Jurassic	Spatsizi & Horn Mountain alkaline	**Felsic intrusive (EMJf).** Felsic dikes with common dike margin-parallel flow bands and wispy Qtz ribbons. Locally includes m-wide tabular to 100 m-wide bulbous bodies of intrusive breccia containing angular to amoeboid Pl-phyric (20%, 1-2 mm) clasts, some flow-banded autoclasts and rare Aug-Pl-phyric clasts	Cuts Horn Mountain lower mafic volcanic unit; mafic volcanic complex
		Hornblende-bearing plagioclase porphyry (EMJh). Sparse Pl (lath-like to slightly platy) porphyry dikes, locally with minor Hbl, trace Mag. Only observed at two locations	Cuts Horn Mountain middle maroon volcanic unit with indistinct irregular contacts
		Hornblende monzonite (EMJmz). Kfs-Hbl-Pl-phyric monzonite dikes with minor Mag. Only observed at two locations	Cuts mafic intrusive complex
		Platy plagioclase porphyry (EMJpp). Pl-phyric porphyry dikes and stocks with coarse Pl plates (1-3 cm, approximately 5:4:1 aspect ratio) set in a dark green to black aphanitic groundmass. Magnetic to highly magnetic	Cuts mafic intrusive complex, locally with gradational contacts
		Mafic intrusive (EMJm). Variably textured Aug-Pl-phyric intrusive rocks. Generally Aug-phyric (15%, 2-5 mm, locally up to 10 mm), locally comprising well-crystallized Aug microdiorite and microdiorite with up to 85% 0.5-1 mm Pl. Locally amygdaloidal. 1 to 50 m-wide planar to bulbous sills, dikes and intrusive bodies. Resistant, dark grey to green weathering	Cuts Spatsizi argillite, siltstone & sandstone unit; Spatsizi volcaniclastic sandstone unit; Horn Mountain lower mafic volcanic and middle maroon volcanic units
Late Triassic	Stikine subalkaline	**Cake Hill pluton (LTrCH).** Medium- to locally coarse-grained equigranular Hbl Qtz monzodiorite, granodiorite (this study) to Qtz monzonite (van Straaten et al., 2012) containing accessory Ttn. Resistant, blocky, light-medium grey weathering. U-Pb zircon ages of 221±3 Ma, 218.2±1.3 Ma (Anderson and Bevier, 1992; van Straaten et al., 2012)	Unconformably overlain by Spatsizi basal conglomerate unit

ridge gossan. In drill core, a plagioclase (-augite?) porphyry hosts anhydrite-pyrite±chalcopyrite veins. This porphyry returned a preliminary U-Pb zircon age of ca. 173 Ma (see Section 8). Texturally and compositionally the porphyry in drill core resembles the dikes that are exposed on Silica ridge. The intrusions lack the pervasive clay alteration of their wall rocks. They are interpreted as syn-hydrothermal, as they cut (advanced) argillic alteration, and host porphyry-style alteration (see Section 6).

A few medium-grained equigranular augite quartz diorite intrusive bodies are found near Silica ridge (Fig. 15). Texturally similar medium-grained equigranular diorite was intersected in drill core (Section 6). It cuts the plagioclase porphyry described above, and appears to be coeval with porphyry-style hydrothermal alteration (see Section 6).

Fig. 15. Tanzilla phase (Middle Jurassic); medium-grained equigranular augite quartz diorite (MJd).

4.4. Three Sisters intrusions (Middle Jurassic)

Pink feldspar porphyry dikes are locally found in the northern half of the map area. They are tentatively correlated with similar feldspar porphyries described in the Gnat Pass area (Tees Creek intrusive, Three Sisters plutonic suite of van Straaten et al., 2012).

4.5. Snowdrift Creek intrusions (Late Jurassic)

One of the youngest intrusive phases in the area is the Snowdrift Creek pluton, a northwesterly elongate mostly recessive granodiorite, quartz diorite to tonalite body underlying an area of about 100 km^2 (Figs. 2, 3). The pluton hornfelses the mafic intrusive complex and feldspathic wackes of the Takwahoni Formation. The pluton is also interpreted to cut the Kehlechoa fault, which places Takwahoni Formation against Horn Mountain Formation and coeval subvolcanic intrusions. The oldest K-Ar hornblende age on the Snowdrift Creek pluton is 160.8 ±2.5 Ma (Stevens et al., 1982; Hunt and Roddick, 1987). A sample collected for U-Pb zircon analysis returned a preliminary 160-161 Ma age (R. Friedman, pers. comm., 2015).

Hornblende and plagioclase porphyritic diorite dikes and rare sills are found throughout the map area. In them, sizes, shapes and abundance of phenocrysts vary considerably, but acicular hornblende is common (Fig. 16). These intrusions locally follow north-northeast trending faults that cut the Horn Mountain Formation. An unaltered acicular hornblende-phyric diorite dike of this suite cuts the Silica ridge gossan and the plagioclase porphyry.

Fig. 16. Snowdrift Creek phase (Late Jurassic); acicular hornblende and plagioclase porphyritic dike (LJd).

5. Structure

The structural pattern in the detailed study area is relatively simple, with most bedding in the Spatsizi Formation and Horn Mountain Formation showing right-way-up, uniform moderate northerly dips (Figs. 3, 4). Local variations in bedding attitude are likely related to faulting and/or paleoslopes in a volcanic edifice. The homoclinal Hazelton Group appears to be unconformably overlain by right-way-up, more shallowly north-dipping strata of the Bowser Lake Group (Figs. 3, 4).

The Takwahoni feldspathic wacke sequence in the hanging wall of the Kehlechoa fault north of Glacial Lake shows upright open folds with wavelengths of at least 600 metres and subhorizontal west-northwest to northwest plunging fold axes (Fig. 11). Limited cleavage-bedding measurements indicate southwesterly fold vergence.

East of the McBride River the Horn Mountain Formation and overlying Bowser Lake conglomerates show subhorizontal to gentle easterly dips. The Takwahoni units in the hanging wall of the Kehlechoa fault are strongly deformed and sheared. Erratic bedding and cleavage attitudes reflect disharmonic folding and competency contrasts between the conglomerate lenses and surrounding argillites.

5.1. Regional fault systems

Faults and lineaments in the study area comprise two sets. The older set comprises northwest-striking dextral faults and north-northeast to northeast striking normal faults that cut the Hazelton Group and older units of Stikinia. Younger, generally west to northwest striking thrust faults (including the King

Salmon, Kehlechoa and McBride faults), juxtapose the Cache Creek terrane to the north with Whitehorse trough strata and, in turn, Stikinia. They also appear to truncate faults of the older set.

5.1.1. Early dextral and normal faults

A major fault is inferred under Quaternary cover along the valley of the upper Tanzilla River (Figs. 2, 3). The informally named Tanzilla River fault shows about two kilometres of apparent right-lateral offset of the basal unconformity, the largest apparent offset of any early structure in the area. It is projected to join a previously-mapped regional north-northwest trending fault that offsets the Cake Hill pluton and Three Sisters pluton (Gabrielse, 1998; van Straaten et al., 2012; Fig. 2). The fault coincides with a northwest-trending aeromagnetic lineament along the upper Tanzilla River.

A parallel structure to the southwest shows an apparent 750 metre right-lateral offset of the basal unconformity (southwest corner of Fig. 3; Bowen, 2013). A third northwest-striking fault is in the valley of a west-flowing northern tributary of the Tanzilla River (near section A-A', southeast corner of Fig. 3). Slickenfibres on this fault indicate dip-slip, north-side-down movement; those along a subsidiary fault indicate dextral movement. The main fault shows an apparent 580 m right-lateral offset of the felsic volcanic breccia subunit and an inferred decrease in offset towards the northwest (Fig. 3).

Several northeast to north-northeast striking faults have been recognized in the study area. The informally named Camp 1 fault shows an apparent 320 m dextral offset of the basal unconformity. Distant visual observations show only a minor offset of the Spatsizi-Horn Mountain contact, suggesting that that the structure may have been a growth fault with an east side-down movement. A parallel fault 400 m to the west shows only minor offset. Farther north the Camp 1 fault continues as a well-defined lineament that is spatially associated with orange-brown iron-carbonate altered rocks with a well-defined spaced fracture cleavage. A fault immediately west of an unnamed 2096 m high peak (Fig. 3) shows an apparent 230 m dextral offset of the Spatsizi-Horn Mountain contact and underlying basal unconformable contact, and based on the similar orientation is interpreted as an east-side-down normal fault. In the east, the Snowdrift Creek fault along the identically named creek, forms a pronounced lineament and orange-brown altered shear zone. A similarly oriented northeast-trending fault, inferred to occupy the valley east of Silica ridge, appears to define the western boundary of the mafic intrusive complex, and the eastern boundary of widespread alteration at the Silica ridge gossan. Based on the apparent thickening of the maroon volcanic unit to the west, a penecontemporaneous west-side-down movement is inferred. A parallel fault aligns with a northeast trend of orange-brown altered recessive saddles in three ridges west and southwest of Silica ridge (Fig. 17). The fault appears to coincide with the abrupt eastern end of the West gossan, and the westernmost extent of the Silica ridge gossan. A tentative east-side-down normal movement is inferred.

