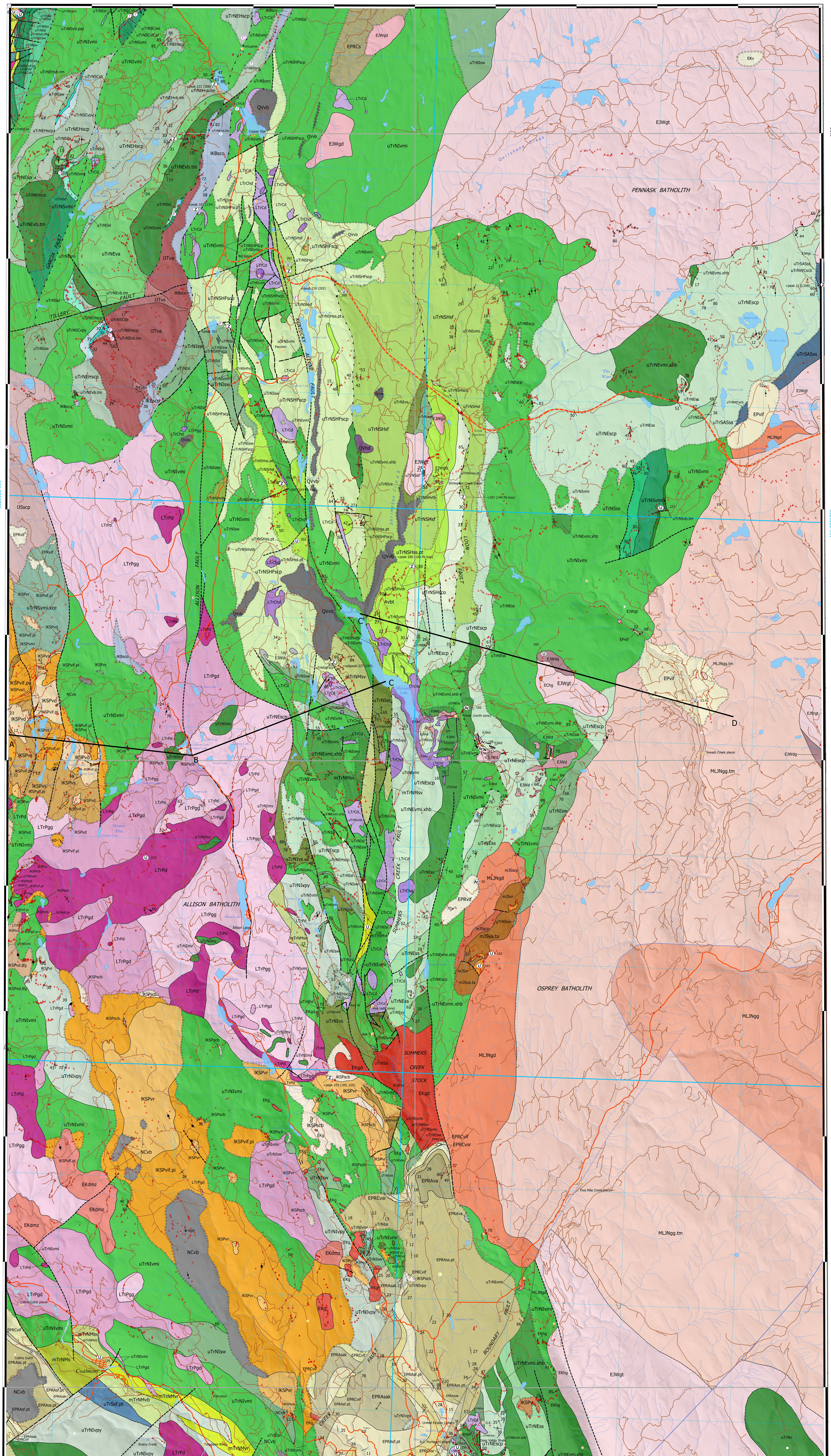
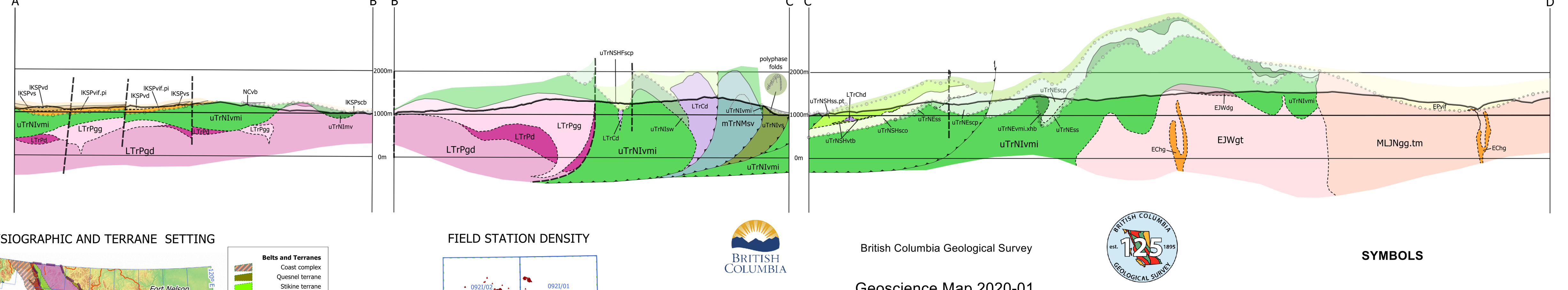
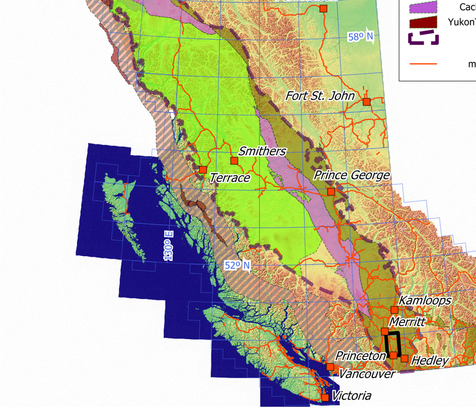


Projection: UTM zone 10, central longitude 120.5°, North American datum 1983

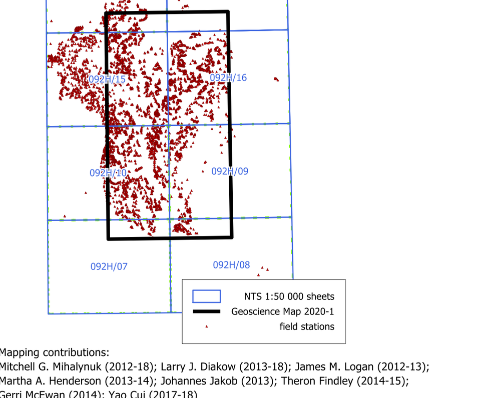
SCHEMATIC CROSS SECTIONS



PHYSIOGRAPHIC AND TERRANE SETTING



FIELD STATION DENSITY



British Columbia Geological Survey

Geoscience Map 2020-01

Sheet 1 of 2

Southern Nicola Arc Geology

NTS 92H/7NE, 8NW, 9W, 10E, 15E, 16W, 92I/1SW, 2SE

Mitchell G. Mihalynuk and Larry J. Diakow

Scale 1:50,000

0 kilometres 5

Recommended citation:
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This is part of a broader compilation:
Diakow, L.J., and Mihalynuk, M.G., in press. Digital geology compilation of southern Quesnel terrane. In: Digital geology of British Columbia. British Columbia Ministry of Energy, Mines and Low Carbon Innovation, British Columbia Geological Survey, https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology

SYMBOLS

- Geological contact: defined, approximate, inferred
- Unconformity: defined, approximate, inferred
- Fault: defined, approximate, inferred
- Thrust fault: defined, approximate, inferred
- Extensional fault, inferred
- Fault, extensional fault, or contact inferred from geophysical data
- Fold hinge (anticline, syncline), form lines
- Bedding: tops known, overturned, inclined, vertical
- Igneous flow fabric, dike (inclined, vertical) 44 65
- Brittle shear; slaty cleavage; schistosity (inclined, vertical)
- Glacial striae: unidirectional, bidirectional
- MINFILE producer, past producer, developed prospect, prospect; commodity: copper, gold, silver, limestone/marl, bentonite, coal, pyrophyllite
- Age data: macrofossil, microfossil, U-Pb TIMS, detrital zircon — F f U Z
- Permian, Triassic, Jurassic, Cretaceous, Paleogene
- Road (divided highway, paved road, gravel road)
- Field station

LEGEND

This legend adopts a consistent, easily parsed, machine-readable format. Descriptive segments are separated by the pipe symbol, '|', as follows: composition | colour, texture | mineralogy | structure | other distinguishing features | interpreted environment, correlation, age (isotopic, fossil). All Nicola Goup 'formation' names used herein remain informal.

