

# Cordilleran magmatism in Yukon and northern British Columbia: characteristics, temporal variations, and significance for the tectonic evolution of the northern Cordillera

A. Zagorevski<sup>1\*</sup> and C.R. van Staal<sup>2</sup>

---

*Zagorevski, A. and van Staal, C.R., 2021. Cordilleran magmatism in Yukon and northern British Columbia: characteristics, temporal variations, and significance for the tectonic evolution of the northern Cordillera; in Northern Cordillera geology: a synthesis of research from the Geo-mapping for Energy and Minerals program, British Columbia and Yukon, (ed.) J.J. Ryan and A. Zagorevski; Geological Survey of Canada, Bulletin 610, p. 95-122. <https://doi.org/10.4095/326063>*

---

**Abstract:** Geochemical and temporal characterization of magmatic rocks is an effective way to test terrane definitions and to evaluate tectonic models. In the northern Cordillera, magmatic episodes are mostly interpreted as products of continental arc and back-arc settings. Re-evaluation of Paleozoic and Late Mesozoic magmatic episodes presented herein highlights fundamental gaps in the understanding of the tectonic framework of the northern Cordillera. In many cases, the character of magmatism and temporal relationships between various magma types do not support existing tectonic models. The present re-evaluation indicates that some of the magmatic episodes are best explained by lithospheric extension rather than arc magmatism. In addition, comparison to modern analogues suggests that many presently defined terranes are not the fundamental tectonic building blocks, but rather combine distinctly different tectonic elements that may not be related each other. Grouping of these distinctly different tectonic elements into single terranes hinders the understanding of Cordilleran evolution and its mineral deposits.

**Résumé :** La caractérisation géochimique et temporelle des roches magmatiques permet de mettre à l'épreuve les définitions des terranes et d'évaluer les modèles tectoniques. Dans la Cordillère septentrionale, les épisodes magmatiques sont considérés surtout comme les produits de contextes d'arc continental et d'arrière-arc. Or, la réévaluation des épisodes magmatiques du Paléozoïque et du Mésozoïque tardif que nous présentons ici fait ressortir les lacunes fondamentales de notre compréhension du cadre tectonique de la Cordillère septentrionale. En effet, dans plusieurs cas, le caractère du magmatisme et les relations temporelles entre divers types de magma n'appuient pas les modèles tectoniques existants. Notre réévaluation indique que certains des épisodes magmatiques s'expliqueraient mieux par une extension lithosphérique que par un magmatisme d'arc. De plus, notre comparaison avec des analogues modernes laisse à penser que plusieurs terranes tels qu'ils sont actuellement définis ne sont pas des blocs tectoniques fondamentaux, mais qu'ils intègrent différents éléments tectoniques distincts sans relations mutuelles. Ainsi, le regroupement de ces éléments tectoniques très distincts les uns des autres en terranes particuliers nuit à la compréhension de l'évolution de la Cordillère et de ses gîtes minéraux.