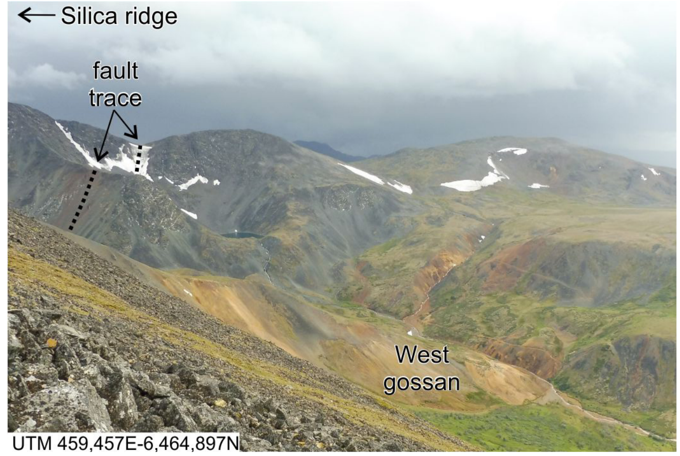


Fig. 17. West gossan looking towards the southwest. The fault west of Silica ridge cuts crudely stratified Horn Mountain Formation maroon volcanic unit (lmJHMv) in the background of the photo.

The normal movement on the north-northeasterly faults is consistent with east-west extension. Their linkage to the west-northwesterly dextral faults suggests that the north-northeasterly faults represent the extension direction in a regime of dextral simple shear in a west-northwest to east-southeast direction.

5.1.2. Late thrust faults

Regional southwest-vergent thrust faults transect the mapped area (Fig. 2; Gabrielse, 1998). They formed in a regime of north-south to north-northeast to south-southwest shortening during accretion of the Quesnel, Cache Creek, and Stikine terranes (Mihalynuk et al., 2004). The King Salmon fault is the master fault that emplaces rocks of the Cache Creek terrane above Stikinia.

The Kehlechoa fault was first recognized by Gabrielse (1998) as a major southerly splay that joins the King Salmon fault 20 km east of the mapped area (Fig. 1). It carries a sequence of Upper Triassic limestones of the Sinwa Formation and Jurassic (Sinemurian to Toarcian) rocks of the Takwahoni Formation in its hanging wall, above younger (Bajocian) rocks of the Bowser Lake Group in its footwall. According to Gabrielse (1998), the western end of the Kehlechoa fault departs from the base of the Takwahoni Formation and loses its definition in the volcanic package near the McBride River. Our interpretation differs from Gabrielse (1998). We recognize a north-striking and steeply to gently east-dipping fault, exposed at several locations on the ridge east of the McBride River. The structure separates sedimentary rocks of the Whitehorse trough (hanging wall) from Stikinia rocks (footwall). Hanging wall fine-grained sedimentary rocks and polymictic conglomerates (Toarcian) are in structural contact with Bowser Lake chert clast-bearing conglomerates (Bajocian) and underlying gently dipping maroon Horn Mountain volcanic rocks. The structure is commonly cut by north-trending, post-kinematic dikes, and is interpreted as a thrust or reverse fault. Its north-south orientation marks a strong departure from the general west-northwest strike of the Kehlechoa fault. It may be a tear fault or lateral ramp.

Previous structural interpretations for the area east of the McBride River included three to five north-dipping thrust panels composed of a variety of Takwahoni sedimentary sequences that are in turn thrust above Bowser Lake sedimentary rocks (Gabrielse, 1998). We propose a simpler explanation that invokes two structural panels. The lower panel includes a stratigraphic succession of Norian limestone, Sinemurian clastic rocks, and a Toarcian unit of mainly argillite and siltstone that contains discrete lenses and blocks of conglomerate. No Pliensbachian faunas have been recovered from this sequence (Gabrielse, 1998). The upper thrust panel contains extensive Pliensbachian feldspathic wackes interbedded with argillite, siltstone, and local conglomerate. The two panels are separated by the McBride River fault, which outcrops on a ridge 4.5 km east of the McBride River. There, it juxtaposes Pliensbachian Takwahoni monomictic conglomerates and underlying Toarcian Takwahoni polymictic conglomerates across a steeply-dipping zone of strongly sheared argillites. The McBride River fault is inferred to join the main Kehlechoa fault between the mapped area and the McBride River (Fig. 2).

Farther west, we infer that the Kehlechoa fault follows the base of the Pliensbachian Takwahoni unit, changing back to a west-northwesterly orientation as it crosses the McBride River. Previously, the contact between the Takwahoni Formation and the structurally underlying and assumed older volcanic rocks was mapped as a depositional contact (Gabrielse, 1998). We interpret this contact as a south-directed thrust fault separating strata of the Whitehorse through from Hazelton and Bowser Lake Group strata based on: 1) the juxtaposition of older rocks (Pliensbachian; Gabrielse, 1998) above younger rocks (Iverson et al., 2012; this study); 2) the presence of a well-developed aeromagnetic lineament (Aeroquest Airborne, 2012) in a wide overburden-filled valley; 3) an orientation that is similar to the King Salmon fault, approximately five kilometres to the north; and 4) the juxtaposition of homoclinal strata against folded Takwahoni units.

Importantly, the Kehlechoa fault is cut by the Snowdrift Creek pluton. The preliminary age on this intrusive body (see Section 8) suggests that shortening related to accretion of Stikinia to the Cache Creek and more inboard terranes was before early Late Jurassic.

In the detailed study area, a west-northwest striking, steeply northeast-dipping ductile shear zone is exposed (northeast corner of Fig. 3). The informally named Gopher shear zone is at least 275 m wide and consists of strongly altered quartz-sericite-clay schist (see Section 6 for details). Strong flattening fabrics parallel the shear zone. The schist contains local porphyroclasts, weakly developed down dip mineral lineations (this study) and northwest-plunging oblique stretched quartz lineations (Luckman et al., 2013). Although kinematic indicators were not observed, a reverse (to reverse oblique) shear sense is inferred based on: 1) a roughly similar orientation as regional-scale thrust faults; 2) its crosscutting relationship with respect to the alteration system at Tanzilla; and 3) the orientation of mineral lineations. This structure is interpreted as a minor shear synthetic with the King Salmon-Kehlechoa thrust system, developed preferentially in a zone of strong alteration. It has no apparent expression west of the valley that separates it from the Silica ridge gossan.

6. The Tanzilla prospect

The Tanzilla gossan, which includes quartz, sericite, clay and/or pyrite alteration, extends along strike for over five kilometres in the northern part of the detailed study area. The gossan includes the main Silica ridge (Fig. 18), the West gossan (Fig. 17) and the Gopher zone (Fig. 3). The earliest documented exploration in the Tanzilla area took place from 1965 to 1976, following discovery of porphyry copper mineralization at Gnat Pass in the early 1960s. The earliest reported activities at Tanzilla included geochemical sampling, geophysical surveys, trenching and diamond drilling, apparently aimed at testing the potential for porphyry copper-molybdenum mineralization (Dolmage, Campbell & Associates Ltd., 1971; Fominoff and Crosby, 1971; Smee, 1971; Stevenson, 1973; BC Department of Mines and Petroleum Resources, 1974, p. 511; Clouthier and Vyselaar, 1975; Schroeter, 1977; British Columbia Geological Survey, 2015). Results from the trenching and drilling were never reported. The property was explored intermittently during the 1980s and 1990s, including geochemical and geological work by Akiko-Lori that focussed on the potential for volcanogenic massive sulphide mineralization (Baker, 1992). More recent exploration interpreted Tanzilla as a high-sulphidation epithermal system, based on the extensive silicification, pyritization and localized argillic and advanced argillic alteration (Travis, 2004; Holbek, 2006; 2008). The Tanzilla property was acquired by West Cirque Resources Ltd. in 2011. West Cirque (now Kaizen Discovery Inc.), in partnership with Freeport-McMoRan Corporation of Canada Limited, carried out a geophysical survey and a Terraspec alteration mineral study. The Terraspec-aided field study confirmed the

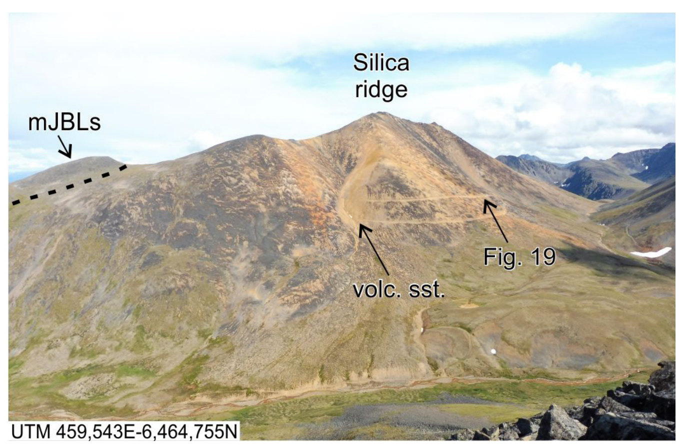


Fig. 18. West side of Silica ridge. Unconformably overlying Bowser Lake sedimentary rocks (mJBLs) are exposed in the far north. Location of Figure 19 indicated, as well as the location where abundant scree of well-stratified volcaniclastic sandstone (‘volc. sst.’, lmJHMv) was observed.

presence of advanced argillic alteration with an assemblage of alunite, pyrophyllite and topaz at the northern part of Silica ridge, and pyrophyllite±topaz at the Gopher zone (Luckman et al., 2013; Fig. 3). Phyllic (quartz-sericite-pyrite), argillic (illite-chlorite-smectite), and intermediate argillic (kaolinite-dickite) alteration assemblages are common throughout the remainder of the Tanzilla gossan. The geophysical and Terraspec study were followed by diamond drilling in 2014 and 2015 (Barresi et al., 2014; Barresi and Luckman, 2015). The goal of the drilling was to test for porphyry-style alteration and mineralization below the strongly altered advanced argillic lithocap exposed at the surface (Barresi et al., 2014).