Layered Rocks

Anthropocene

*** Avbt** — basaltic trachyandesite | black, red-brown oxidzed surface, glassy, highly vesicular | microlites of clinopyroxene and plagioclase; xenocrysts of quartz, feldspar, and clinopyroxene | scoria, spatter, rare flows | commonly with embedded charcoal | dating of charcoal consistently shows contamination with post-nuclear testing carbon-14 (see Canil et al., 2018)

Quaternary

QVvb — Valley basalt | black, dull grey weathered; highly vesicular | olivine-bearing| multiple, thin flows, columnar jointed || preserved as a sinuous semi-continuous escarpment adjacent to current drainages, which approximate paleovalleys that once channeled these lavas; locally rest upon interglacial sediments, therefore they are Pleistocene

Neogene
Chilcotin Group

NCvb — basalt flows, interflow breccia and oxidized reddish scoria | black fresh, dark brown to tan weathered; aphanitic, amygdaloidal to vesicular | plagioclase microlites, olivine phenocrysts; zeolite and chalcedony amygdules | local columnar jointing | volatile-rich as indicated by interconnected vesicles | can be confused for similar, but younger flows of unit QVvb

Eocene
Kamloops Group

EKv — undivided; andesite, dacite, rhyolite flows, breccia and tuffs; minor sandstone and conglomerate

Penticton Group

EPvif — dacite to rhyolite tuffs predominate, rare ash-flow tuff | greyish white, tan; aphanitic to fine-medium sparsely porphyritic, locally flow laminated, rarely welded | phenocrysts of grey quartz (common), orthoclase (rarely to 1 cm), biotite (common, rarely to 1.5 cm) ± acicular hornblende

Princeton Group

EPRs — undivided; sandstone, conglomerate ||||| rare outlier of possible Allenby Formation overlying Tulameen ultramafite, and encountered by drilling at Copper Mountain mine

EPRvif — dacite to rhyolite flows, minor related breccia and tuffs | light grey groundmass | plagioclase, vitreous hornblende prisms (20%), ± oxyhornblende, biotite (1-2%), trace quartz, ±sanadine | flow laminated | widespread and centred on Fig Lake graben, thickest to the northwest on Spius Formation (Lower Cretaceous) as multiple cliff-forming flows, and thinning to the southeast and east of Shovelnose Mountain, locally as scattered outliers on Shea conglomerate (Jurassic)

Allenby Formation

EPRAva — andesite flows | light to dark grey; vesicular | plagioclase ± olivine phyric ||| high stratigraphically, atop sedimentary units of the Allenby Formation; previously assigned to Upper Volcanic Formation (Read, 1987)

EPRAss.pt — tuffaceous sandstone, minor siltstone, sparse layers of carbonaceous shale and coal; local rhyolitic vitric crystal tuff (Asp Creek and Tailings ash beds) | white to ochre-weathering | tuff contains biotite, quartz, plagioclase and sanadine crystal pyroclasts || waterlain vitric tuffs of both the Asp Creek and Tailing ashes are replaced by heulandite and clinoptilite; minor bentonite

EPRAsf.pt — carbonaceous shale, coal, minor sandstone, rhyolitic vitric-crystal tuff (Snowpatch ash) | grey, maroon || waterlain vitric tuff interval replaced by zeolites, heulandite and clinoptilite; minor bentonite. A similar rhyolite tuff, Princeton ash, higher stratigraphically in the Vermillion shale, lacks zeolite replacement

EPRAscp — volcanic and quartz-pebble conglomerate, volcanic sharpstone conglomerate, coarse wacke | tan to brown |||| possible detrital sources include the Nicola Group and Nelson suite intrusions

EPRAsak — arkosic sandstone, minor siltstone, rare shale; local basal boulder conglomerate | generally white, green-brown at the base |||| correlative with Coldwater Formation in the Merritt basin

Cedar Formation

EPRCvif — intermediate compositions prevail, varying to felsic compositions in a heterogenous combination of flows and volcaniclastic rocks, and lesser sedimentary rocks | aphanitic to porphyritic textures | mainly plagioclase with or without pyroxene, hornblende, biotite and quartz

EPRCvsr — lahar, pyroclastic breccia (?), minor flows; minor sedimentary interbeds | red or brown

Lower Cretaceous
Spences Bridge Group
Pimainus Formation

lKSPv — undivided; andesitic to felsic flows, tuffs; minor sandstone, conglomerate ||||| probably equivalent to the Pimainus Formation

lKSPvd — dacite flows| brownish orange to pinkish; porphyritic with glomerocrysts, rarely amygdaloidal | plagioclase to 4mm (15-20%), rare hornblende | massive with rare flow laminae | cliff-forming unit locally columnar jointed

lKSPvd.tfg — dacitic vitrophyric flows, rare lapilli tuff or welded tuff | greyish weathering; black glass groundmass | medium-grained plagioclase phenocrysts (to 40%) | faint flow laminations locally, generally massive, devoid of layering | sparse entrained angular felsic lapilli | interpreted as a flow dome

lKSPvr — rhyolite flows; local volumetrically minor welded ash-flow tuff| green, weathers whitish mauve or reddish brown with alternating off-white and oxidized red to purplish flow laminations; lithophysae, devitrification to spherulites and nodules| medium-size phenocrysts of plagioclase (10-20%)| local columnar jointing (e.g. at the base and summit of Shovelnose Mountain)

lKSPvmi — basaltic andesite and andesite flows; rare pyroxene-rich sandstone and conglomerate | grey-green and greyish maroon where oxidized; porphyritic, less commonly aphanitic or amygdaloidal | medium-grained plagioclase (20-30%) and chlorite-altered pyroxene (1-3%) ||| similar andesitic flow units occur at multiple stratigraphic levels, and require other distinctive bounding Spences Bridge stratigraphic units in order to distinguish these from identical flows characteristic of the Iron Mountain formation

lKSPvs — sandstone, pebble-cobble conglomerate locally predominant | subangular and rounded || sandstones medium thick, planar bedded and locally cross-laminated; massive unstructured polymictic orthoconglomerate | common carbonaceous plant debris | distinctive mineralogy and felsic clasts supports local provenance from underlying ash-flow tuff (lKSPvif.pi), and abundant rounded granitic clasts represent mixing of detritus from an external source

lKSPvsr — heterolithic volcanic conglomerate; sandstone and siltstone | fine clastic rocks greenish-grey weathering to drab olive green; spheroidal weathering | minute angular plagioclase, traces of hornblende (?) and quartz grains | subhorizontal medium to thickly bedded, interlaminated siltstones with load casts, abundant carbonaceous debris and rare tree trunks | conglomerate (intervals to 30m thick) consists of unsorted subrounded to angular cobbles and boulders (1.5m max) composed of andesite to rhyolite compositions, derived from the Spences Bridge Group | coarse deposits are interpreted as debris flow cutting into, and overlying, shallow water clastic rocks, that together form a lenticular deposit within unit lKSPvif.pi

lKSPvif.pi — dacite to rhyolite ash-flow tuff; derived epiclastic interbeds (see unit lKSPvs) | light green matrix; locally weathers to porcelaneous flaggy fragments, and in some cliff exposures, large diameter cavities develop as a consequence of differential weathering | predominantly lapilli, sparse blocks; angular to subangular | distinctive cognate pyroclasts of rhyolite are light green, off white and pink, aphanitic and lesser flow laminated, accidental granite, and abundant aphanitic and porphyritic andesite; distinctive crystal pyroclasts in trace quantities include quartz and biotite, and ubiquitous plagioclase | except for relatively thin welded intervals identified by fiamme, the unit is typically non-welded and very thick to massively bedded | rare carbonized tree trunks; carbonaceous plant debris is common in clastic beds near the base and top of the unit | represents an explosive, topographically controlled valley-fill deposit, and precursor to effusive rhyolite (unit lKSPvr)

lKSPscb — polymictic conglomerate, sandstone and siltstone interbeds | poorly sorted, matrix to clast-supported || well bedded sandstones, locally cross stratified | rhyolitic detritus (Spences Bridge provenance), also abundant granitic detritus and other lithologies indicate local derivation from underlying sources (i.e. Nicola Group) | heterolithic conglomeratic deposits, at or near base of the Pimainus Formation, represent recurring tectonic instability as the Spences Bridge volcanism commences

Upper Jurassic to Lower Cretaceous
Bates chert conglomerate unit

lKBsco — chert pebble conglomerate with lesser sandstone, argillite and polymictic conglomerate layers near base | orange weathered; unsorted well rounded pebble to boulder-size clasts | grey, greenish and black chert clasts predominate | massive thick beds with sandstone lenses locally displaying low-angle cross stratification || youngest detrital zircon populations ~163 Ma and possibly as young as 134 Ma (Mihalynuk et al., 2016); on the basis of reported Lower Pleinsbachian (Lower Jurassic) radiolaria from chert clasts, a Cache Creek terrane provenance is suspected

Middle to Upper Jurassic
Skwel Peken Formation

mJSvr — rhyolite flows and autobreccia, minor welded tuff | light green |||| comagmatic with the granodiorite marginal phase of the Osprey batholith; U-Pb TIMS age 163.2 ± 0.15 Ma (Mihalynuk et al., 2016)

mJSva.tx — andesite breccia, lesser flows and tuffs | dark green-brown | phenocrysts of plagioclase, ± pyroxene

mJSscp — conglomerate with abundant tuffaceous layers ||||| stratigraphic lowest of three units in an outlier assigned to the Skwel Peken Formation; presumed to represent an extrusive equivalent of the Osprey batholith, marginal phase (unit MLJNgd)

Lower Jurassic

lJTva — Tillery volcanic unit; andesitic flows, breccia, sparse interflow conglomerate | grey-green; fine to medium porphyritic, amygdaloidal | mainly plagioclase, minor pyroxene phenocrysts || radiating white zeolite amygdules | subaerial volcanic unit of uncertain age

lJTvs — Tillery volcanosedimentary unit; lapilli tuff, ash tuff mixed with pebble conglomerate and sandstone, siltstone | maroon | clasts are generally aphanitic to fine feldspar porphyries | poorly to well-bedded | recessive, rubbly-weathering interval | interpreted as the basal bed of the Tillery andesite that locally marks a disconformable contact with the underlying Voght basalt (unit uTrNEvb.tm)

lJSscp — Shea conglomerate unit || polymictic cobbles include granitic, aphanitic to porphyritic volcanic, siliceous mudstone, 'cherty' clasts in shades of grey, black and green | reddish oxidized, unsorted clasts in coarse sandstone matrix; red soil where poorly exposed | an otherwise strikingly similar unit, Harmon conglomerate (unit uTrNEHscp), contains abundant rhyolite and limestone cobbles; maximum depositional age from detrital zircons, <190, 185? Ma (dating site immediately west of map area)