---

<sup>1</sup>Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

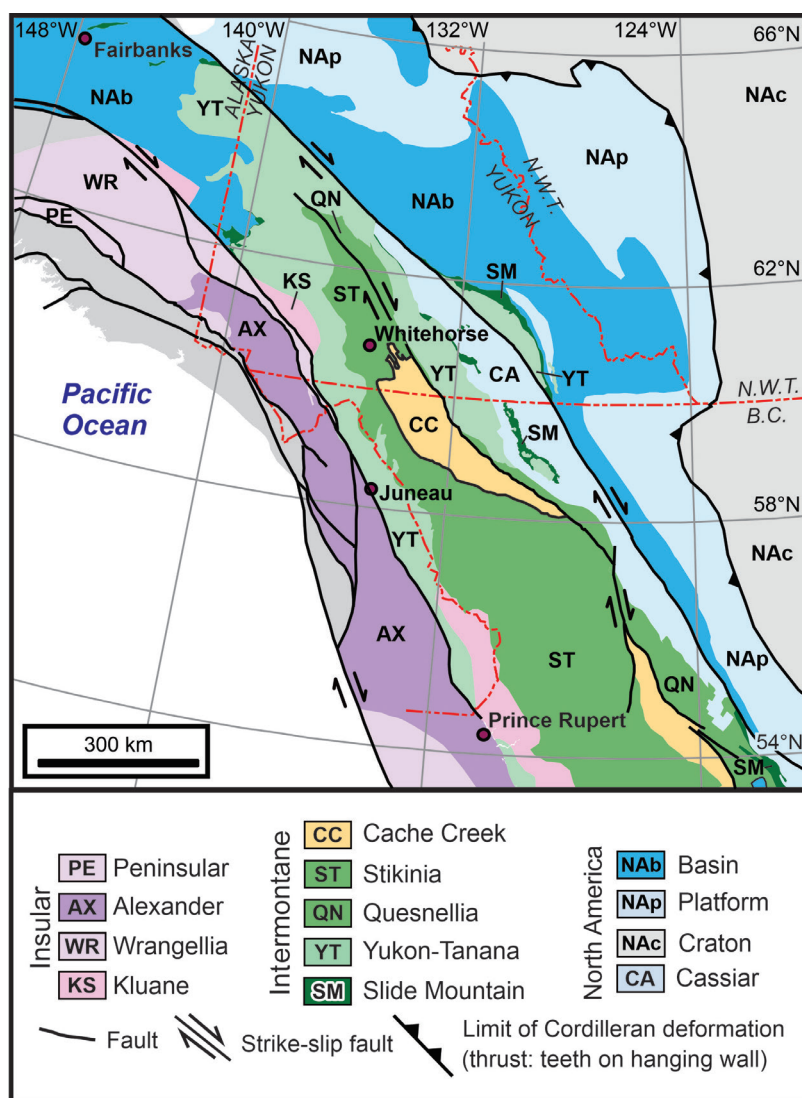
<sup>2</sup>Geological Survey of Canada, 1500-625 Robson Street, Vancouver, British Columbia V6B 5J3

\*Corresponding author: A. Zagorevski (email: [alex.zagorevski@nrcan-rncan.gc.ca](mailto:alex.zagorevski@nrcan-rncan.gc.ca))

## INTRODUCTION

The northern Canadian Cordillera is characterized by episodic magmatism that occurred prior to and following accretion of outboard Intermontane and Insular superterrane (Fig. 1). With the exception of the Cache Creek terrane (Fig. 1), much of the Cordilleran magmatism is interpreted to be related to continental and intraoceanic arc development and rifting (e.g. Piercey et al., 2006; Nelson et al., 2013). Cordilleran magmatism is characterized by well defined high-flux episodes in the Mesozoic (e.g. DeCelles et al., 2009) and Paleozoic (e.g. Colpron and Nelson, 2006); however, the present configuration of the Cordillera, where it is bound by the Cascadia subduction zone to the west, has biased many models of magmatism. This bias has resulted in interpretation of many of the magmatic episodes as arc flare-ups, and the concept of Cordilleran batholiths as voluminous roots of continental magmatic arcs.

A long history of mapping and research in the northern Cordillera has resulted in a tremendous volume of modern geochemical and geochronological data on the various magmatic episodes as well as abundant, related data sets such as volcanology, sedimentology, metamorphism, and structure. The sheer volume of these data precludes a comprehensive treatment herein. This paper only addresses select magmatic episodes, including Paleozoic within-plate magmatism in the Intermontane terranes, Permian Klondike assemblage magmatism in the Yukon-Tanana terrane, and mid-Cretaceous magmatism that overlaps all terranes. For each magmatic episode, data from Yukon and northern British Columbia is summarized, existing models are evaluated and compared to modern and/or recent well studied analogues. The authors demonstrate that the default interpretation of Cordilleran magmatism as arc-related is likely incorrect and should be systematically re-evaluated. Such re-evaluation will improve tectonic models and provide a better context for mineral deposits.