Field observations made as part of this study focused on establishing protoliths throughout the Tanzilla gossan, and constraining the relationship between alteration, mineralization, and intrusive activity. At Silica ridge, common strong silicification and widespread quartz-clay-pyrite alteration are generally texturally destructive. However, on the northeast ridge, flow-banded rhyolite and rhyolite breccias, and local laminated rocks were observed. On the northwest ridge, local exposures of texturally-intact volcanic breccias were found. We consider these rocks as part of the Horn Mountain Formation upper felsic volcanic unit (Table 1). In the gully northwest of the summit, angular scree of well-stratified volcaniclastic sandstone was observed, similar to the uppermost volcaniclastic interval of the Horn Mountain Formation maroon volcanic unit (see Section 3.1.2.; Fig. 18). On the lower scree slopes west-southwest of the summit, angular blocks of locally layered and felsic flow-banded clast-bearing volcanic breccias were found. The volcanic breccias are themselves hydrothermally brecciated, with angular clasts displaying jigsaw-fit textures set in a dark grey siliceous matrix (Fig. 19). These volcanic breccias are tentatively interpreted as a felsic bed in the Horn Mountain maroon volcanic unit. The Silica ridge alteration system is locally cut by plagioclase and augite-plagioclase porphyries. Based on drill core and surface observations we interpret these porphyries as syn-hydrothermal. In drill core, the porphyries: 1) lack the (advanced) argillic alteration of overlying volcanic rocks; 2) are chlorite-sericite-pyrite, albite to biotite-magnetite altered, and host stockwork veins and hydrothermal breccias; and 3) are cut by a diorite spatially associated with the strongest porphyry-style alteration. At surface exposures, the porphyry dikes lack the intense (advanced) argillic alteration of the surrounding wall rocks, and are chlorite-epidote altered.

Fig. 19. Faintly bedded felsic volcanic breccias (lmJHMv?) cut by medium-dark grey silica-cemented jigsaw-fit hydrothermal breccia.

The Silica ridge alteration system is overlain in the north by weakly altered to unaltered rock types. On the northeast spur, the Horn Mountain upper mafic volcanic unit marks an abrupt change from strong quartz-clay-pyrite alteration in predominantly texturally destructive altered rocks to overlying essentially unaltered augite-phyric flows. The contact occurs in a talus-covered zone approximately 5 m wide. Slightly higher in the stratigraphy, a polymictic conglomerate to breccia contains plagioclase-phyric felsic clasts and grey siliceous clasts in a weakly altered matrix. The siliceous clasts likely represent strongly silicified rock types derived from the underlying Silica ridge gossan. Mafic volcanic rocks of the upper unit exposed along the creek west of Silica ridge are gossanous and altered. This suggests that, at least locally, the basal part of this unit was deposited before (or during) the main hydrothermal event, or during its waning stages. On the northwest spur, conglomerate and sandstone of the Bowser Lake Group overlie strongly altered rocks; the unit is locally epidote-chlorite-pyrite altered, contains abundant hypabyssal clasts and a few pyritic clasts. An angular discordance suggests an unconformable contact (see Section 3.1.3.). The upper mafic volcanic unit was not observed in this location, either as a result of non-deposition or erosion. The Bowser Lake sedimentary unit appears to have been deposited during the waning stages of the hydrothermal event.

The Gopher zone, 2.5 km east-southeast of Silica ridge, trends northwest and is at least 275 m wide (Fig. 3). It consists of strongly sheared silicified rocks and quartz-sericite-clay schists. Blueish lazulite, an anhydrous phosphate mineral, is commonly observed. Drill core (hole TZ15-02, Barresi and Luckman, 2015) and field observations show that the main protolith at the Gopher zone is a variably sheared and altered coarse platy plagioclase porphyry. Strong flattening fabrics in phyllic-altered rocks parallel the borders of the zone. The zone probably formed during post-alteration reverse shearing.

The West gossan is in a valley system 2.7 km west of Silica ridge (Fig. 17). The area is predominantly quartz-sericite-pyrite altered. Beyond the southern edge of the gossan, the alteration changes to chlorite-epidote (propylitic) assemblages. Protoliths in the gossan are difficult to establish due to texturally destructive alteration. However, beyond the southern edge of the gossan a 120 m wide zone of propylitic chlorite-epidote alteration was observed in green altered volcanic breccias that show identical textures, and grade into, the Horn Mountain maroon volcanic unit farther south.

Two north-northeast trending faults on either side of Silica ridge (see Section 5.1., Figs. 3, 17) appear to coincide with significant changes in the distribution and/or style of alteration at the Tanzilla gossan. At the eastern end of the West gossan, quartz-silica-pyrite alteration and unaltered maroon volcanic rocks are separated by a 50 m wide covered area that lines up with a well-developed lineament marked by orange-brown recessive notches on several ridges. Farther north, the lineament appears to form the western end of the Silica ridge alteration system. A second fault is inferred within the valley east of the Silica ridge alteration system. The fault separates the areally extensive Silica ridge gossan from the linear, and much more areally restricted, Gopher zone alteration. In addition, the fault marks the approximate western end of the Early to Middle Jurassic mafic intrusive complex (Table 3).

Observations from diamond-drill hole TZ15-01 (this study; Barresi and Luckman, 2015), drilled on the northern flanks of Silica ridge, are summarized in Figure 20a. The drill hole first intersects strongly texturally destructive intermediate to advanced argillic alteration that grades down to slightly less intense quartz-clay altered felsic volcanic breccias (Fig. 20b), and then a chlorite-pyrite to chlorite-sericite-pyrite altered plagioclase porphyry intrusion. Petrographic observations show that the chlorite-(sericite-)pyrite altered porphyry contains significant biotite hornfels overprinted by hydrothermal sericite (see Section 7.3). The alteration intensity in the porphyry locally increases in a zone of albite-altered quartz-anhydrite-pyrite±chalcopyrite stockwork (Fig. 20c), before grading back into chlorite-pyrite alteration. The alteration in the plagioclase porphyry transitions downward into albite (Fig. 20e) and then potassic alteration assemblages generally associated with areas of more intense hydrothermal brecciation and a coarser-grained dioritic intrusive phase (Fig. 20f). The plagioclase porphyry was sampled for U-Pb zircon geochronology, and an anhydrite-pyrite-molybdenite vein (Fig. 20d) was sampled for Re-Os geochronology (see Section 8). Assay results indicate anomalous copper and molybdenum values in the top and central portion of the drill hole (Fig. 20a; Kaizen Discovery Inc., 2015).

In summary, the relatively broad advanced argillic lithocap at Silica ridge is hosted at the contact between the middle maroon volcanic unit and the upper felsic volcanic unit of the Horn Mountain Formation. The lithocap and volcanic host rocks are cut by plagioclase porphyry and equigranular diorite intrusions displaying porphyry-style alteration and local chalcopyrite mineralization at depth. The Horn Mountain upper mafic volcanic unit and discordantly overlying Bowser Lake sandstone and conglomerate unit were deposited during the waning stages of, and following, hydrothermal activity. A relatively narrow band of advanced argillic alteration at the Gopher zone (east of Silica ridge; Fig. 3) is hosted in a platy plagioclase porphyry intrusion, which was emplaced in the mafic subvolcanic intrusive complex. Post-hydrothermal shearing has significantly affected the Gopher zone.

7. Petrology and lithogeochemistry

In this section we present observations of 28 petrographic thin sections and summarize the preliminary results from 27 lithogeochemistry samples. Full analytical results, trace element plots and further interpretations will be provided in a later publication. With a few exceptions, samples were taken from representative least altered coherent rocks or igneous clasts. Petrographic examination confirmed that most samples have only been affected by low-grade metamorphism, with a low percentage of hydrous and carbonate minerals. Low-grade metamorphic assemblages were observed in mafic samples from the southern and central parts of the area. They include chlorite, carbonate and epidote, mostly in volcanic breccia matrix, which was excluded from the geochemical samples. Two thin sections contain prehnite-clinozoisite or pumpellyite. Very fine-grained biotite±actinolite and biotite hornfels assemblages are in samples from the mafic intrusive complex and upper mafic volcanic unit in the northern part of the area. Two of the felsic samples are heavily silicified, which disqualified them from chemical classification. One sample was excluded based on a high loss on ignition value.

Samples were processed and analyzed at Bureau Veritas (formerly Acme Labs). Samples were crushed to ≥70% passing 10 mesh (2 mm), homogenized, and riffle split. Then a 250 g subsample was pulverized to ≥85% passing 200 mesh (75 µm). A total of 49 elements were analyzed by lithium metaborate/tetraborite fusion and ICP (18 major and minor elements) or ICP-MS (31 trace elements). Loss on ignition values were determined by igniting a sample split and measuring the weight loss. Carbon and sulphur were determined by combustion and Leco analysis. A total of 14 base metals, precious metals and other volatile elements were analyzed by aqua regia digestion of a 0.5 g sample split and ICP-MS. Results of pulp duplicates and internal standards were monitored to ensure analytical reproducibility and accuracy. Major element lithogeochemical results are portrayed in a total alkali vs. silica plot (Fig. 21).