Middle to Upper Triassic (and base of Lower Jurassic)
Nicola Group

uTrNv — undivided; mafic to intermediate volcanic rocks with variable proportions of flows and pyroclastic rocks; rare limestone | shades of dark green to oxidized maroon | typically medium- to coarse-phenocrysts dominated by plagioclase, lesser clinopyroxene, ± scant hornblende

Shrimpton formation (Rhaetian to Hettangian)

uTrNSHsf — siltstone and sandstone, minor argillite locally with rare off-white rhyolitic ash laminations; local impure limestone lenses or thin beds; scarce polymictic pebble conglomerate | grey-black to brown, commonly rusty || thin to medium-thickly bedded | calcareous argillite and limestone locally contain rare ammonoids and pelecypods and ichthioliths, no conodonts | marine sedimentary rocks onlapping the arc-derived clastic apron units represented by the Elkhart fomation and most of the lower Shrimpton formation; zircons extracted from rhyolitic ash tuff return an age of 200.2 ±1.1 Ma

uTrNSHsl — limestone || minor isolated thin beds or lenses ||| all samples collected for conodonts are barren suggesting the strata may be of earliest Jurassic age

uTrNSHvtb — trachybasalt flows and minor autoclastic breccia | grey-green | flesh-coloured, medium-grained analcime diagnostic, augite and plagioclase phenocrysts | isolated thin flows 0.3 m to ~10 m thick, mainly restricted to the Shrimpton unit, uTrNSHss.pt

uTrNSHss.pt — sandstone (tuffite) containing distinctive volcanic-fallout crystal-pyroclasts, polymictic conglomerate || trace quantities of minute (<2mm) crystal pyroclasts include copper-coloured biotite, apatite and quartz | well-bedded fine clastic interval typical, but locally as relatively thin beds within conglomeratic deposits | may contain carbonaceous plant debris, rare fossil crinoids | terrestrial arc-margin depositional setting

uTrNSHsco — monzonite cobble-rich conglomerate, sandstone | orange-weathering; subangular-subrounded monzonite and pyroxene-basalt clasts predominate | massive with thin bedded sandstone layers | may contain diagnostic volcanic-fallout crystal proclasts of biotite and apatite in the matrix; rare plant debris | suspected provenance from pluton unit LTrChd and Nicola volcanic rocks; proximal facies around Iron Mask batholith includes angular, coarse, ±copper-stained blocks

uTrNSHFscp — Fairweather polymictic conglomerate unit; minor sandstone | red to green | clasts mainly of Nicola Group pyroxene-phyric basalt and andesite, lesser monzonite and diorite clasts from the Copper Mountain suite; subangular to subrounded, poorly sorted | typically massive stuctureless beds with thin, faintly bedded sandstone intervals || immature arc-derived conglomeratic deposits, previously interpreted as lahars (Preto, 1979), forming a terrestrial to littoral clastic apron that draped and prograded outward from the Nicola arc margin

Whistle Formation (late Norian to Rhaetian)

uTrNWCscb — Copperfield breccia, and /or conglomerate | grey, buff and pink; well rounded and angular clasts to boulder size | limestone comprises >95% of clasts; matrix contains abundant plagioclase, quartz, chert and volcanic detritus | fine clastic layers display evidence of soft sediment deformation, chaotic bedding | depositional age inferred from cross-cutting Hedley intrusions, including Banbury and Larcan stocks and dated Toronto stock (~195.5 ± 1.2 Ma, Mortensen, 2014) | widespread marker unit at the base of the Whistle Formation; formed by collapse of a Triassic platformal carbonate and west-directed gravity slide onto unconsolidated clastic facies of the Aberdeen Formation (Ray and Dawson, 1994)

Elkhart formation (previously called Paradise and Harmon successions, Mihalynuk et al., 2016)

uTrNEscp — polymictic conglomerate, sandstone, locally prominent augite, ±hornblende andesite porphyry flows | orange weathering; unsorted, rounded and subangular clasts || except for minor bedded sandstone, typically massive | mainly volcanic clasts (Nicola Group source), but locally medium-grained monzonite and diorite are predominant; rare gabbro and pyroxenite; and sparse carbonate | conglomeratic deposits record arc erosion and deposition as an outer arc clastic apron; timing of deposition inferred from 40/39Ar dates obtained from an intercalated hornblende-rich andesite flow (~210 Ma) and similar dike (~207 Ma)

uTrNEss — feldspathic sandstone, siltstone, rare argillite | brown to tan, rusty weathering; fine to medium grained | indistinct planar beds up to metres-thick || generally as thin discontinuous beds within unit uTrNEscp; may be easily confused with similar thick isolated deposits of unit uTrNIsw

uTrNEvmi.xhb — basalt and andesite flows, volcanic breccia; minor conglomerate | dark green, medium to coarse porphyritic and amygdaloidal textures | plagioclase, pyroxene, ±acicular hornblende ||| 40/39Argon dates on hornblende andesite flow (~210 Ma) and similar dike cross cutting unit uTrNEscp (~207 Ma); in absence of distinctive hornblende-phyric flows, this unit is difficult to distinguish from mafic flow unit, uTrNIvmi, of the Iron Mountain formation

uTrNEsl — limestone | grey, locally hematitic ||| thin lenticular beds

uTrNEvs — crystal-ash tuff, lapilli tuff; volcanic siltstone | pale green to white, may be oxidized to maroon; fine grained || finely laminated, graded bedding || silica-rich and hematitic near the Iron Mask batholith

uTrNEvb.tm — Voght basalt, flows and interflow sandstone | green grading to oxidized shades of maroon; megacrystic plagioclase porphyry and amygdaloidal textures | diagnostic plagioclase megacrysts (1.5 cm) and pyroxene phenocrysts | thick , planar bedded (5 to 70 m thick), commonly separated by recessive, bedded sandstone || eruptive age unknown; however, tentatively included as a medial arc volcanic facies in the Elkhart formation

uTrNEva — Voght andesite, flows, lapilli tuff, and minor sandstone | grey-green, medium porphyritic and amygdaloidal textures | diagnostic oxidized red-rimmed pyroxene phenocrysts ||| eruptive age unknown; stratigraphically below unit uTrNEvb.tm; dramatic lateral thickness variation

uTrNEHvb.tm — basalt, flow and/or sill(?) | dark green; megacrystic porphyry | plagioclase laths to 7mm || interpreted as a solitary flow unit (to 20m thick); locally at the base of the Harmon conglomerate, and elsewhere as an interlayer within the conglomerate

uTrNEHscp — Harmon conglomerate and recessive thin sandstone | reddish oxidized hematitic groundmass, poorly sorted, polymictic rounded clasts to boulder size | distinguished locally from similar oxidized conglomerates (specifically units lJSscp and uTrNEscp) by abundant clasts of limestone and flow-banded rhyolite (provenance from underlying Castillion member, Selish Mountain formation); interlayered sandstones may contain coaly detritus | interpreted as a terrestrial, intra-arc coarse clastic facies, marking a regional erosional unconformity and end of the main constructional stage of the Nicola magmatic arc, that spanned approximately 240 to 214 Ma

Selish formation (early to middle Norian; Western belt upper stratified unit of Mihalynuk et al., 2016)

uTrNSss — sandstone and siltstone, limestone-pebble-cobble conglomerate | light to dark grey | medium to coarse grained | abundant plagioclase, pyroxene, and sparse limestone pebbles in sandstones | mudstone rip-up clasts in sandstone, load cast, local convolute bedding in silt-sandstone indicate slumped soft sediment deformation | conglomerate clasts are mostly limestone with lesser basalt and rare white aphanitic clasts of probable volcanic origin

uTrNSvd.pac — dacitic fine lithic and crystal-ash tuffs | light green to maroon ||| distinguished by up to 2% quartz grains

uTrNSsl — limestone | grey ||| isolated limestone beds and lenses

Intrusive Rocks

Quaternary

QVhd — gabbro |||| interpreted as a volcanic neck and possible feeder to unit QVvb flows

Eocene
Coryell suite

EChg — rhyolite | yellow, buff to white, aphyritc to megacrystic porphyritic | K-feldspar, smokey quartz | dike, possible volcanic neck east of Missezula Lk | includes possible feeder to Penticton Group strata

Early Cretaceous

EKdmz — monzonite, syenite | shades of reddish orange; medium to coarse grained, equigranular or porphyritic | <5% chlorite-altered mafic minerals ||| isolated small stocks which may be cogenetic with nearby monzonite-syenite dikes that comprise a northerly-trending swarm that crosscut Spences Bridge Group strata

EKg — leucogranite to mafic microdiorite | pink to dark grey ||| formerly included with 'Allison Creek stocks' of Preto (1979), nomenclature now abandoned

EKgd — granodiorite, quartz monzonite, minor granite | grey to pink; medium to coarse grained | biotite-hornblende || mafic xenoliths common | includes several undated, poorly exposed intrusives near the summit of Shovelnose Mtn. and Summers Ck. stock

EKhg — granitic, felsite, syenitic to monzonitic dikes | white, buff, orange, pink; typically coarse-grained porphyries and aphanitic textures | plagioclase, ±orthoclase, ±quartz, biotite, ±hornblende | rarely flow banded | typically as multiple, parallel north-trending dikes in swarms (evident at Copper Mountain deposit, where known as 'Mine dikes'); contact relationships elsewhere suggest that felsic dikes were emplaced synchronously adjacent to dioritic dikes (unit EKhd) | comagmatic with the Verde Creek pluton, and probable feeder dikes to volcanic units of the Spences Bridge Group