**Figure 1.** Lithotectonic map of northern Cordillera (modified from Colpron and Nelson, 2011).

## GEOCHEMISTRY AS AN INDICATOR OF TECTONIC SETTING

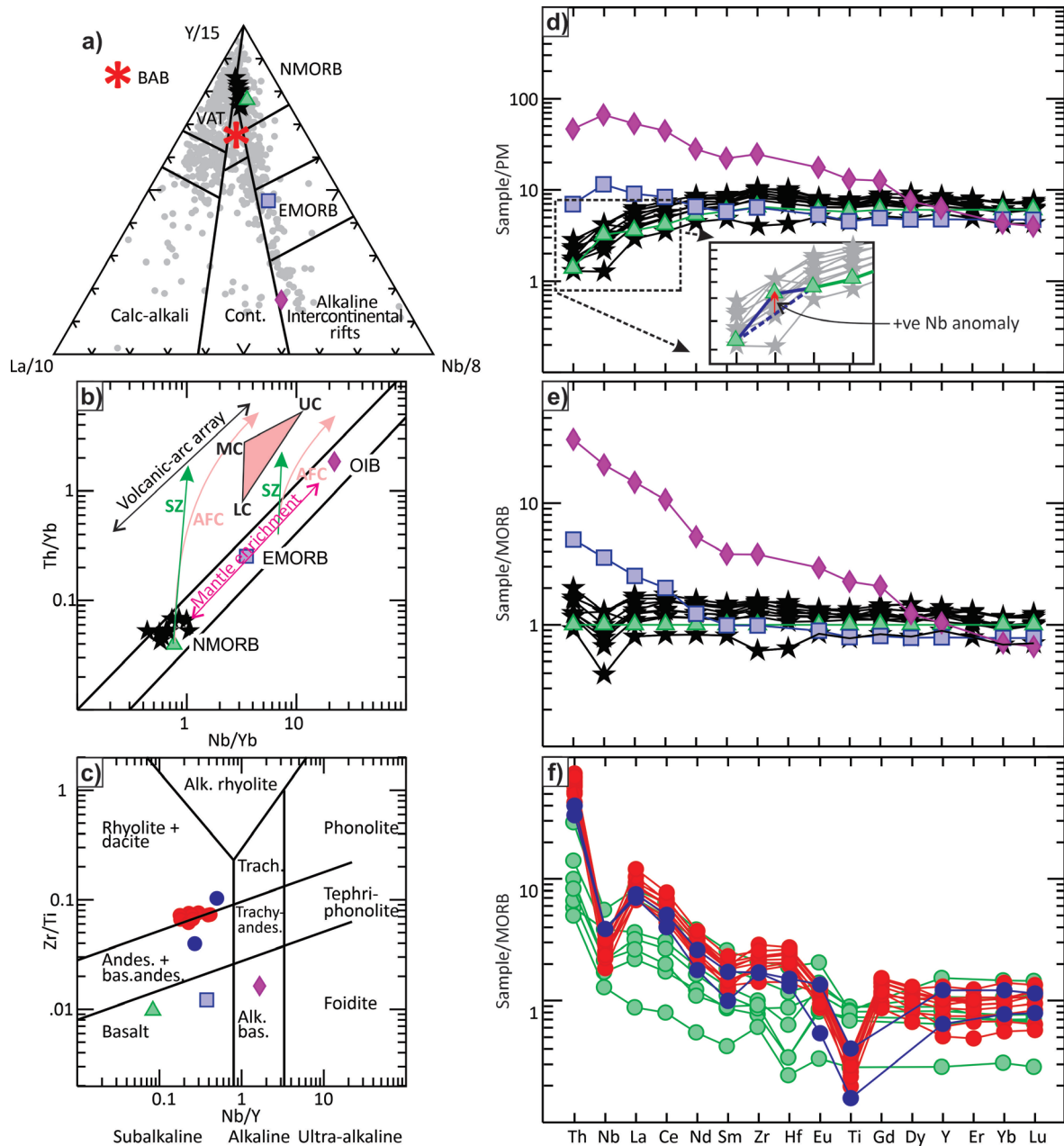
Evaluation of magmatic episodes presented herein relies heavily on published whole-rock geochemistry data. Whole-rock geochemistry can be effectively used to discriminate between various magma types and different tectonic settings. This can be accomplished by using normalized extended element diagrams, and binary and/or ternary discrimination plots (Fig. 2). Discrimination plots (Fig. 2a, b, c) have the advantage of allowing visualization of a large number of samples. Most of the older tectonic discrimination plots were developed using very sparse data sets (e.g. Winchester and Floyd, 1977; Pearce, 1996) with significant analytical limitations (e.g. poor resolution of Th and Nb analyzed by X-ray fluorescence (XRF), incomplete dissolution of samples resulting in inaccurate high field-strength analyses). As such, they are inherently inaccurate. In addition, all discrimination plots have much more overlap between fields than the drawn boundaries suggest (Fig. 2a). For example, a majority of tectonic discrimination diagrams fail to effectively differentiate between island-arc tholeiite, back-arc tholeiite, and mid-ocean-ridge basalt. As such, geological relationships are required in order to make the most accurate assessment. Throughout this contribution, the La-Y-Nb (Cabanis and Lecolle, 1989), Zr/Ti-Nb/Y (Pearce, 2014), and Th/Yb-Nb/Yb (Pearce, 2014) plots are utilized because these plots create significant spread in the data and allow relatively easy visualization of suites of samples, tectonic setting, and processes. In these diagrams, Zr/Ti is a fractionation index, Nb/Y and Nb/Yb are alkalinity indices, whereas Th/Nb and La/Nb are indicators of arc or crustal contribution.