7.1. Alkaline mafic volcanic and subvolcanic rocks

Ten mafic volcanic rock and mafic subvolcanic intrusive rock samples from the upper Spatsizi Formation, lower Horn Mountain Formation and the mafic intrusive complex all show similar microscopic features. The samples contain euhedral to broken, faintly green-yellow pleochroic (Na-rich?), stubby to equant, up to 1 cm augite crystals. Many of these show delicate concentric growth zones. Augite glomerocrysts are common. Plagioclase phenocrysts are generally smaller than augites, but may be as abundant or more abundant. All plagioclases are andesine in composition. The plagioclase crystals display patchy zoning but not oscillatory zoning. Some of the most mafic samples contain chlorite-carbonate-serpentine-epidote pseudomorphs after olivine. The groundmass consists of plagioclase, interstitial K-feldspar and very fine-grained mafic and opaque minerals. The presence of abundant K-feldspar is predominantly based on the intense sodium cobaltinitrite stain of samples. However, in some samples, groundmass K-feldspar can be readily distinguished from plagioclase. One sample shows platy plagioclase megacrysts set in a K-feldspar-rich groundmass (unit EMJpp). Lithogeochemical results show predominantly trachybasalt (potassic trachybasalt, minor hawaiite) to basaltic trachyandesite (shoshonite) compositions (Fig. 21), which accords well with petrographic observations

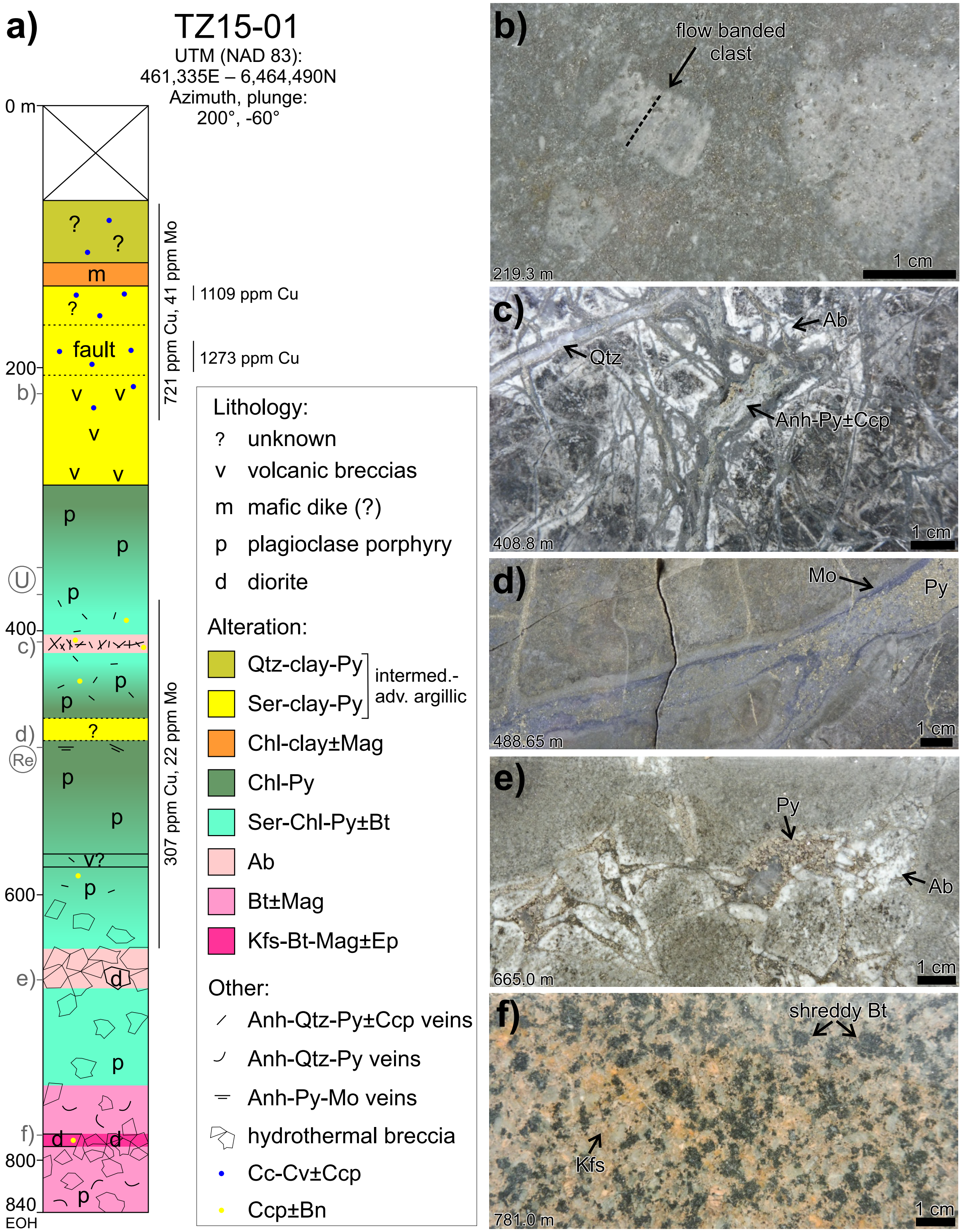


Fig. 20. Diamond-drill hole TZ15-01. **a)** schematic log showing lithology, alteration, veining, hydrothermal brecciation, and mineralization. Photographs illustrate **b)** volcanic breccia texture, including flow-banded clast, **c)** anhydrite-quartz-pyrite-chalcopyrite stockwork with strong albite alteration, **d)** anhydrite-pyrite-molybdenite vein cutting chlorite-pyrite altered rock, **e)** hydrothermally brecciated plagioclase porphyry, and **f)** K-feldspar-biotite altered medium-grained equigranular dioritic intrusive. Sample levels for U-Pb (U) and Re-Os geochronology (Re) indicated. Mineral abbreviations after Kretz (1983); Ser: sericite.

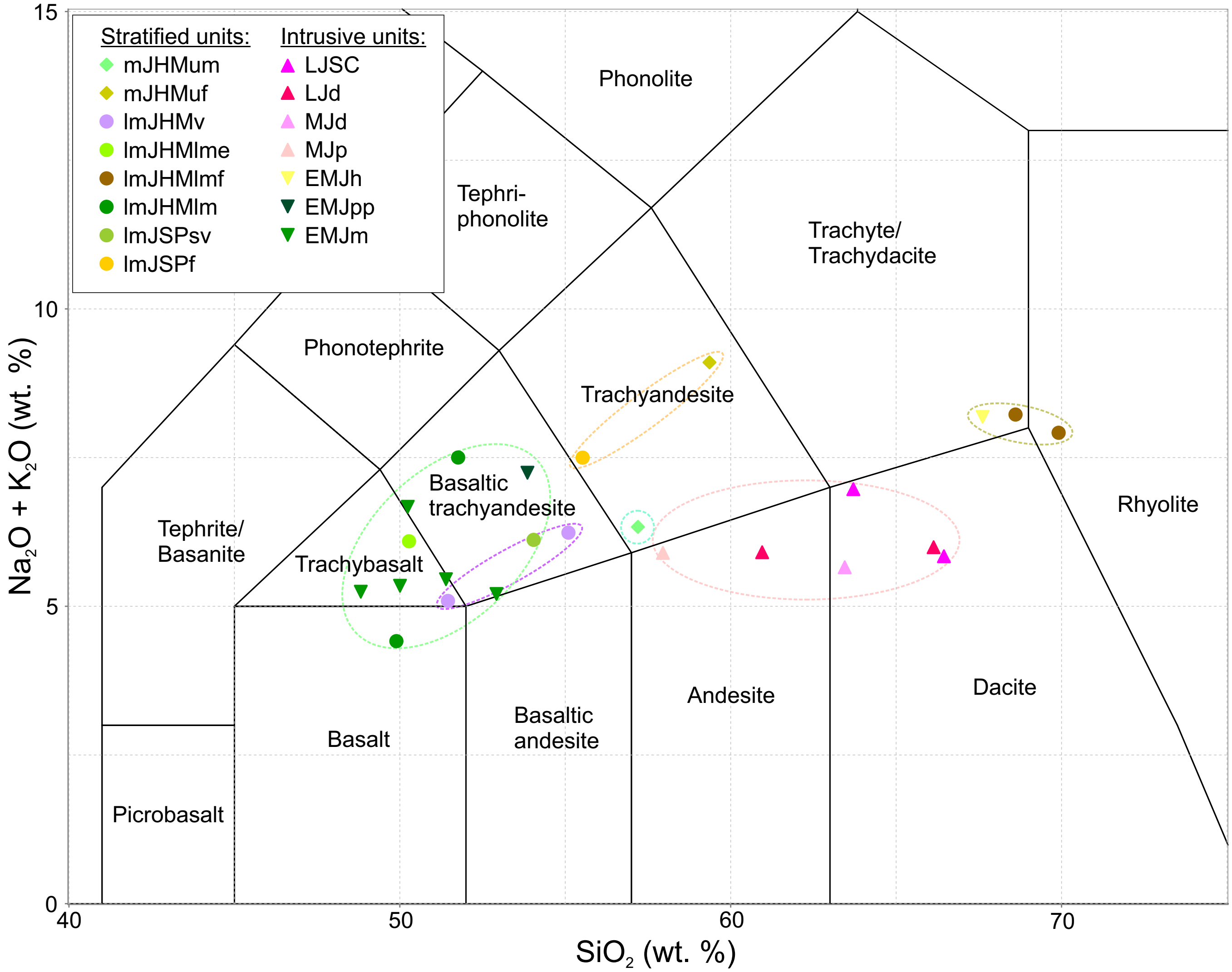


Fig. 21. Total alkalis vs. silica classification diagram (after Le Maitre, 1989) showing results of 24 representative least-altered samples from lithological and intrusive units in the study area.

indicating abundant groundmass K-feldspar in these otherwise mafic rocks.

One sample of the Horn Mountain Formation maroon volcanic unit shows an augite and plagioclase phenocryst population similar to that discussed above. Based on staining, the sample is estimated to contain only small amounts of K-feldspar. This is reflected in the geochemical data showing a trachybasalt composition, with $Na_2O - 2 > K_2O$ resulting in classification as hawaiite (Fig. 21). A sample from a blood red to maroon glassy flow classifies as a basaltic trachyandesite (mugearite), at odds with the original felsic field classification.

A sample from the upper mafic volcanic unit of the Horn Mountain Formation contains plagioclase, augite, and minor hornblende crystals set in a moderately K-feldspar-rich groundmass. The geochemical classification as trachyandesite (latite) is somewhat at odds with the high abundance of augite, dark colour and mafic character of the volcanic unit, and may be caused by biotite hornfelsing, the presence of xenocrystic phases, or cryptic alteration.