Late Jurassic

LJd — diorite| grey, rusty weathered; fine grained | hornblende-bearing | dike containing blebs, veinlets and disseminations of chalcopyrite in the Southwest zone at Miner Mountain prospect

Middle to Late Jurassic
Nelson suite (Osprey batholith)

MLJNgg.tm — granite, granodiorite | white to pinkish grey | medium to coarse grained | with or without megacrysts of potassium feldspar, up to 15 % biotite>hornblende || non-magnetic phase generally lacks megacrysts, is denoted MLJNgg

MLJNgd — granodiorite, quartz monzodiorite; minor diorite and quartz diorite | greyish pink, medium to coarse equigranular | up to 15 % mafics dominated by biotite and lesser hornblende ||| border phase of the Osprey batholith

Early Jurassic
Wildhorse suite (Pennask and Bromley batholiths)

EJWgd — granodiorite predominates, local tonalite to quartz diorite || biotite-hornblende bearing ||| plug/stock sized bodies peripheral to larger Wild Horse, Pennask and Bromley batholiths which are predominantly composed of this unit

EJWgt — tonalite to quartz diorite with late, pink pegmatite and aplite dikes at the margin (Pennask); granodiorite with diorite and quartz diorite localized near border (Bromley) || light grey to pink; medium to coarse grained, equigranular | hornblende and biotite generally <15%; sphene-rich at Pennask || amphibole ± biotite hornfels developed locally at contact with country rocks (unit uTrNmh)

EJWd — diorite, quartz diorite, monzodiorite, rare gabbro | grey; medium to coarse grained, holocrystalline and porphyritic | ubiquitous pristine hornblende (<20%) || small stocks and dikes

EJWdg — gabbro, quartz gabbro, diorite | dark green; medium to coarse grained, equigranular; locally gabbroic pegmatite | hornblende ± biotite, or pyroxene || minor isolated intrusive phases peripheral to Pennask and Bromley batholiths; includes Mount Riordon stock, probably a satellite of the Bromley (Ray and Dawson, 1994); U-Pb age of ~193 Ma (Mihalynuk et al., 2016)

Late Triassic

LTrNShf — rhyolite | light green, aphanitic to sparsely porphyritic | plagioclase phenocrysts | local sub-horizontal columnar joints | chalcedony and comb-textured veinlets | interpreted as hypayssal intrusions comagmatic with the Castillion member, Selish formation

Copper Mountain suite

LTrChyx — monzonite breccia | breccia of hydrothermal origin carrying copper mineralization at Big Kidd and Ketchan properties

LTrChd — monzonite, syenite, feldspar porphyry | orange, salmon pink and grey-green, medium-grained porphyries | predominantly zoned plagioclase, potassium-feldspar, augite, ±hornblende | locally brecciated || interpreted as subvolcanic intrusives, locally associated with mineralized hydrothermal breccia (unit LTrChyx, Big Kidd and Ketchan properties); also probable erosional source for monzonite clast-rich conglomerate in the Shrimpton formation (unit uTrNSHsco); elsewhere presumed association with breccia and tuffs at Dufferin Hill (Iron Mask batholith)

LTrCd — diorite, syenodiorite, quartz diorite, gabbro, diorite breccia | fine to medium grained; equigranular to porphyritic | pyroxene, less commonly hornblende-bearing || intense saussurtization and potassium feldspar alteration where they host mineralization (e.g. Miner Mtn, Ketchan and Axe developed prospects) | main distribution of plug-size bodies in a north-trending tract between Princeton and Merritt, also includes isolated plugs, some in contact with gabbro-pyroxenite (unit LTrCdg) intruding the Nicola Group, exposed between Tulameen ultramafite and Copper Mountain stock

Mount Pike suite (Allison batholith)

LTrPgg — granite, quartz monzonite | pink to oxidized reddish orange; medium grained, equigranular, locally miarolitic | chloritized biotite (1-5%) ||| granite, the youngest phase (circa 223 Ma) of the Allison batholith, extends south and southwest beneath Spences Bridge Group strata, resurfacing with other phases of the batholith as satellite intrusions

LTrPgd — granodiorite | pink or greyish, medium grained |||| the granodiorite phase of the Allison batholith extends to the south and southwest beneath Spences Bridge Group strata, resurfacing with other phases of the batholith as satellite intrusions

LTrPd — diorite, minor quartz diorite, rare gabbro | dark green, medium to coarse grained, inequigranular | pyroxene and/or hornblende-bearing, chlorite-epidote altered ||| diorite is presumed to be the oldest phase of the Allison batholith, which extends to the south and southwest beneath Spences Bridge Group strata resurfacing near Tulameen townsite as a multiphase satellite intrusion, and farther northwest, the batholith's extent is considered represented by small isolated dioritic apophyses

BC Geological Survey

BCGS Geoscience Map 2020-01

Sheet 2 of 2

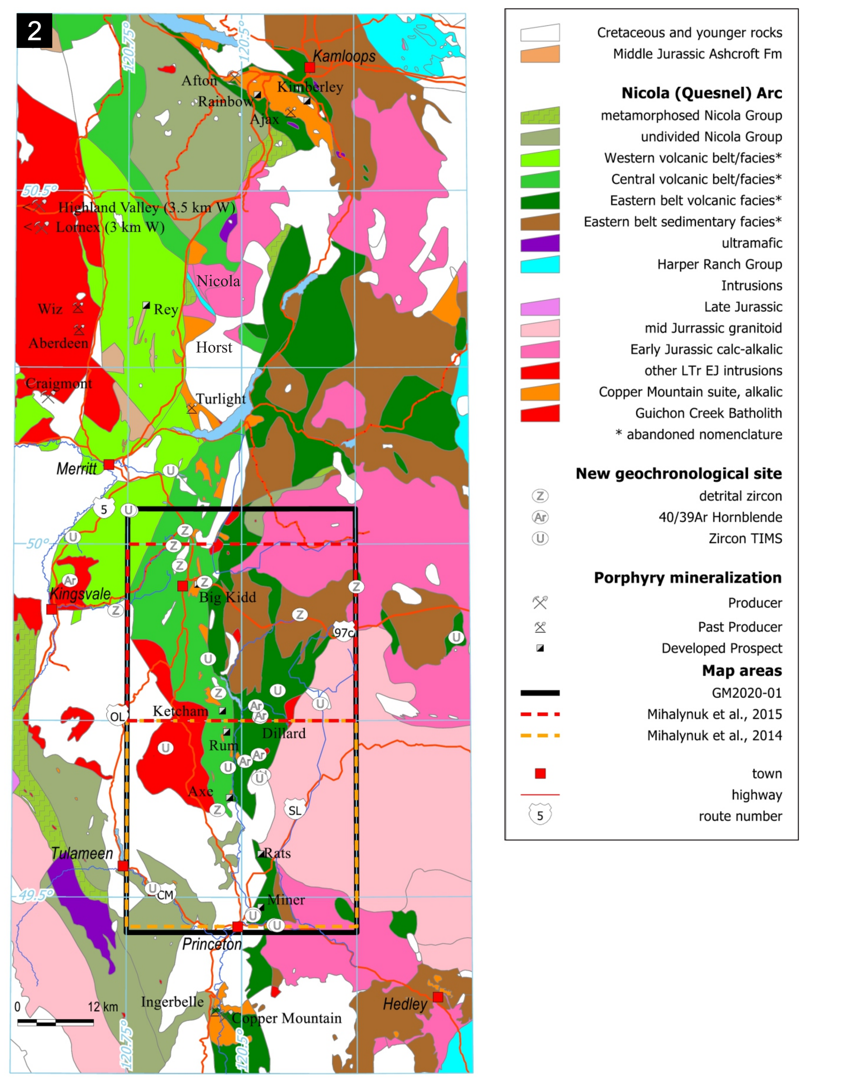
NTS 92H/7NE, 8NW, 9W, 10E, 15E, 16W, 92I/1SW, 2SE