Mafic igneous rocks are by far the most useful rocks for constraining the tectonic setting because they are the most direct probes of the underlying mantle. Mafic discrimination plots generally require volcanic rocks, or at least rocks with liquid-like compositions. In general, this requirement can relatively easily be satisfied either by petrography (e.g. basalt and fine-grained diabase are likely liquid-like composition whereas pegmatite and layered gabbro are not) or examination of geochemical data (*see* Pearce, 1996). This contribution avoids plotting mafic cumulate samples throughout. In contrast to mafic rocks, composition of felsic and intermediate rocks is predominantly controlled by crustal processes, including fractionation, assimilation, and anatexis of pre-existing basement. In general, felsic rocks are very poor indicators of tectonic setting, but they are very good probes of the underlying crust. Most of the felsic tectonic discrimination plots are based on plutonic rocks; however, both volcanic and plutonic rocks are plotted for reference.

Normalized extended element diagrams are not well suited to display very large data sets, but provide the most complete visualization of data because they plot all discrimination-relevant elements (Fig. 2d, e, f). As such, the

ratio of the elements can be qualitatively compared between samples and relative to a normalization factor. The choice of normalizing factors varies between studies and commonly includes primitive mantle (PM), mid-ocean ridge basalt (MORB), upper continental crust (UCC), chondrite, or a particular reference sample. In a theoretical sense, the choice of the normalizing factor, whether it is primitive mantle or any other standard, does not matter as long as a sample from a known tectonic setting is plotted for reference; however, some plots allow a much more intuitive interpretation of samples, suites, and processes. Many studies utilize primitive mantle, which is a modelled composition of the mantle following formation of the core, but prior to differentiation of the early crust, as the normalization factor. Although this plot is useful for understanding evolution of the early Earth and for evolution of mantle reservoirs, this plot is poorly suited for comparison of crustal samples and for determining the tectonic setting. This plot effectively forces the user to relate their magmas to a model of a mantle reservoir that no longer exists, rather than comparing their samples to an expected melt that is produced from modern mantle in a known tectonic setting. As a result, samples from most tectonic settings (such as MORB) do not plot as smooth lines on primitive mantle-normalized diagrams (Fig. 2d). This necessitates plotting of reference samples, and comparison of log-normalized anomalies (Fig. 2d, inset). This is an especially acute problem when differentiating mid-ocean-ridge basalt from back-arc basalt (BAB) and island-arc tholeiite (IAT). On a primitive mantle-normalized plot, MORB, EMORB (enriched mid-ocean ridge basalt), and ocean-island basalt (OIB) have a positive Nb anomaly (Fig. 2d), because primitive mantle reservoir has higher Th/Nb ratio than the average modern mantle array (Pearce et al., 2008). As such island-arc tholeiite and back-arc basalt may either have a negative Nb anomaly or they may lack a Nb anomaly on a primitive mantle-normalized plot.