7.2. Alkaline felsic volcanic and subvolcanic rocks

Five samples were taken from the Spatsizi felsic volcanic subunit, felsic clasts in the Horn Mountain lower mafic volcanic unit (lmJHMlmf), the Horn Mountain upper felsic volcanic unit and a hornblende-bearing plagioclase porphyritic dike (unit EMJh). In these, plagioclase phenocrysts and (trachytic) plagioclase microcrysts are set in a K-feldspar-rich groundmass. Plagioclase generally lacks oscillatory zoning, except locally in samples from each of unit EMJh and felsic clasts in the lower mafic volcanic unit. The K-feldspar is identified by staining, as it is too fine grained to be resolved optically. The K-feldspar in these rocks is entirely igneous, occurring as a fine-grained, evenly-distributed interstitial component of the groundmass. Only a weak subgreenschist overprint is evident. Plagioclase and augite are generally fresh, veins are absent, and indicators of potassium metasomatism are lacking.

Samples from the Spatsizi platy plagioclase megacrystic volcanic unit and the Horn Mountain upper felsic volcanic unit lie in the trachyandesite field (latites; Fig. 21). This chemical classification captures the potassium-rich nature of these units, but their intermediate (rather than felsic) compositions may be due to abundant large and partly resorbed plagioclase xenocrysts. A more felsic, trachytic, melt composition is suggested based on: 1) a plagioclase and K-feldspar-rich groundmass lacking petrographically observable mafic minerals; 2) trachytic textures, common amygdules, abundant puzzle-fit to clast-supported volcanic breccias and tuffs, indicating hydrous viscous melts and explosive eruptions; and 3) plagioclase-only phenocryst content.

A sample from a moderately plagioclase-phyric dike (unit EMJh) shows abundant very fine-grained groundmass K-feldspar, and is classified as a trachyte. Two samples of felsic clasts in the Horn Mountain lower mafic volcanic unit display plagioclase crystals set in a groundmass with abundant K-feldspar and minor quartz. Based on lithogeochemistry the samples are classified as trachyte and rhyolite (Fig. 21).

7.3. Subalkaline intrusive rocks

The plagioclase porphyry dikes and augite quartz diorite intrusive rocks show little to no modal K-feldspar. Plagioclase is normal and oscillatory zoned, in contrast to the patchy-zoned plagioclase in the alkaline volcanic suite. The plagioclase porphyry samples contain dense mattes of biotite hornfels, or relict biotite hornfels overprinted by sericite. Lithogeochemistry classifies these rocks as andesite to dacite (diorite to granodiorite) and, together with the petrography, suggest a subalkaline affinity.

The Snowdrift Creek pluton was sampled at two locations. Samples are medium-grained equigranular granodiorite to quartz monzodiorite; they contain biotite, hornblende and oscillatory zoned plagioclase. Lithogeochemistry confirms this assignment.

Two samples from post-hydrothermal hornblende diorite dikes show little to no modal K-feldspar and normal- and oscillatory-zoned plagioclase. Lithogeochemical results indicate a diorite to granodiorite composition (Fig. 21).

8. Geochronology

Uranium-lead zircon and argon-argon muscovite studies at the Pacific Centre for Isotopic and Geochemical Research (University of British Columbia) and rhenium-osmium molybdenite studies at the Canadian Centre for Isotopic Microanalysis (University of Alberta) are ongoing and will be reported in detail elsewhere. A sample of plagioclase porphyry (unit MJp) from diamond-drill hole TZ15-01 (Figs. 3, 20) yielded a preliminary U-Pb zircon age of ca. 173 Ma (Fig. 22). R. Friedman (pers. comm., 2015) reports a preliminary U-Pb zircon age of 161-160 Ma from a sample of the Snowdrift Creek pluton collected east of Silica ridge (Fig. 3).

9. Discussion

9.1. Horn Mountain Formation regional correlatives

The Horn Mountain Formation may be more extensive than is presently known. Based on a review of the literature we suggest that equivalent units may be developed more regionally. Taken together, the following occurrences suggest that late Early to Middle Jurassic Horn Mountain volcanism could have occurred over a 110 km-long belt along and near the northeastern margin of Stikinia.

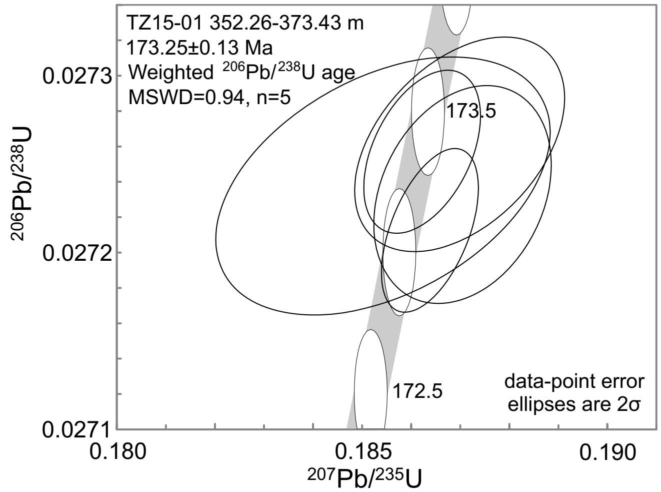


Fig. 22. U-Pb zircon concordia diagram showing chemical abrasion thermal ionization mass spectrometry (TIMS) results for plagioclase porphyry sample (unit MJp) from drill core TZ15-01 (352.26-373.43 m). See Figure 20.

Area 'A'. The area northeast of the junction of the McBride and Stikine rivers has been mapped as undivided Triassic to Jurassic, and Lower Jurassic volcanic rocks (Area 'A', Fig. 1; Gabrielse, 1998; Evenchick and Thorkelson, 2005). In this area a ≥750 m thick succession is composed of red and green epiclastic sandstone, tuff, augite and/or plagioclase-phyric volcanic breccias and flows, rare banded rhyodacite and spherulitic rhyolite (Erdman, 1978; Jones, 1992). The succession lies east of the McBride River pluton, with a 184 ±8 Ma U-Pb zircon age (Anderson and Bevier, 1992). The contact between the pluton and volcanic rocks is not exposed, but apparent contact metamorphic textures may suggest an intrusive relationship (Anderson, 1983). The Lower Jurassic age for some of the volcanic rocks is based on Toarcian fossils and a four-point Rb-Sr whole rock isochron age of 191 ±9 Ma from rocks near Mount Sister Mary (Erdman, 1978). These ages are more consistent with inclusion in the lower part of the Hazelton Group, and may suggest the succession is somewhat older than the Horn Mountain Formation in its type area. However, in the top 100 m of the section, maroon siltstone is interbedded with chert and volcanic clast-bearing conglomerate (Erdman, 1978). Similar maroon volcanic rocks assigned to the Bowser Lake Group are described north of the Pitman fault in the adjacent 1:250,000 scale map sheet (Read and Psutka, 1990; Evenchick and Thorkelson, 2005). The latter two descriptions suggest relationships similar to what we observed between the Horn Mountain maroon volcanic rocks and Bowser Lake chert clast-bearing conglomerates east of the McBride River. Rocks farther west (immediately south of the Hotailuh batholith and north of the Pitman fault) were mapped as undivided Triassic and Jurassic rocks (Evenchick and Thorkelson, 2005). No information is available on the nature of the contacts with the Beggerlay Creek pluton (Late Triassic). They may represent Stuhini Group or Horn Mountain Formation volcanic rocks.

Area 'B'. Volcanic rocks are reported in the northern outlier of Bowser Basin between the Kehlechoa, Kutcho and Pitman faults (Area 'B', Fig. 1). Volcanic rocks assigned to the Bowser Lake Group are well exposed in the east, close to Mount Blair. They are described as dark grey- to mauve- and maroon-weathering feldspar-augite-phyric flows, dark green aphanitic volcanic rocks, and layered pink-, purple- and maroon-weathering tuff (Erdman, 1978; Gabrielse, 1998), similar to the Horn Mountain Formation. Also similar to relationships east of McBride River presented above, near Mount Blair the volcanic rocks are intercalated with chert clast-bearing pebble conglomerate, sandstone, siltstone and shale of the Bowser Lake Group. The volcanic rocks are older than the pluton southeast of Mount Blair, which has a K-Ar hornblende age of 159 ±6 Ma (Erdman, 1978). Sedimentary rocks interpreted as the basal part of the Bowser Lake sequence in the western part of the outlier yielded middle Bajocian fossils (Gabrielse, 1998). If these volcanic rocks correlate to the Horn Mountain Formation, then the upper part of the succession may be as young as late Middle Jurassic.

Area 'C'. Exposed south of the Hotailuh batholith and south of the Pitman fault, the Mount Brock volcanics (Area 'C', Fig. 1) is a >4 km thick succession that conformably overlies Pliensbachian to Toarcian sedimentary rocks of the Spatsizi Formation, which unconformably overlie granitoid rocks correlated with the Railway pluton (Late Triassic; Smith et al., 1984; Read and Psutka, 1990). Strata 100 and 400 m above the base of the Mount Brock volcanics contain early and middle Toarcian ammonites, respectively (Evenchick and Thorkelson, 2005). The succession includes maroon-grey and green volcanic rocks, pink flow-layered rhyodacite, felsic pyroclastic rocks (locally densely welded), grey to light grey bioclastic limestone, and green and maroon tuffaceous sedimentary rocks (Evenchick and Thorkelson, 2005). Phenocrysts in the Mount Brock lava flow deposits are predominantly plagioclase, with subordinate pseudomorphed olivine and augite; they vary from medium-high K basalt to basaltic andesite, to high K andesite, to high K-shoshonitic dacite (Evenchick and Thorkelson, 2005). Intrusions generally concordant with the Mount Brock volcanic strata are correlated with the McEwan Creek pluton, with a U-Pb zircon age of 183.5 ±0.5 Ma (Thorkelson, 1992; Evenchick and McNicoll, 1993). In both stratigraphic position and lithology the Mount Brock volcanics appear similar to the Horn Mountain Formation. Fossil ages from the underlying Spatsizi Formation are similar, or somewhat older. However, the age constraint provided by crosscutting sills correlated with the McEwan Creek pluton suggests that the succession may be slightly older than the Horn Mountain Formation in its type area.