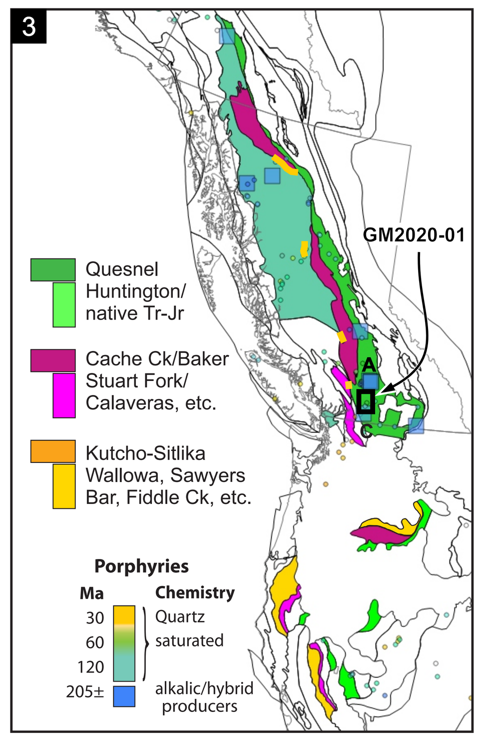
Southern Nicola Arc Geology

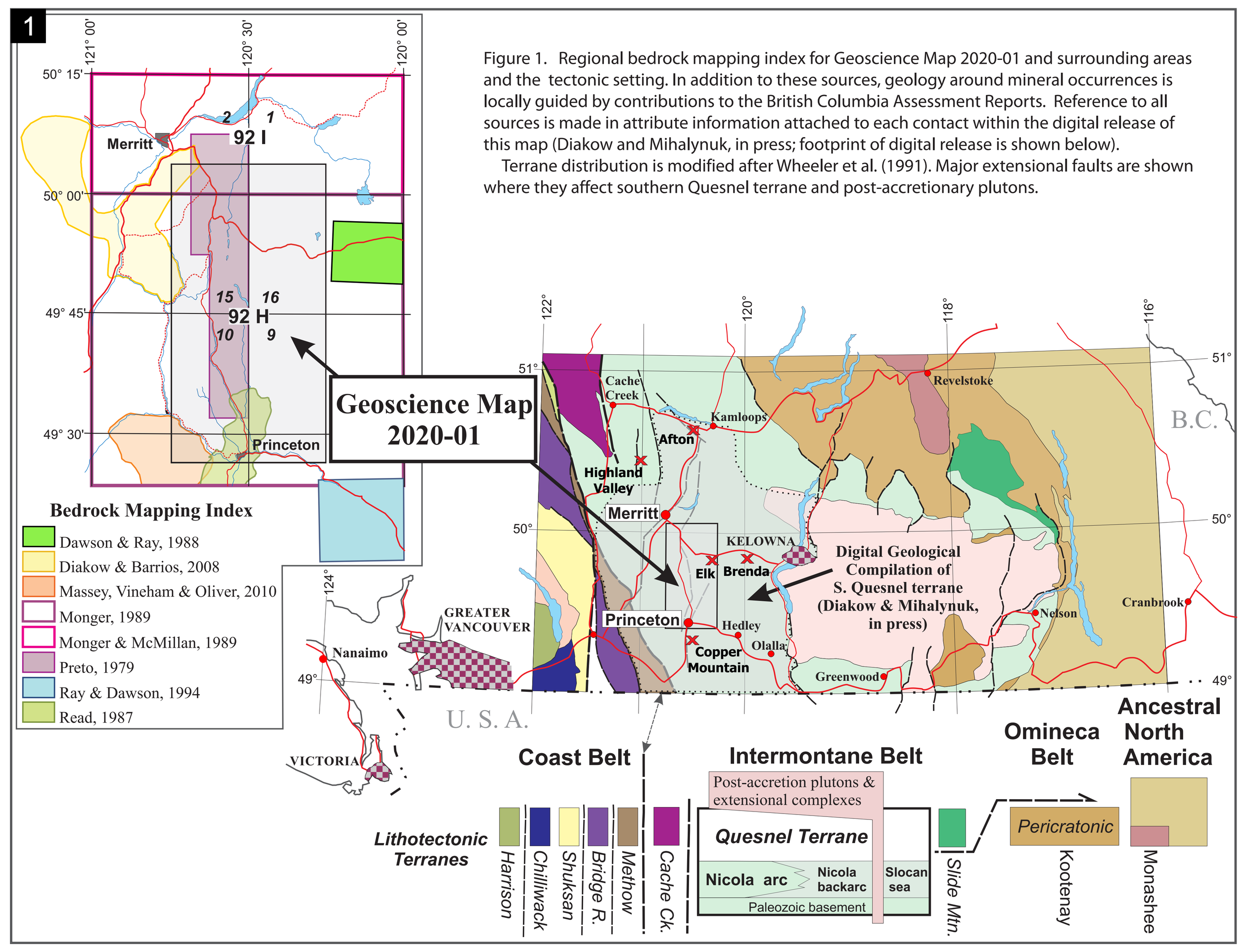
Mitchell G. Mihalynuk and Larry J. Diakow

SUPPLEMENT

digital files available for download at:
https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/publications/geosciencemaps







History of work

The earliest geological mapping in the area was by Dawson (1879) who named the Nicola Group. Systematic regional mapping was conducted in the north by (Cockfield, 1948) at ~1:250 000-scale. Within and adjacent to the map area, detailed mapping focussing on the Nicola Group began with Schau (1968; Fig. 1) and was expanded to the central corridor of the southern Nicola arc with local mapping (Christopher, 1973; Lefebure, 1976). These studies were integrated with 1:50 000 scale mapping between Merritt and Princeton (Preto, 1979), and all were incorporated into regional 1:250 000-scale maps produced by Monger (1989) and Monger and McMillan (1989). In the west and northwest, mapping by Diakow and Barrios (2008) focussed on Early Cretaceous volcanic rocks. In the south, early regional mapping was by Rice (1947) at ~1:250 000-scale, followed by more detailed mapping of coal-bearing Eocene rocks in Princeton basin by McMechan (1983) and Read (1987), which was incorporated into 1:50 000 scale mapping by Massey et al., (2010).

Owing in part to its important metal endowment, the southern Nicola arc has been extensively explored (see reviews in Preto, 1979; Mihalynuk and Logan, 2013a, 2013b; Mihalynuk et al., 2014a, 2015; and references therein). Since 2012, the Southern Nicola Arc Project (SNAP; Mihalynuk and Logan, 2013a, 2013b; Mihalynuk et al., 2014a, 2014b, 2015, 2016) has remapped at 1:20 000-scale an area situated between the producing deposits at Copper Mountain to the south (Preto and Nixon, 2004) and Iron Mask batholith to the north (Logan and Mihalynuk, 2006; Fig. 2). Geoscience map 2020-01, is a synthesis of results from the Southern Nicola Arc Project (SNAP) at 1:50 000-scale. It benefits from new geochronological data (Fig. 4) and it presents a redefined Nicola Group with new informal lithostratigraphy (Fig. 5).

Regional geological setting and tectonic history

Southern Nicola arc has traditionally been considered rooted on Paleozoic basement elements (Read and Okulitch, 1977) included as part of the Quesnel terrane (Coney et al., 1980). These comprise disparate stratigraphy with sedimentary rocks that contain fossils as old as Ordovician (Read and Okulitch, 1977; Pohler, et al., 1989) to Permian, and volcanic rocks of both island and MORB tectonic affinities (Massey and Dostal, 2013; Mortensen et al., 2017). At the latitude of the present study area, but beyond its borders, diverse oceanic rocks comprise Quesnel basement. West of Princeton, these rocks have been mapped as the Eastgate-Whipsaw assembblage (Fig. 6; Massey et al., 2010) and dated as Early Permian (~281 – 283 Ma; Oliver, 2011). East of Hedley, the Quesnel basement rocks have been referred to by many names. Those closest to the southern part of the map area are the Apex Mountain complex (Monger, 1989); farther east are the Kobau, Knob Hill, Attwood, and Anarchist 'groups' or 'assemblages'. Those near the northern part of the map area are the Harper Ranch and Chapperon groups. Protolith ages range from Devonian to Early Permian and magmatic components are chemically and isotopically primitive, with little evidence of a continental margin substrate (Ghosh, 1995; Massey et al., 2013; Massey and Dostal, 2013). However, evidence of an old continental margin affiliation is seen in Precambrian detrital zircon populations recovered from Paleozoic basement stratigraphy in the Apex Mountain complex (Mortensen et al., 2017). Similar detrital zircon populations are also found in overlying Upper Triassic Slocan Group in strata of the former Hedley basin that lie unconformably on Apex Mountaion complex unpublished data). Erosion and transport of these old zircon grains directly from western North America may have occurred during the Triassic, but they could also be recycled from Paleozoic sedimentary strata of the Apex Mountain complex that had received North American-sourced detritus.

Paleozoic arc rocks are known regionally as the Harper Ranch Group and are widely considered as originating on the flank of western North America as the arc sparked to life in the Devonian (Monger et al., 1972; Monger, 1977; Mihalynuk et al., 1994; Ferri, 1997), as early as ~390 Ma (Massey et al., 2013). Most paleogeographic models invoke extensive back-arc basin formation as this Paleozoic Quesnel arc was rifted from its continental margin homeland (e.g., Harms, 1986; Ferri, 1997). It may have rooted in the continental margin to the south forming a hybrid oceanic arc/back-arc basin like the modern Aleutian arc (Fig. 7; Nelson, 1993; Mihalynuk et al., 1994). As the back-arc basin grew to oceanic proportions, Quesnellia apparently became sufficiently isolated from North America to permit the colonization of endemic organisms, the fossil remains of which are not seen in adjacent parts of cratonic North America today (Ross and Ross, 1983, 1985; Belasky et al., 2002; see discussion in Roback and Walker, 1995, and Ferri, 1997).