Plotting samples on a MORB-normalized plot (Fig. 2e) largely negates the plotting of reference samples for regional tectonic studies. This plot utilizes rocks that are extracted from depleted MORB mantle and as such, it allows easy comparison of processes between tectonic settings (Pearce, 1996, 2014). The slope of the Nb-Ti-heavy rare-earth elements (HREE) indicates the degree of depletion or enrichment of the baseline mantle, the absence of a negative Nb anomaly indicates a within-plate setting, whereas crustal contamination or derivation from metasomatized, suprasubduction-zone mantle leads to negative Nb anomalies on the MORB-normalized plots (Pearce, 1996, 2014). As the purpose of most extended trace-element plots in regional studies is to compare suites of samples and to infer their tectonic setting, MORB-normalized plots are much more intuitive and obvious to nonspecialists. Extended trace-element plots can include a large number of mobile elements (Ba, Sr, K, etc.). As many samples collected during regional and mine-scale studies have experienced significant alteration and metamorphism, these mobile elements are not useful for determining tectonic setting.



**Figure 2.** Geochemical characteristics of volcanic rocks from different settings. Selected Slide Mountain terrane data plotted for reference (black stars) (Lapierre et al., 2003). Normal mid-ocean-ridge basalt (MORB, green triangle), enriched mid-ocean-ridge basalt (EMORB, blue square), and ocean-island basalt (OIB, purple diamond) values from Sun and McDonough (1989); BAB = back-arc basalt, Cont = continental. **a)** A La-Y-Nb plot (Cabanis and Lecolle, 1989) can be effective in determining the tectonic setting of mafic rocks, but like most discrimination plots, there is significant overlap between fields, as shown by the global range of back-arc data (grey, downloaded from [www.earthchem.org/petdb](http://www.earthchem.org/petdb) [accessed 26 July 2019]; search parameter = back-arc). **b)** Nb/Yb-Th/Yb plot showing effects of source mantle enrichment, subduction input, and crustal contamination (Pearce et al., 2008; Pearce, 2014). MC = middle crust, UC = upper crust, LC = lower crust, SZ = subduction zone enrichment, AFC = assimilation fractional crystallization, black star symbol = selected Slide Mountain terrane data. **c)** Nb/Y-Zr/Ti rock type discrimination (Pearce, 1996). Alk. = alkali, trach. = trachyte, andes. = andesite, bas. = basalt. **d), e)** Comparison of primitive mantle (PM) and MORB-normalized extended trace-element plots. The MORBs have positive Th-Nb-La anomaly on primitive mantle-normalized plots. As such, samples that lack Th-Nb-La anomaly on primitive mantle-normalized plots can be misinterpreted as MORBs, whereas MORB-normalized plots clearly show the negative anomaly for the suite of Slide Mountain terrane samples. Black star = selected Slide Mountain terrane data, purple diamond = ocean-ridge basalt, purple square = EMORB, green triangle = MORB. **f)** Paleozoic Stikine assemblage samples from Tulsequah Chief area. Older felsic data (blue) show similar patterns, but significant differences in Zr, Hf, Nb, and Th compared to newer data (red; Fig. 2c). Mafic samples (green) indicate either analytical problems and/or significant alteration effects as indicated by highly variable Zr/Hf and La/Nb ratios. These data are generally unreliable for tectonic setting discrimination.



## Data vintage and sample purpose

Older data sets are generally less reliable than modern data sets because analytical methodologies have drastically improved in the last several decades. Many older data sets had to contend with incomplete dissolutions of samples, which resulted in poor resolution of high field-strength elements (mainly Zr-Ti-Nb; Fig. 2c, f). This analytical problem has been mostly overcome by borate fusion of samples prior to dissolution, although some analytical laboratories and some analytical procedures do not fuse samples. Older data sets also had higher detection and quantification limits and poorer resolution of elements that are useful for tectonic setting discrimination. As such, older data should be treated with caution. Sample purpose and collection strategies should also be taken into account when working with compiled geochemical data. For example, data collected for the purpose of alteration studies around mineral deposits are commonly not suited for regional studies because high degrees of fluid-rock interaction can mobilize the majority of elements, even those that are generally considered ‘immobile’.