Area 'D'. Immediately west of the Hotailuh batholith Gabrielse (1998) mapped a several square kilometre area underlain by undivided Triassic and Jurassic volcanic rocks that likely represents an erosional remnant of the Horn Mountain Formation (Area 'D' on Figs. 1, 2). Near this area, a stratigraphic section on the north flank of Thenatlodi Mountain, currently interpreted as Lower to Middle Triassic, contains lithologically similar sedimentary strata, with the same stratigraphic architecture, as the Spatsizi Formation section east of Gnat Pass (Iverson et al., 2012).

Area 'E'. Early to Middle Jurassic volcanic rocks have not been reported southwest of Dease Lake (Logan et al., 2012a; b). However, a several square kilometre area of maroon to purple latite, K-feldspar-phyric trachyte, vesicular pyroxene basalt, and minor volcanic sandstone currently interpreted as Late Triassic Stuhini Group are spatially associated with the Hluey Lake biotite-K-feldspar-plagioclase monzonite to syenite (U-Pb zircon age of 166.5 ±0.7 Ma, Logan et al., 2012b; Area 'E', Fig. 1). The maroon volcanic rocks are potassic, mineralogically similar to the intrusive syenite, and have a distinct trace element composition compared to other Late Triassic volcanic rocks (Logan and Iverson, 2013). They may correlate with the Horn Mountain Formation.

9.2. Late Early to early Late Jurassic magmatic activity

The Horn Mountain Formation is part of a broader, multi-stage, alkaline to calc-alkaline Toarcian to Oxfordian magmatic belt that spans the Stikine and Cache Creek terranes in northern British Columbia and southern Yukon.

The late Early to early Middle Jurassic alkaline subvolcanic intrusions related to the Spatsizi Formation and the Horn Mountain Formation represent the earliest stages of magmatism. The belt of volcanic rocks extends for at least 50 km, and perhaps 110 km, in a west-northwest to east-southeast direction (see Section 9.1.).

A later stage includes a northwest to east-southeast trend, at least 300-400 km long, of Middle Jurassic (ca. 170 Ma) quartz-bearing calc-alkaline plutons that span 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 (Fig. 1; Mihalynuk et al., 1992). Several similarly-aged intrusive bodies outcrop between Atlin and Dease Lake, including the Slaughterhouse, McMaster, Llangorse, Tachilta Lakes, Granite Lake, Tanzilla(?) and Pallen plutons (Fig. 1; Gabrielse, 1998; Mihalynuk et al., 2004; Logan et al., 2012a; b). Farther southeast, and immediately south of the study area, is the Three Sisters pluton (Middle Jurassic; Fig. 2). Results from three U-Pb zircon analyses range from 169-171 Ma (Anderson and Bevier, 1992; van Straaten et al., 2012). The 173 Ma calc-alkaline plagioclase porphyry associated with the hydrothermal system at Tanzilla is part of this intrusive phase.

A small quartz-deficient biotite-K-feldspar-plagioclase monzonite to syenite stock spatially associated with local copper and gold mineralization is exposed northeast of Hluey Lakes (Area 'E', Fig. 1; Logan et al., 2012a). The stock yielded a U-Pb zircon age of 166.5 ±0.7 Ma (Logan et al., 2012b) and may represent a feeder system to continued Horn Mountain volcanism during the late Middle Jurassic (see Section 9.1.).

U-Pb zircon ages are lacking for plutons of inferred Middle-Late Jurassic age east of the Three Sisters pluton (Fig. 1), but an intrusive body near Mt. Blair yielded a K-Ar hornblende age of 159 ±6 Ma (Erdman, 1978), and an intrusion near Mt. Albert Dease returned a K-Ar biotite age of 167 ±6 Ma (Wanless et al., 1979). This Middle-Late Jurassic intrusive suite may extend into Quesnellia. An unnamed intrusive body 55 km north of the Snowdrift Creek pluton has yielded K-Ar hornblende ages as old as 157 ±2.4 Ma (Hunt and Roddick, 1987; Gabrielse, 1998). Recent U-Pb zircon geochronology of the Pitman batholith returned 170-171 Ma ages from two samples 3 and 12 km east of the terrane-bounding Kutcho fault (Takaichi and Johnson, 2012).

To date, only one pluton (calc-alkaline Snowdrift Creek) has yielded an early Late Jurassic crystallization age (160-161 Ma, preliminary U-Pb zircon, R. Friedman, pers. comm., 2015). Further work is required to determine how widespread this magmatic pulse is.

9.3. 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 Middle Jurassic, arc is represented by widespread volcanic rocks in southern and central Stikinia (Fig. 1). In general, the magmatic belts and interpreted arc axes shifted progressively from north to south.

During the Late Triassic, voluminous augite-phyric mafic magmatism was predominant along the northern to eastern margin (current reference frame) of Stikinia, resulting in eruption of Stuhini Group 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 in a synorogenic clastic wedge across all three terranes and adjacent parts of the Cache Creek terrane (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., 2015a) as Stikinia accreted with neighbouring terranes to the east and west (Nelson et al., 2013). A final, post-accretionary, 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, proximal to the Cache Creek-Stikinia suture.

Timing of the Cache Creek-Stikinia collision is well constrained as late Early to Middle Jurassic. The youngest Cache Creek cherts that have been overprinted by blueschist facies sodic amphiboles are Pliensbachian to Toarcian (Mihalynuk et al., 2004). Ar-Ar 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 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, and are intruded by a 173-160 Ma belt of plutons that cut the Stikinia-Cache Creek suture zone. Finally, their shoshonitic chemistry is suggestive of a syncollisional origin (e.g. Miocene shoshonites on Fiji, Gill and Whelan, 1989). Lithogeochemical data show that the Middle Jurassic calc-alkaline plutons (Mihalynuk et al., 1992; van Straaten et al., 2012), possible Horn Mountain correlatives (Logan and Iverson, 2013) and Horn Mountain Formation (van Straaten and Nelson, 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; see below).

9.4. Alteration and mineralization

The Tanzilla gossan consists of an advanced argillic lithocap overlying porphyry-style alteration at depth. The system includes: 1) multi-phase calc-alkaline porphyritic to equigranular intrusive rocks; 2) zoned potassic to chlorite-sericite to phyllic to intermediate and advanced argillic alteration; 3) local stockwork veins and hydrothermal breccias; and 4) local chalcopyrite, bornite, and molybdenite in veins and stockworks and as disseminations.

The Tanzilla hydrothermal system formed in the foreland of an actively developing fold-and-thrust belt. The structural regime provided the physical trigger for magmatic activity, and likely influenced the hydrothermal system through block faulting, tilting, and erosion. A down-dropped structural block bound by north-northeast trending faults hosts the Silica ridge alteration system. Evidence for erosion within the Horn Mountain volcano-sedimentary strata is found near the top of the middle maroon volcanic unit, locally with the upper felsic volcanic unit, at and near the base of the mafic volcanic unit, and at the unconformable contact with the overlying Bowser Lake conglomerates. The latter two erosional contacts likely developed during the waning stages of the hydrothermal event; these weakly altered lithologies cover the system to the north. The potential for blind mineralization below the late- to post-hydrothermal cover deserves further attention. The angular discordance at the Horn Mountain-Bowser Lake contact may be explained by approximately 15° northward tilting as a result of ongoing arc-arc collision.

Other mineral showings and prospects in the region have been the subject of early-stage exploration. They are associated with late Early to early Late Jurassic alkaline to calc-alkaline magmatic activity, and show characteristics compatible with calc-alkalic to alkalic porphyry systems. Geological mapping at the McBride gossan about 25 km east-southeast of Tanzilla (Fig. 2) by Teck Resources Limited shows that the property is underlain by grey, green and maroon augite- and/or feldspar-phyric volcanic rocks cut by dioritic dikes (Jutras et al., 2014). A petrographic study shows that the dikes lack modal K-feldspar (Jutras et al., 2014), suggesting they may be part of the same calc-alkaline suite as plagioclase porphyry and dioritic intrusions at Tanzilla. The McBride property hosts widespread phyllic alteration, with local areas of potassic (K-feldspar-magnetite) alteration, quartz-magnetite veins, and hydrothermal magnetite breccias returning anomalous copper and gold values in grab samples (Jutras et al., 2014). Notably, the gossan lacks reports of widespread argillic alteration. The alteration and mineralization may be suggestive of the upper levels of a porphyry system.

The Nup prospect (or MO, MINFILE 104I 059; Fig. 2) is in the Snowdrift Creek valley east of the Gopher zone (Fig. 3). Drilling by Paget Moly Corporation in 2008 intersected volcanic tuffs, platy plagioclase porphyritic intrusions, and biotite granodiorite of the Snowdrift Creek pluton. Anomalous molybdenum values were intersected in several drill holes, generally associated with widely spaced quartz-K-feldspar-molybdenite±chalcopyrite veins (Barresi, 2008). The presence of mineralization in the Snowdrift Creek pluton suggests it is early Late Jurassic or younger.

The Hu prospect (MINFILE 104J 013), northwest of Hluey Lakes, is associated with a Middle Jurassic monzonite to syenite stock (Area 'E', Fig. 1; Logan et al., 2012a; b). K-feldspar and carbonate alteration are concentrated along intrusive contacts and northeast-trending brittle faults, with grab samples returning elevated copper and gold values (Logan et al., 2012a; b).