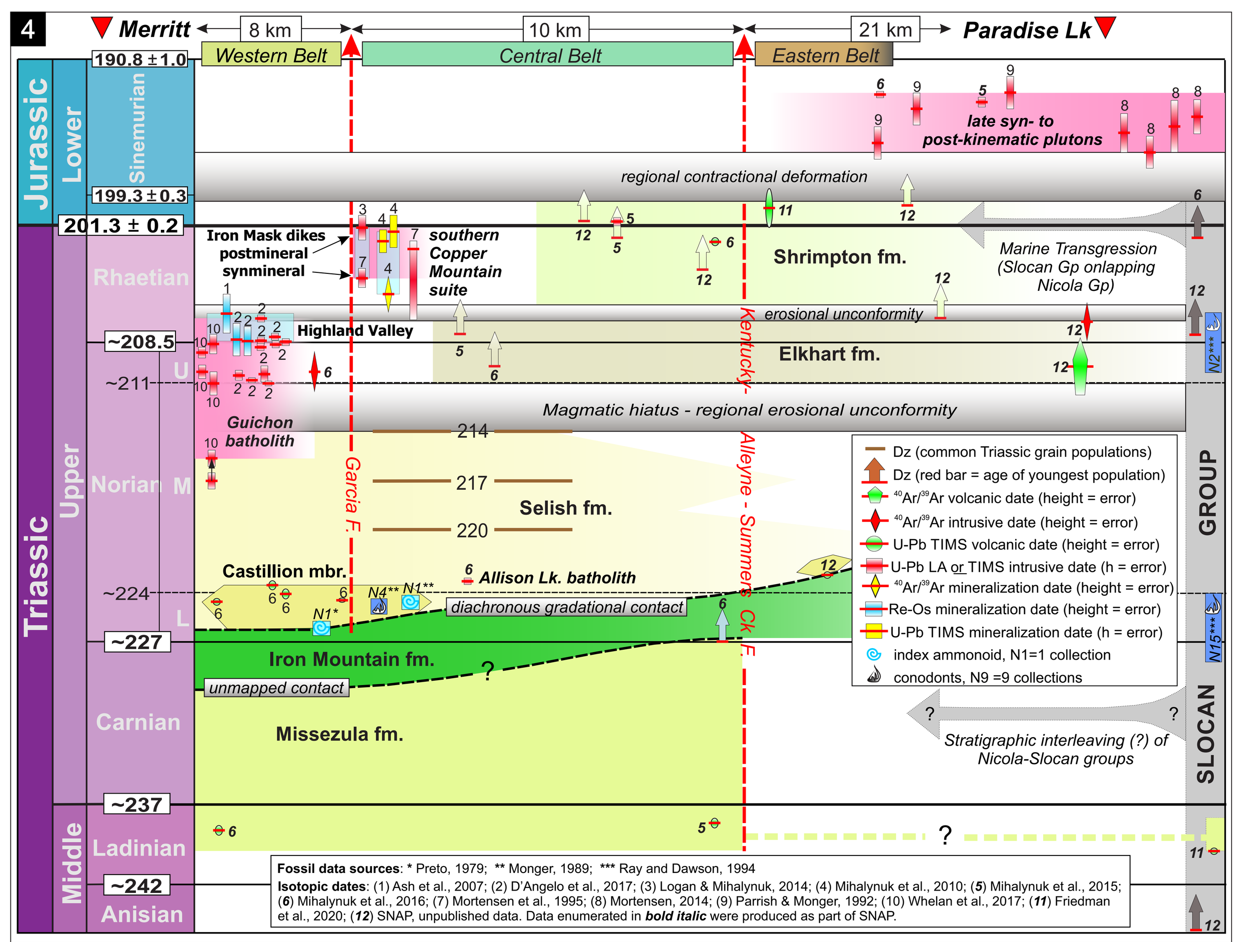
Consumption of the overgrown back arc basin is thought to have began in the Permian. However, evidence for a subduction complex between Quesnel terrane and North America is lacking in central BC (e.g. Ferri, 1997) and in southern BC, even evidence of arc magmatism is scarce, limited to clasts in sedimentary rocks (Beatty et al., 2006); although it has been

Southern Nicola Arc Project field mappers

Mitchell G. Mihalynuk (2012-18); Larry J. Diakow (2013-18); James M. Logan (2012-13); Martha A. Henderson (2013-14); Johannes Jakob (2013); Theron Findley (2014-15); Gerri McEwan (2014); Yao Cui (2017-18)

Age determinations

Isotopic dates by R. Friedman (UBC); Microfossil identifications by M. Orchard (MJO Microfossil Services)



porphyry and hornblende-augite-basalt porphyry, monzonite, diorite, and relatively scarce limestone, gabbro and pyroxenite; all lithologies of the Nicola Group or nearby comagmatic plutons.

Mafic flows form discontinuous beds and locally thick accumulations within the clastic deposits. Several compositional clans of basalt to basaltic andesite porphyries exist, distinguished by the relative proportions of plagioclase, hornblende and pyroxene phenocrysts. Isolated, thin dikes intrude the polymictic conglomerates. $^{40}Ar/^{39}Ar$ dates on hornblende from a hornblende-phyric flow and from a dike cutting sandstone are ~210 Ma and ~207 Ma, respectively.

An outlier of Elkhart formation in Kane Valley (former Harmon succession) southeast of Merritt differs from facies to the east near Elkhart Lake. A conspicuous, maroon-weathering basal conglomerate (Harmon conglomerate, unit uTrNEHscp) of substantial thickness (~ 560 metres), underlies the valley bottom and exhibits an abrupt erosional unconformity with underlying carbonate of the Castillion member, Selish formation. Clasts in the conglomerate are flow-banded rhyolite, dacite, and limestone boulders derived exclusively from the Selish formation. It grades upwards into recessive maroon sandstone interbeds in a volcanic-dominant 'Voght' subunit (uTrNEva, vb) in which lower andesite flows are overlain by an interval of distinctive coarse bladed plagioclase porphyritic basalt flows collectively forming up to 750 metres of section. The youngest detrital zircon populations from the Harmon conglomerate have returned maximum ages for deposition on detrital zircons of <222 (peak, with youngest multigrain population ~208), and ~220 Ma (peak, with youngest reliable multigrain population ~213) from a sandstone bed positioned higher stratigraphically, close to the contact with the overlying 'Voght' subunit.

Shrimpton formation

The Shrimpton formation (previously referred to as Shrimpton succession in Mihalynuk et al., 2015) is the youngest stratigraphic unit of the Nicola Group. Widespread in the central and eastern parts of the map area, it comprises three main depositional subunits that unconformably overlie the Elkhart formation. Stratigraphic lowest and oldest is a monzonite clast-rich conglomerate up to 390 m thick that occupies an eastward-emplaced thrust panel, the trace of which is well exposed along the Coquihalla Connector at Loon Junction. The other subunits, presumed to occupy a slightly higher stratigraphic positions, comprise coextensive and contemporary stratigraphy that differ significantly in lithology and depositional setting. They consist of marine clastic deposits which cover a broad area in the east-central map area and, in the west, pass across a gradational contact into terrestrial conglomerate deposits.

The marine clastic unit generally weathers recessively and is mainly composed of layered sandstone and siltstone, rare thin limestone and minor pebble conglomerate locally containing notable tuffaceous components of crystal pyroclasts or ash-tuff laminae. Ultrapotassic basalt, distinguished by analcime phenocrysts, form discontinuous exposures rarely up to several tens of metres thick in the tuffaceous sandstone-siltstone unit.

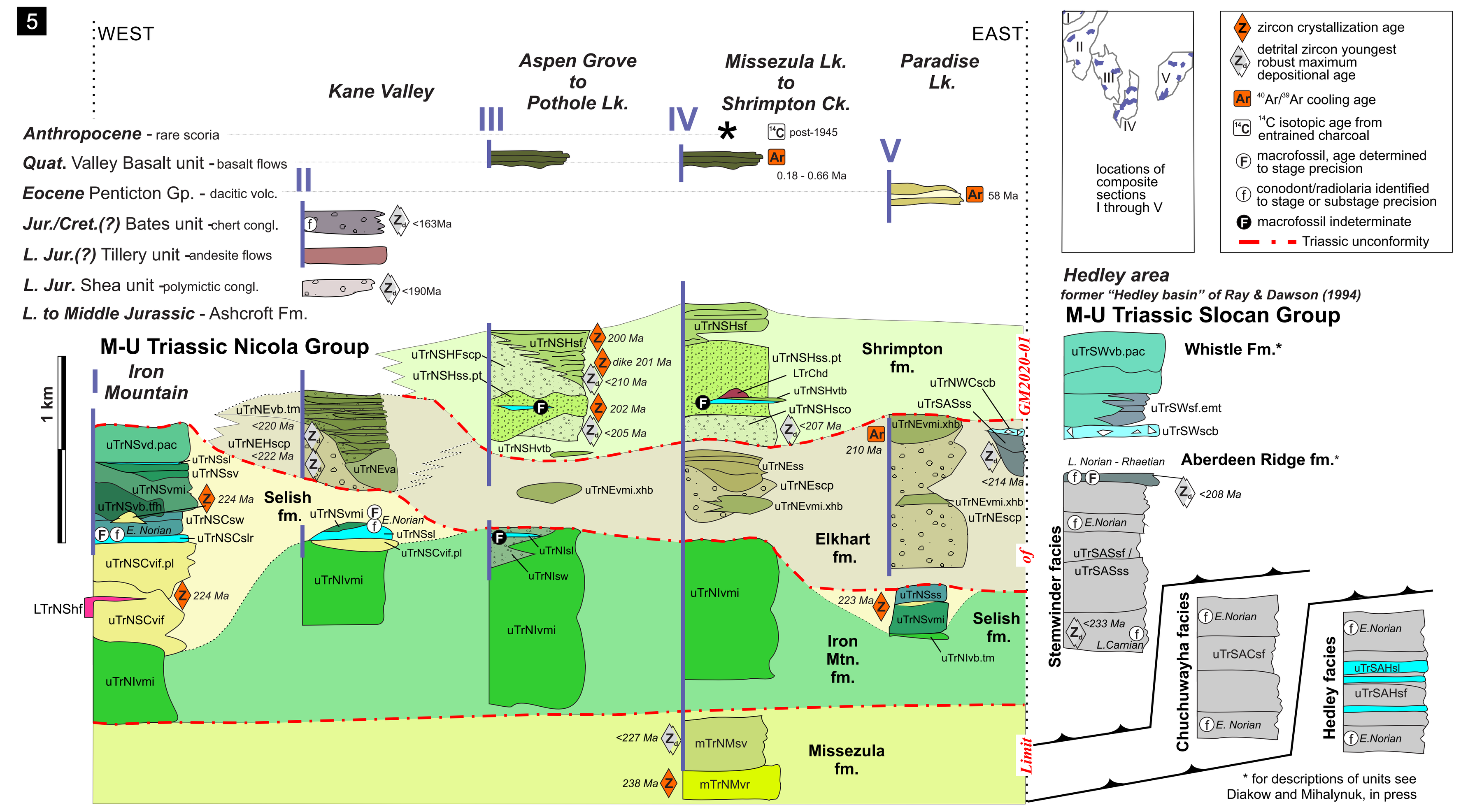
A major conglomeratic unit of undetermined thickness (Fairweather conglomerate, unit uTrNSHFscp) is widely distributed west of Kentucky-Alleyne fault where it drapes the Iron Mountain formation. This unit, studied in detail and previously interpreted as lahars (Christopher, 1973; Lefebure, 1976) is mainly composed of subangular to rounded cobbles and boulders of Nicola mafic volcanic porphyries, and intrusive clasts of diorite and monzonite.