## Geochemical data

Geochemical data utilized in this manuscript (Zagorevski, 2020) are compiled from multiple sources of different vintage, including existing regional compilations (Piercey et al., 2006; Milidragovic et al., 2016; Ryan et al., 2018; Zagorevski, 2018). For the purpose of this manuscript, terrane and stratigraphic assignments listed in the original sources have largely been retained, with the exception of the Atlin and Cache Creek terranes, where ophiolites (Atlin) were separated from the carbonate platform (Cache Creek; *see* Zagorevski et al., this volume). Many published sources do not list detailed rock descriptions. As such, much of the data were classified based on the listed rock types (plutonic, volcanic, sedimentary) and composition (mafic, intermediate, felsic). A rigorous check of individual samples for consistency with their compositional assignments has not been performed. Only obvious errors were corrected (e.g. chert listed as volcanic, ultramafic listed as mafic or felsic); however, the volume of data ( $n > 3000$ ) largely negates any individual outliers for the purpose of this contribution. The majority of samples were assigned a mean age that is listed for the constituent stratigraphic unit in online geology databases (Cui et al., 2017; Yukon Geological Survey, 2019), or in the source literature. Whenever there is an obvious connection between samples and reliable radiometric ages, a radiometric age was assigned. As such, age errors for individual samples range from less than  $\pm 1$  Ma where reliable age data are available, to more than  $\pm 50$  Ma where stratigraphic units are only broadly defined (e.g. Mississippian to Middle Permian). The present authors realize that  $\pm 50$  Ma errors are geologically unreasonable, nonetheless, data plotted against loosely constrained ages are generally validated by available precise age data and show broad, interpretable

trends over time. Lastly, although the authors avoided compiling questionable data, some data of dubious quality have been retained in regions with sparse data (e.g. Fig. 2c). As stated above, the overall volume of the data set largely negates any individual outliers when looking at broad geochemical trends through time.

---

## PALEOZOIC WITHIN-PLATE MAGMATIC CRISIS

---

Devonian to Permian magmatism is well documented on the Laurentian margin, Yukon-Tanana, Slide Mountain, Cache Creek, Stikine, and Quesnel terranes where it exhibits a variety of characteristics ranging from primitive tholeiite and boninite through to highly evolved A-type granitoid rocks and ocean-island basalt (e.g. Piercey et al., 2006). Many studies noted a significant plume (ocean-island basalt and E-MORB) component in Paleozoic magmatic rocks of the parautochthonous Laurentia (Dusel-Bacon et al., 2006; Piercey et al., 2006), Yukon-Tanana (Piercey et al., 2006, 2012), Slide Mountain (Lapierre et al., 2003; Tardy et al., 2003; Piercey et al., 2012), Stikine (Gunning et al., 2006), Quesnel (Simard et al., 2003, 2007), and Cache Creek terranes (Tardy et al., 2001; Lapierre et al., 2003; English et al., 2010; McGoldrick et al., 2017). The purpose of this section is to broadly compare its duration and setting within-plate magmatism within and between these terranes (Fig. 3), to discuss previously proposed analogues, and to evaluate their significance for terrane definitions. For a detailed and previously accepted interpretation of Paleozoic tectonics and magmatism, the reader is referred to regional syntheses of Colpron et al. (2006), Nelson and Colpron (2007), and Nelson et al. (2013).