Post-subduction (syncollisional) porphyry systems around the world range from calc-alkalic porphyry Cu-Mo (Gangdese belt, Tibet; Yang et al., 2009; Wang et al., 2014) to calc-alkalic porphyry Cu and associated high-sulphidation epithermal Cu-Au (Tampakan, Philippines; Rohrlach and Loucks, 2005) to alkalic porphyry Au-Cu (Cadia, Australia; Holliday et al., 2002; Fox et al., 2015). These deposits may provide analogues for porphyry systems associated with the Horn Mountain Formation of British Columbia and their possible, but as yet untested, regional correlatives.

10. Conclusions

In this paper we describe results from one month of fieldwork and preliminary results from lithogeochemical and geochronological studies on an unusual late Early to Middle Jurassic volcanic succession exposed on the northeastern margin of Stikinia. Before 2012, the sequence was interpreted as Stuhini Group (Triassic) and undivided Triassic to Jurassic volcanic rocks. Our work confirms the suggestion of Iverson et al. (2012) that these volcanic rocks are part of the Hazelton Group. The succession postdates widespread arc volcanism of the lower part of the Hazelton Group, is coeval with deposition of predominantly sedimentary rocks of the upper part of the Hazelton Group, and is concurrent with accretion of the Stikine and Cache Creek terranes.

We formally propose the name Horn Mountain Formation for this ca. 5.4 km thick volcanic succession. It consists mainly of green to maroon augite±plagioclase-phyric trachybasalt to trachybasaltic andesite volcanic breccias and lesser plagioclase-phyric to aphyric trachyte to trachyandesite, and is cut by numerous, roughly coeval subvolcanic feeder dikes, sills and stocks. The succession conformably overlies a 0.7-1 km thick Toarcian predominantly sedimentary sequence that we correlate to the Spatsizi Formation, which unconformably overlies the Cake Hill pluton (Late Triassic). The Horn Mountain Formation is unconformably to conformably overlain by Bajocian conglomerates, chert clast-bearing conglomerates, and sandstones of the Bowser Lake Group. Petrographic observations and major element lithogeochemistry indicate that the Toarcian to Bajocian volcanic rocks and related subvolcanic intrusions are largely quartz deficient, K-feldspar-rich and alkaline in composition. 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.

A revised structural interpretation extends the Kehlechoa thrust fault to juxtapose rocks of the Whitehorse trough above Toarcian to Bajocian rocks of the Horn Mountain Formation and Bowser Lake Group. The Snowdrift Creek pluton (early Late Jurassic) stitches the thrust fault, and constrains fault movement to Bajocian-Oxfordian.

The Horn Mountain Formation hosts the Tanzilla gossan, composed in part of an advanced argillic lithocap overlying porphyry-style alteration at depth. A calc-alkaline plagioclase porphyry that hosts porphyry-style alteration yielded a preliminary U-Pb zircon age of 173 Ma.

The alkaline Horn Mountain Formation, calc-alkaline Tanzilla intrusions, Three Sisters plutonic suite and Snowdrift Creek pluton formed during Stikine-Quesnel arc-arc collision. The protracted late Early to early Late Jurassic syncollisional magmatic event represents a potential new metallogenic epoch for the Canadian Cordillera and is prospective for calc-alkalic to alkalic porphyry- and epithermal-style mineralization.

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References cited

Aeroquest Airborne, 2012. Report on a helicopter-borne magnetic survey (Aeroquest Job #11-046) for Geoscience BC. Geoscience BC Report 2012-2, 11p.

Alldrick, D.J., 1993. Geology and metallogeny of the Stewart mining camp, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Bulletin 85, 105p.

Anderson, R.G., 1983. Geology of the Hotailuh batholith and surrounding volcanic and sedimentary rocks, north-central British Columbia. Unpublished Ph.D. thesis, Carleton University, Ottawa, Ontario, Canada, 669p.

Anderson, R.G., and Bevier, M.L., 1992. New late Triassic and early Jurassic U-Pb zircon ages from the Hotailuh Batholith, Cry Lake map area, North - Central British Columbia. In: Radiogenic age and isotopic studies: Report 6, Geological Survey of Canada Paper 92-02, pp. 145–152.

Baker, N.W., 1992. Report on the T-Horn claims, Cry Lake area, Liard Mining Division. British Columbia Ministry of Energy and Mines, Assessment Report 22458, 11p.

Barresi, T., Bradford, J., and Luckman, N., 2014. 2014 Diamond drilling report on the Tanzilla property, northwestern British Columbia. British Columbia Ministry of Energy and Mines, Assessment Report 35471, 46p.

Barresi, T., 2008. Diamond drilling report on the MO property (MO mineral claims). British Columbia Ministry of Energy and Mines, Assessment Report 30933, 22p.

Barresi, T., Nelson, J.L., Dostal, J., and Friedman, R., 2015a. Evolution of the Hazelton arc near Terrace, British Columbia: stratigraphic, geochronological, and geochemical constraints on a Late Triassic – Early Jurassic arc and Cu–Au porphyry belt. Canadian Journal of Earth Sciences, 52, 466-494.

Barresi, T., Nelson, J.L., and Dostal, J., 2015b. Geochemical constraints on magmatic and metallogenic processes: Iskut River Formation, volcanogenic massive sulfide-hosting basalts, NW British Columbia, Canada. Canadian Journal of Earth Sciences, 52, 1-20.

Barresi, T., and Luckman, N., 2015. 2015 diamond drilling report on the Tanzilla property, northwestern British Columbia. British Columbia Ministry of Energy and Mines, Assessment Report, 42p.

BC Department of Mines and Petroleum Resources, 1974. Geology, exploration and mining in British Columbia. British Columbia Department of Mines and Petroleum Resources, 642p.

Bowen, B.K., 2013. Technical report on the Galaxie project. Liard Mining Division, British Columbia, Canada. NI 43-101 Report, 140p. Available from http://sedar.com/.

British Columbia Geological Survey, 2015. MINFILE - British Columbia mineral inventory database. Available from http://minfile.gov.bc.ca/.

Brown, D.A., Gunning, M.H., and Greig, C.J., 1996. The Stikine project: Geology of western Telegraph Creek map area, northwestern British Columbia. British Columbia Ministry of Employment and Investment, British Columbia Geological Survey Bulletin 95, 130p.

Clouthier, G.A., and Vyselaar, J., 1975. Geological and geophysical report on the Tom Group 1. BC Ministry of Energy and Mines, Assessment Report 5769, 6p.

Colpron, M., Crowley, J.L., Gehrels, G., Long, D.G.F., Murphy, D.C., Beranek, L., and Bickerton, L., 2015. Birth of the northern Cordilleran orogen, as recorded by detrital zircons in Jurassic synorogenic strata and regional exhumation in Yukon. Lithosphere, 7, 541-562.

Currie, L.D., and Parrish, R.R., 1997. Paleozoic and Mesozoic rocks of Stikinia exposed in northwestern British Columbia: Implications for correlations in the northern Cordillera. Geological Society of America Bulletin, 109, 1402-1420.

Diakow, L.J., and Webster, I.C.L., 1994. Geology of Fawnie Creek map area (NTS 93F/3). In: Geological Fieldwork 1993, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 1994-1, pp. 15–26.

Dolmage, Campbell & Associates Ltd., 1971. Owl mining claims. Liard Mining division. Physical work for assessment. British Columbia Ministry of Energy and Mines, Property File 19789, 15p.

Erdman, L.R., 1978. Petrology, geochronology and geochemistry of Jurassic volcanic and granitic rocks of the Cry Lake and Spatsizi map sheets, north-central British Columbia. Unpublished B.Sc. thesis, The University of British Columbia, Vancouver, B.C., Canada, 63p.

Evenchick, C.A., and McNicoll, V.J., 1993. U-Pb age for the Jurassic McEwan Creek pluton, north-central British Columbia: regional setting and implications for the Toarcian stage boundary. In: Radiogenic age and isotopic studies: report 7, Geological Survey of Canada Paper 93-2, pp. 91-97.

Evenchick, C.A., and Thorkelson, D.J., 2005. Geology of the Spatsizi River map area, north-central British Columbia. Geological Survey of Canada Bulletin 577, 276p.

Fominoff, P.J., and Crosby, R.O., 1971. Report on magnetometer & induced polarization surveys. Owl Property. Dease Lake area, British Columbia. British Columbia Ministry of Energy and Mines, Assessment Report 3292, 7p.

Fox, N., Cooke, D.R., Harris, A.C., Collett, D., and Eastwood, G., 2015. Porphyry Au-Cu mineralization controlled by reactivation of an arc-transverse volcanosedimentary subbasin. Geology, 43, 811-814.

Gabrielse, H., 1998. Geology of Cry Lake and Dease Lake map areas, North-Central British Columbia. Geological Survey of Canada Bulletin 504, 147p.

Gagnon, J.-F., Barresi, T., Waldron, J.W.F., Nelson, J.L., Poulton, T.P., and Cordey, F., 2012. Stratigraphy of the upper Hazelton Group and the Jurassic evolution of the Stikine terrane, British Columbia. Canadian Journal of Earth Sciences, 49, 1027-1052.

Gillespie, M.R., and Styles, M.T., 1999. BGS rock classification scheme. Volume 1. Classification of igneous rocks. British Geological Survey Research Report RR99-06, 52p.

Gill, J., and Whelan, P., 1989. Early rifting of an oceanic island arc (Fiji) produced shoshonitic to tholeiitic basalts. Journal of Geophysical Research: Solid Earth, 94, 4561-4578.

Hallsworth, C.R., and Knox, R.W.O., 1999. BGS rock classification scheme. Volume 3. Classification of sediments and sedimentary rocks. British Geological Survey Research Report RR99-03, 44p.

Henderson, C.M., and Perry, D.G., 1981. A Lower Jurassic heteroporid bryozoan and associated biota, Turnagain Lake, British Columbia. Canadian Journal of Earth Sciences, 18, 457-468.