Dacitic lithic tuff, and tuff resedimented as immature volcanic grit beds, form a discontinuous band several hundred metres wide (formerly called Zig unit of Mihalynuk et al., 2016) in the Fairweather conglomerate. Fine apatite, biotite and quartz derived from tuff comprise a few percent to only trace amounts in these rocks, but are significant because of their broad dispersal throughout the Shrimpton formation, and as a mineralogic marker to establish contemporaneity of deposition between terrestrial and marine subunits.

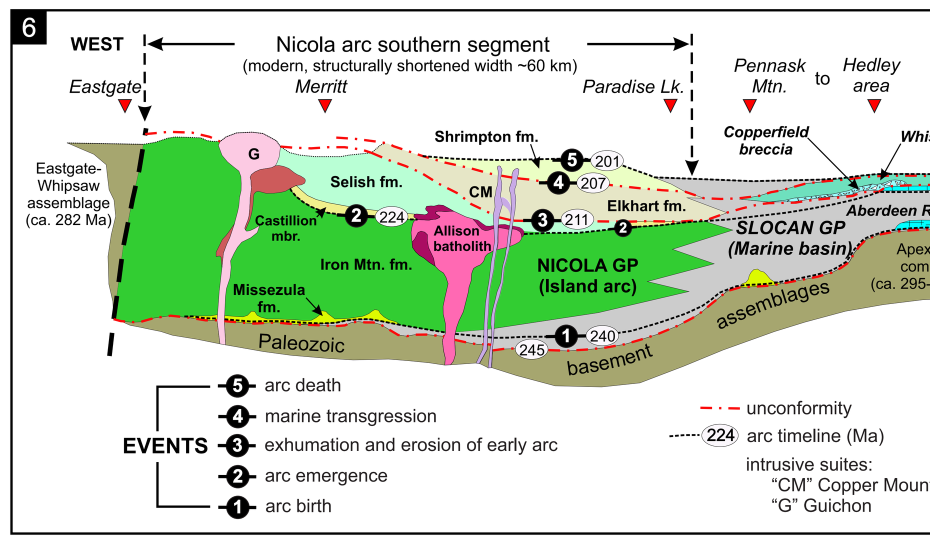
Geochronology from the Shrimpton formation includes: two U-Pb zircon samples, felsic tuffs in both terrestrial (~202 Ma) and marine tuffaceous sedimentary units (~200 Ma), and U-Pb detrital zircons samples of which three are terrestrial rocks (<207, <202 and <201 Ma) and one is from shallow lagoonal facies (<204 Ma, with nearby, metre-thick limestone layer) and one is from marine strata interlayered with thin analcime basalt flows (<200 Ma; Fig. 4). The detrital zircon samples all favour Rhaetian stage as the maximum time of deposition. During this time, at least two vigorous felsic eruptions resulted in fallout of crystals and ash-size fragments, which settled in both terrestrial and marine environments. A U-Pb 202 Ma date is the older volcanic pulse which occurred within an interval of overall declining Nicola arc magmatism. This volcanism also corresponds with a marine incursion that resulted in submarine deposits onlapping those of the terrestrial arc margin. Thin limestones, calcareous black siltstone and tuffaceous siltstone in the marine section contain rare ammonoids of indeterminate age. A younger ash-bearing interval with conspicuous, discrete layers up to 3 cm thick returned a U-Pb age of ~200 Ma (Friedman et al., 2020). This earliest Jurassic age from topmost strata of the Nicola Group marks the culmination of Nicola arc evolution in southern Quesnel terrane.

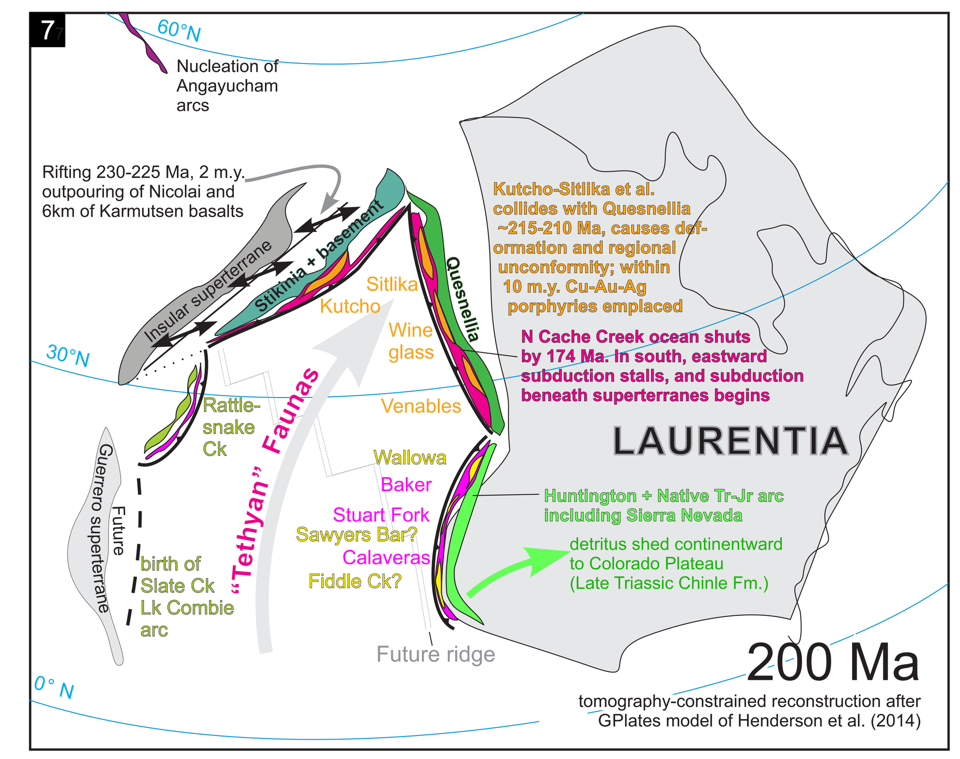
Nicola Arc-Slocan Basin Evolution

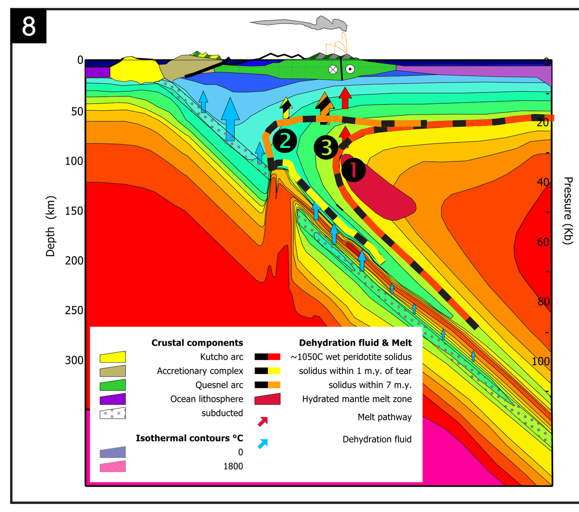
Nicola Group stratigraphy records Middle and Late Triassic magmatic arc development. At least one major unconformity is recognized in the Middle Norian suggesting a period of tectonic instability, and a magmatic hiatus that apparently lasted more than 3 million years. This unconformity effectively separates current lithostratigraphy of the Nicola Group into two developmental stages: a lower stage dominated by arc-building constructional episodes, and an upper stage of arc destabilization and a protracted interval of subaerial erosion and intermittent to waning arc magmatism. In this upper stage, the predominant arc-derived clastic deposits and accumulations of mafic volcanic rocks coalesce with marine deposits during a transgressive event that marks terminal deposition of the Nicola arc.



Norian, a period of arc instability and incision is recorded by the partly subaerial western Elkhart and largely submarine eastern Elkhart formation. Arc collision may be responsible for the instability. Undated picritic basalts occur near this transition and overlying units of the Shrimpton formation include ultrapotassic flows containing analcime. Between ~205 and 200 Ma Shrimpton formation strata transition upsection and to the east from shallow to deeper water facies. Slocan Group strata in the Hedley area are isoclinally folded, extensively repeated by thrust faults, and contain abundant Precambrian detrital zircons. In contrast, Nicola Group is affected by mostly open folds, with thrust faults identified only locally, and Precambrian zircons are rare or totally absent.







Nicola arc development is coeval with upper Slocan Group which records extents of the 'Slocan sea' interpreted to onlap the ancient North American margin (e.g. Thompson et al., 2006). Earliest known sedimentary deposits of the Slocan Group are Anisian age (247.2 - 242 Ma from timescale of Cohen et al., 2013) previously included in Harper Ranch Group (Thompson et al., 2006); it is not until the Ladinian stage (~242 - 237 Ma) that depositional events recorded by Nicola strata and the Slocan Group begin to overlap, for 40 million years, from late Middle Triassic into earliest Jurassic. A reconstruction of Nicola arc paleogeography envisages an earliest episode in which bimodal volcanoes of the Missezula formation formed spaced, low relief cones or domes, possibly constructed atop old Paleozoic arc crust. This embryonic Nicola arc may have formed a line of volcanic centres that coalesce with marine clastic rocks at the western margin of the 'Slocan sea'. Existence of Precambrian detrital zircons of probable North American provenance help in constraining the location of the 'Slocan sea' basin axis to east of the Nicola arc as no Nicola Group detrital samples analyzed thus far has revealed a Precambrian zircon.