Late Devonian to Mississippian evolution of the Laurentian margin, Yukon-Tanana, Slide Mountain, Quesnel and Stikine terranes is intimately linked (e.g. Colpron et al., 2006; Murphy et al., 2006; Nelson and Colpron, 2007). Most workers agree that a continental arc developed on the Laurentian margin by the Late Devonian. This continental arc rifted from the Laurentian margin in the Late Devonian to Early Mississippian, forming the Yukon-Tanana, Quesnel, and Stikine terranes and opening a back-arc basin, largely represented by the Slide Mountain terrane. Whereas these terranes share a common genesis, their evolution during the Carboniferous and Permian was distinctly different. Following rifting, Laurentian margin became the passive edge of the Slide Mountain Ocean and was magmatically quiescent until the Late Triassic. The Yukon-Tanana terrane experienced episodic continental arc magmatism throughout the Carboniferous and Permian. Stikinia and Quesnellia are also characterized by Paleozoic arc and rift-related magmatism, although, especially in Stikinia, this magmatism is juvenile and did not involve significant contributions from continental crust. The Slide Mountain terrane experienced episodic Carboniferous and Permian magmatism and marine

sedimentation; however, in contrast to the Yukon-Tanana terrane, the character of magmatism indicates largely rift-related settings. Piercey et al. (2006) presented a very detailed overview of magmatic cycles related to the Yukon Tanana terrane.

Late Devonian parautochthonous Laurentian margin is exposed in the Alaska Range, Yukon-Tanana Uplands (Dusel-Bacon et al., 2006; Piercey et al., 2006), western Yukon (White River Assemblage, Mount Burnham orthogneiss: Ryan et al., 2013b, 2018), and eastern Yukon (Earn Group: Gordey, 2013). These rocks are characterized by calc-alkaline and peralkaline felsic rocks and ocean-island basalt, indicative of continental rift setting (Fig. 3a).

Late Devonian to Permian Yukon-Tanana terrane in northwestern British Columbia (Florence Range and Boundary Range suites: Currie, 1994; Currie and Parrish, 1997; Soucy La Roche and Zagorevski, 2018) and Yukon (e.g. Piercey et al., 2006) is characterized by highly variable magmatism ranging from arc-related boninite (BON), island-arc tholeiite (IAT), and calc-alkaline basalt (CAB) through to abundant within-plate ocean-island basalt and EMORB (Fig. 3b). Ocean-island basalt magmatism occurred throughout the Late Devonian and Carboniferous (Fig. 3b4) in the Snowcap Assemblage, Drury Formation, Pelmac unit, and Klinkit Group (Little Kalsas and Little Salmon formations). The EMORB magmatism spans the entire Late Devonian to Middle Permian history of the Yukon-Tanana terrane (Fig. 3b4) in apparent stratigraphic continuity with, and overlain by arc-related rocks (e.g. Simard et al., 2003; Murphy et al., 2006). The preponderance of rift-related volcanic rocks in parts of the Yukon-Tanana terrane is ubiquitously interpreted as continental arc rifting and development of either interarc rifts (e.g. Simard et al., 2007) and/or a back-arc basin with a highly oblique spreading direction (Fig. 4; e.g. Piercey et al., 2012).

The Slide Mountain terrane is characterized by island-arc tholeiite, EMORB, and ocean-island basalt magmatism (Fig. 3c). The Middle Permian island-arc tholeiite magmatism is geochronologically well constrained; however, the age of many other units is poorly constrained due to the predominantly mafic compositions and commonly imprecise fossil ages (i.e. Mississippian to Permian ca.  $305.4 \pm 53.4$  Ma). Similar to the Laurentian margin and the Yukon-Tanana terrane, data from the Slide Mountain terrane clearly indicate that there was a significant enriched mantle component that resulted in eruption of ocean-island basalt and EMORB