Holbek, P., 2006. Tanzilla project. Tan1 to Tan6 and Tanzilla7 mineral claims. British Columbia Ministry of Energy and Mines, Assessment Report 28433, 16p.

Holbek, P., 2008. Tanzilla project. Tan1 to Tan6 and Tanzilla7 mineral claims. British Columbia Ministry of Energy and Mines, Assessment Report 30032, 19p.

Holliday, J.R., Wilson, A.J., Blevin, P.L., Tedder, I.J., Dunham, P.D., and Pfitzner, M., 2002. Porphyry gold–copper mineralisation in the Cadia district, eastern Lachlan Fold Belt, New South Wales, and its relationship to shoshonitic magmatism. Mineralium Deposita, 37, 100-116.

Hunt, P.A., and Roddick, J.C., 1987. A compilation of K-Ar ages: Report 17. In: Radiogenic age and isotopic studies: Report 1, Geological Survey of Canada Paper 87-2, pp. 143-210.

Iverson, O., Mahoney, J.B., and Logan, J.M., 2012. Dease Lake geoscience project, part IV: Tsaybahe group: Lithological and geochemical characterization of Middle Triassic volcanism in the Stikine arch, north-central British Columbia. In: Geological Fieldwork 2011, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 2012-1, pp. 17–22.

Jones, P.J., 1992. Nun claim group. Geological, geochemical report. British Columbia Ministry of Energy and Mines, Assessment Report 22042, 9p.

Jutras, G., Bickerton, L., Stock, L., Thompson, V., and Beckman, S., 2014. Assessment report on geological, geochemical and geophysical work conducted during July and August 2014 on the McBride mineral tenure. British Columbia Ministry of Energy and Mines, Assessment Report 35038, 40p.

Kaizen Discovery Inc., 2015. Kaizen reports 2015 exploration drill results from its British Columbia projects. Available from http://www.kaizendiscovery.com/.

Kretz, R., 1983. Symbols for rock-forming minerals. American Mineralogist, 68, 227-279.

Le Maitre, R.W., 1989. Classification of igneous rocks and glossary of terms. Oxford University Press, Don Mills, 193p.

Logan, J.M., Moynihan, D.P., and Diakow, L.J., 2012a. Dease Lake geoscienece project, Part I: Geology and mineralization of the Dease Lake (NTS 104J/08) and East-Half of the Little Tuya River (NTS 104J/07E) map sheets, northern British Columbia. In: Geological Fieldwork 2011, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 2012-1, pp. 23-44.

Logan, J.M., Moynihan, D.P., Diakow, L.J., and van Straaten, B.I., 2012b. Dease Lake - Little Tuya River geology (NTS 104J/08, 07E). British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Open File 2012-04, scale: 1:50,000.

Logan, J.M., and Iverson, O., 2013. Dease Lake geoscience project: Geochemical characterizaiton of Tsaybahe, Stuhini and Hazelton volcanic rocks, northwestern British Columbia (NTS 104I, J). In: Geoscience BC Summary of Activities 2012, Geoscience BC Report 2013-1, pp. 11-32.

Logan, J.M., and Mihalynuk, M.G., 2014. Tectonic Controls on Early Mesozoic Paired Alkaline Porphyry Deposit Belts (Cu-Au ± Ag-Pt-Pd-Mo) Within the Canadian Cordillera. Economic Geology, 109, 827-858.

Luckman, N., Celiz, M.A.D., Wetherup, S., and Walcott, P., 2013. 2013 assessment report. Induced polarization, terraspec and structural surveys on the Tanzilla property. 2013 assessment report. Soil geochemical survey on the Pliny property. British Columbia Ministry of Energy and Mines, Assessment Report 34550, 24p.

MacIntyre, D.G., Villeneuve, M.E., and Schiarizza, P., 2001. Timing and tectonic setting of Stikine Terrane magmatism, Babine-Takla lakes area, central British Columbia. Canadian Journal of Earth Sciences, 38, 579-601.

Marsden, H., and Thorkelson, D.J., 1992. Geology of the Hazelton Volcanic Belt in British Columbia: Implications for the Early to Middle Jurassic evolution of Stikinia. Tectonics, 11, pp. 1266-1287.

Mihalynuk, M.G., Smith, M.T., Gabites, J.E., Runkle, D., and Lefebure, D., 1992. Age of emplacement and basement character of the Cache Creek terrane as constrained by new isotopic and geochemical data. Canadian Journal of Earth Sciences, 29, 2463-2477.

Mihalynuk, M.G., Nelson, J., and Diakow, L.J., 1994. Cache Creek terrane entrapment: Oroclinal paradox within the Canadian Cordillera. Tectonics, 13, 575-595.

Mihalynuk, M.G., Erdmer, P., Ghent, E.D., Cordey, F., Archibald, D.A., Friedman, R.M., and Johannson, G.G., 2004. Coherent French Range blueschist: Subduction to exhumation in <2.5 m.y.? Geological Society of America Bulletin, 116, 910-922.

Nelson, J.L., Colpron, M., and Israel, S., 2013. The Cordillera of British Columbia, Yukon and Alaska: Tectonics and metallogeny. In: Colpron, M., Bissig, T., Rusk, B. G., and Thompson, J. (Eds.), Tectonics, Metallogeny and Discovery: The North American Cordillera and Similar Accretionary Settings, Society of Economic Geologists Special Publication 17, pp. 53-110.

Nelson, J., and Mihalynuk, M., 1993. Cache Creek ocean: Closure or enclosure? Geology, 21, 173-176.

Read, P.B., and Psutka, J.F., 1990. Geology of Ealue Lake East-half (104H/13E) and Cullivan Creek (104H/14) map areas, British Columbia. Geological Survey of Canada Open File 2241.

Richards, J.P., 2009. Postsubduction porphyry Cu-Au and epithermal Au deposits: Products of remelting of subduction-modified lithosphere. Geology, 37, 247-250.

Ricketts, B.D., Evenchick, C.A., Anderson, R.G., and Murphy, D.C., 1992. Bowser basin, northern British Columbia: Constraints on the timing of initial subsidence and Stikinia-North America terrane interactions. Geology, 20, 1119-1122.

Rohrlach, B.D., and Loucks, R.R., 2005. Multi-million-year cyclic ramp-up of volatiles in a lower crustal magma reservoic trapped below the Tampakan copper-gold deposit by Mio-Pliocene crustal compression in the southern Philippines. In: Porter, T. M. (Ed.), Super porphyry copper & gold deposits: A global perspective 2, pp. 369-407.

Schroeter, T.G., 1977. Mineral property examinations. In: Geological Fieldwork 1976, BC Ministry of Energy and Mines Report 1977-1, pp. 68-70.

Smee, B.W., 1971. Geochemical soil survey on the Lotus group of claims. BC Ministry of Energy and Mines, Assessment Report 3538, 6p.

Smith, P.L., Thomson, R.C., and Tipper, H.W., 1984. Lower and

Middle Jurassic sediments and volcanics of the Spatsizi area, British Columbia. In: Current Research, Part A, Geological Survey of Canada Paper 84-1A, pp. 117-120.
Stevens, R.D., DeLabio, R.N., and Lachance, G.R., 1982. Age determinations and geological studies. In: K-Ar isotopic ages, report 15, Geological Survey of Canada Paper 81-2, p. 56.
Stevenson, R.W., 1973. Report on silt and rock geochemical survey. British Columbia Ministry of Energy and Mines, Assessment Report 4661, 9p.
van Straaten, B.I., Logan, J.M., and Diakow, L.J., 2012. Mesozoic magmatism and metallogeny of the Hotailuh Batholith, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Natural Gas, British Columbia Geological Survey Open File 2012-06, 58p.
Takaichi, M., and Johnson, C., 2012. Assessment report on the 2011/2012 geological and geophysical program at the Pitman property, BC, Canada. British Columbia Ministry of Energy and Mines, Assessment Report 33340, 23p.
Thomson, R.C., Smith, P.L., and Tipper, H.W., 1986. Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia. Canadian Journal of Earth Sciences, 23, 1963-1973.
Thorkelson, D.J., 1992. Volcanic and tectonic evolution of the Hazelton group in Spatsizi River (104H) map-area, north-central British Columbia. Unpublished Ph.D. dissertation, Carleton University, Ottawa, Ontario, Canada, 281p.
Tipper, H.W., and Richards, T.A., 1976. Jurassic stratigraphy and history of north-central British Columbia. Geological Survey of Canada Bulletin 270, 82p.
Travis, A., 2004. Geological, geochemical and prospecting report undertaken on the Tanzilla property. British Columbia Ministry of Energy and Mines, Assessment Report 27435, 25p.
Wang, R., Richards, J.P., Hou, Z., Yang, Z., Gou, Z., and DuFrane, S.A., 2014. Increasing Magmatic Oxidation State from Paleocene to Miocene in the Eastern Gangdese Belt, Tibet: Implication for Collision-Related Porphyry Cu-Mo ± Au Mineralization. Economic Geology, 109, 1943-1965.
Wanless, R.K., Stevens, R.D., Lachance, G.R., and DeLabio, R.N., 1979. Age determinations and geological studies. In: K-Ar isotopic ages, report 14, Geological Survey of Canada Paper 79-2.
Woodsworth, G.J., Anderson, R.G., Armstrong, R.L., Struik, L.C., and van der Heyden, P., 1991. Chapter 15: Plutonic regimes. In: Gabrielse, H., and Yorath, C. J. (Eds.), Geology of the Cordilleran Orogen in Canada, Geological Survey of Canada, Geology of Canada 4, pp. 491-531.
Yang, Z., Hou, Z., White, N.C., Chang, Z., Li, Z., and Song, Y., 2009. Geology of the post-collisional porphyry copper–molybdenum deposit at Qulong, Tibet. Ore Geology Reviews, Special Issue on Metallogenesis of the Tibetan Collisional Orogen, 36, 133-159.