By Late Carnian into early Norian, established convergence and subduction of Cache Creek ocean produced robust mafic-intermediate eruptions that formed a continuous line of spaced submarine stratovolcanoes that regionally define the Nicola island arc in Quesnellia. In the SNAP area, phases of the composite Allison batholith may mark the roots of a mature stratovolcano responsible for the Iron Mountain formation with substantial thicknesses of mafic-intermediate breccia and flows extending for tens of kilometers. A less robust centre may have existed near the Coldwater pluton situated approximately midway between Merritt and the Allison batholith. West of Merritt, another volcanic centre may have developed, about midway between the magmatic centres represented by the Allison and Guichon batholiths. In this area, mafic strata of the Iron Mountain formation are onlapped by upper levels of Selish formation. However, an early transition from submarine to subaerial deposits is manifest in lowest Selish formation, the Castillion member. This distinctive interval is composed of multiple, subaerial volcanic layers alternating with fossiliferous limestone deposited as patch reefs that flourished on the periphery of this emerging volcanic centre. Interbedded welded tuff and limestone is evidence of sea level fluctuations. Welded tuff and accretionary lapilli tuff in successively higher intervals of the Selish formation establishes ongoing terrestrial deposition to the end of the early constructional stage of Nicola arc in the Middle Norian.

Evidence for growth of Nicola arc between ~214 and 211 Ma is lacking. Neither sedimentary nor magmatic rocks have been recognized in the area of GM2020-01, and dated pulses of Guichon batholith (Whalen et al., 2017) extend the magmatic lull to the northwest. This interval corresponds with a regional unconformity (Logan and Mihalynuk, 2014) that presages a significant change in Nicola arc stability, further widespread uplift and erosion, and comparatively diminished magmatic activity during the upper developmental stage. This major unconformity is recognized in arc stratigraphy throughout Quesnel and Stikine terranes (Logan and Mihalynuk, 2014). By upper Norian renewed arc magmatism is recorded by intrusive activity in the Guichon batholith (~211 Ma) and Coldwater pluton (~210 Ma). Mafic-intermediate volcanic episodes are represented by hornblende-pyroxene phyric flows of the Elkhart formation (~ 210 Ma) and comparatively sparse plagioclase megacrystic flows that are localized as discontinuous accumulations within the mainly epiclastic facies. Erosion to subvolcanic levels along the arc axis is indicated from clast compositions that include a rich assortment of volcanic and intrusive lithologies, derived initially from Selish and Iron Mountain formations and the partly unroofed Allison batholith. Deeply oxidized clastic and interspersed volcanic rocks in these beds represent coalesced alluvial fan-like relics that draped older strata on an incised arc.

Deposition of Elkhart clastic beds continued into Rhaetian, and by ~207 Ma another unconformity is marked by coarse conglomerate grading up to finer clastic marine strata of the Shrimpton formation. Deposition of Shrimpton formation sand, silt and argillaceous strata containing sparse ammonites, signals a marine incursion onto the arc. Volumetrically minor volcanic beds occur in a minimum of two stratigraphic positions in terrestrial and marine lithofacies of the Shrimpton formation. Those of felsic composition and recognized by distinctive dispersed crystal or ash components, have been isotopically dated at ~200 Ma (Friedman et al., 2020) and record last gasps of the Nicola arc.

Contractional deformation

Previous workers saw little evidence of contractional deformation, but major highway construction created outcrops in which thrust faults are well exposed. Projection of age contrainted strata establish older over younger relationships. Structural shortening affected the entire arc (Mihalynuk et al., 2015), possibly in two episodes, at ~214 to ~211 Ma, when a regional unconformity developed; and more clearly, between ~200 Ma (youngest Nicola Group strata with demonstrable thrust faults) and 194 Ma, the age of Pennask batholith (Parrish and Monger, 1992; Fig. 4) which cuts the deformed strata. Younger contraction, probably in the early Cretaceous, thrust Iron Mountain formation westward over the Bates conglomerate unit, and caused structural thickening and metamorphism of the western arc as exposed in the Tulameen River area. Evidence for lead loss or metamorphic overgrowth at 140 - 150 Ma that has been observed in a high proportion of detrital zircon samples may be related to this event. Some thrust faults may have been reactivated as extensional faults during the early Eocene, for example, during uplift of upper amphibolite facies metamorphic rocks in the Nicola Horst (Moore, 2000; Erdmer et al., 2002), about 10 km north of the map area (Fig. 2).

Porphyry mineralization

Two belts of Late Triassic porphyry mineralization are recognized in the southern Nicola arc (Figs. 2, 3; Logan and Mihalynuk, 2014): an older western calc-alkaline belt (Cu-Mo; e.g. Guichon Creek batholith), and relatively younger, eastern alkalic belt (Cu-Au-Ag ±Mo, Pd; e.g. Iron Mask batholith). An even younger belt (Early Jurassic) is to the east at the latitude of GM2020-01, includes the past-producing calc-alkaline Brenda deposit in the Pennask batholith (Fig. 1).

Increasingly more precise geochronologic results from the Late Triassic Nicola porphyry belts have defined the age of calc-alkaline Guichon Creek suite (~215-207 Ma) with mineralizing phases and mineralization emplaced during the last ~2 m.y. between ~209 and~207 Ma (Fig. ; Ash et al., 2007; D'Angelo, et al., 2017; Whalen et al., 2017). Located 20-30 km to the east, the belt of predominantly dioritic and monzonitic intrusions of the alkalic Copper Mountain suite are inherently more difficult to date. The most robust U-Pb data point to emplacement mainly between 205 - 201 Ma with mineralization dated throughout this span (Mortensen et al., 1995; Logan et al., 2007; Mihalynuk et al., 2010; Logan and Mihalynuk, 2014). Many small, undated dioritic intrusions (unit LTrCd) along the central axis of the map area are included in Copper Mountian suite, and some of these intrusions have related porphyry mineralization (Fig. 2).

Close correspondence between the late Upper Triassic age of Nicola arc intrusions and the generation of porphyry mineralization suggests some fundamental trigger in the arc system at this time. In accord with analogous environments (McInnes et al. 1999), thermodynamic calculations (Mungall, 2002) and computational geodynamic models (van der Zedde and Wortel, 2001), Logan and Mihalynuk (2014) proposed that destabilization of normal arc subduction led to generation of metal-laden melts in the mantle wedge between the subducting Cache Creek lithosphere and overlying Nicola arc. After ~30 m.y. of uninterrupted subduction and continuous devolatilization of subducted slab that metasomatized the overlying mantle wedge (Fig. 8), subduction was interrupted as the Cache Creek plate finally delivered the dormant Kutcho arc to the trench, clogging it (Fig. 7). This led to uplift of the Nicola arc, widespread unconformities, and rupture of the subducting slab. Without cold subducted lithosphere isolating the wedge from hot subslab asthenosphere, the metal-enriched, metasomatized parts of the mantle wedge preferentially melted (Fig. 8) and generated protomagmas rich in chalcophile elements (e.g. Cu, Au, Pt, Pd; McInnes et al., 1999).

By one estimate, porphyry mineralization formed during this collision event, a brief 6 m.y. centred at 205 Ma, produced >90% of the known copper resource in the Nicola Group of Quesnel terrane and coeval rocks in its sister, Stikine terrane (Logan and Mihalynuk, 2014). A compilation of the latest U-Pb and Re-Os age data from the southern Nicola arc (Fig. 4) changes the story little. Mineralizing intrusions were concentrated in a western calc-alkalic belt and an eastern, slightly younger alkalic belt over a span of ~8 m.y. from ~209 to 201 Ma. This mineralizing period followed a protracted stage of predominantly mafic arc construction and normal evolution of calc-alkalic arc crust sufficiently thick to generate granodioritic intrusions. An abrupt switch from normal arc growth (~239 – 214 Ma) to destabilization, uplift, and incision (~214 - 207 Ma), mineralization (209 – 201 Ma) and then dormancy, submergence and crustal shortening (201 - 196 Ma), is recorded in the geology of GM2020-01.

Columbia. In Current Research, Part E, Geological Survey of Canada, Paper 89-lE, pp. 61-67.
Preto, V.A. 1979. Geology of the Nicola Group between Merritt and Princeton: British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Bulletin 69, 90 p.
Preto, V.A., Nixon, G.T., and Macdonald, E.A.M. (2004): Alkaline Cu-Au porphyry systems in British Columbia: Cop per Mountain; BC Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Geoscience Map 2004-3.
Ray, G.E., and Dawson, G.L., 1994. The geology and mineral deposits of the Hedley gold skarn district, southern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Bulletin 87, 156 p.
Read, P.B., 1987. Tertiary stratigraphy and industrial minerals, Princeton and Tulameen basins, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Open File Map 1987-19.
Read, P.B., and Okulitch, A.V., 1977. The Triassic unconformity of south-central British Columbia. Canadian Journal of Earth Sciences, 14, 606-638.
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 Stikinia-North America terrane interactions. Geology, 20, pp. 1119-1122.
Rice, H.M.A., 1947. Geology and mineral deposits of the Princeton map-area, British Columbia, Geological Survey of Canada, Memoir 243, 136 p.