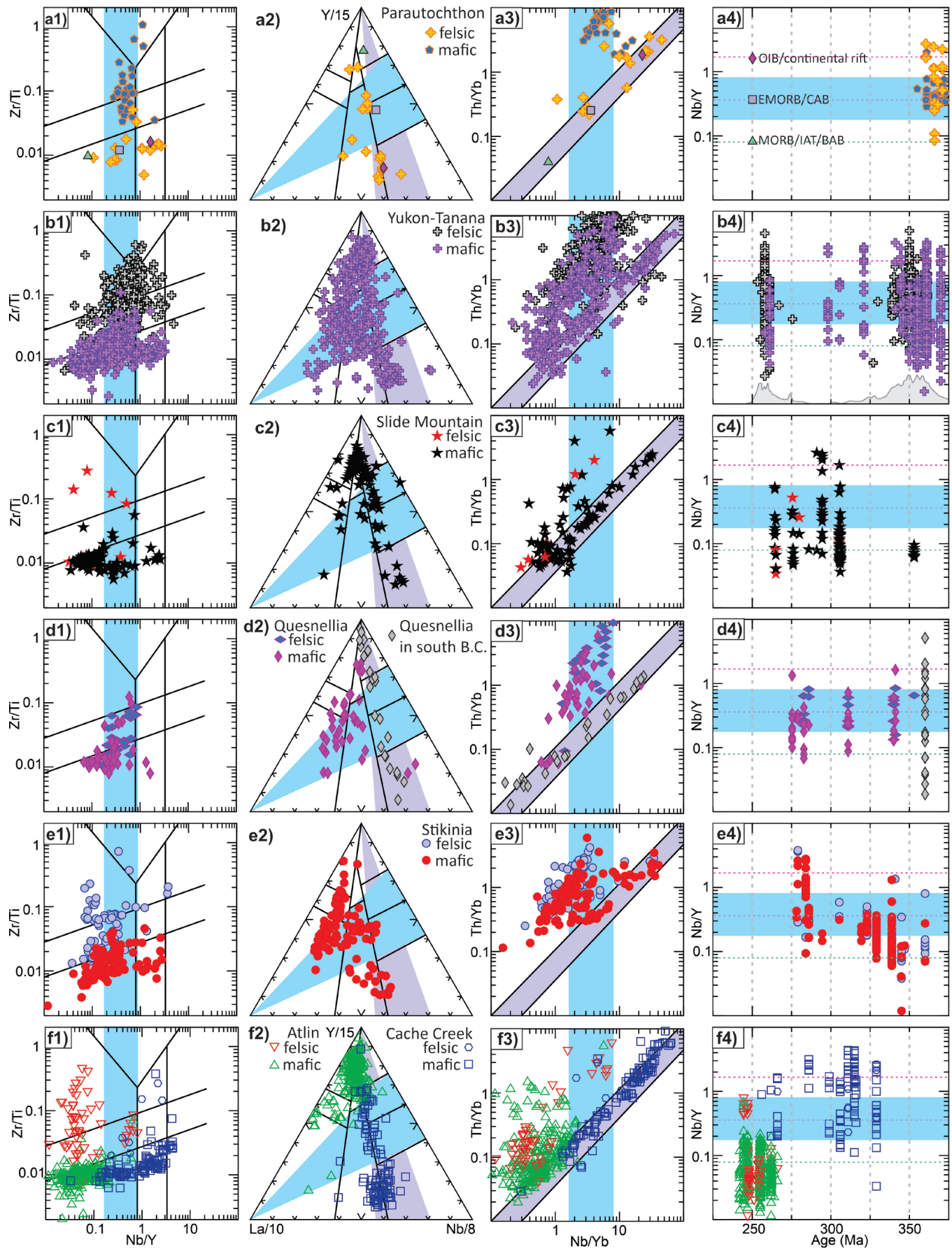
(Fig. 3c). The Slide Mountain terrane has been interpreted to have formed in a Sea of Japan-like back-arc basin between Laurentia and Yukon-Tanana terranes (Fig. 4; e.g. Murphy et al., 2006; Piercey et al., 2006, 2012).

Paleozoic Quesnellia is in part correlative to the southeastern Yukon-Tanana terrane. In northern and central British Columbia, it is characterized by predominantly island-arc tholeiite and calc-alkaline basalt with minor ocean-island basalt (Fig. 3d; Nelson, 1993; Ferri, 1997; Nelson and Friedman, 2004); however, southern British Columbia is characterized by island-arc tholeiite and voluminous EMORB and ocean-island basalt (Fig. 3d; Massey and Dostal, 2013). Similar to the Yukon-Tanana terrane, Paleozoic Quesnellia has been interpreted as an extensional arc system that is coeval with the Slide Mountain terrane back-arc basin (e.g. Nelson and Colpron, 2007).

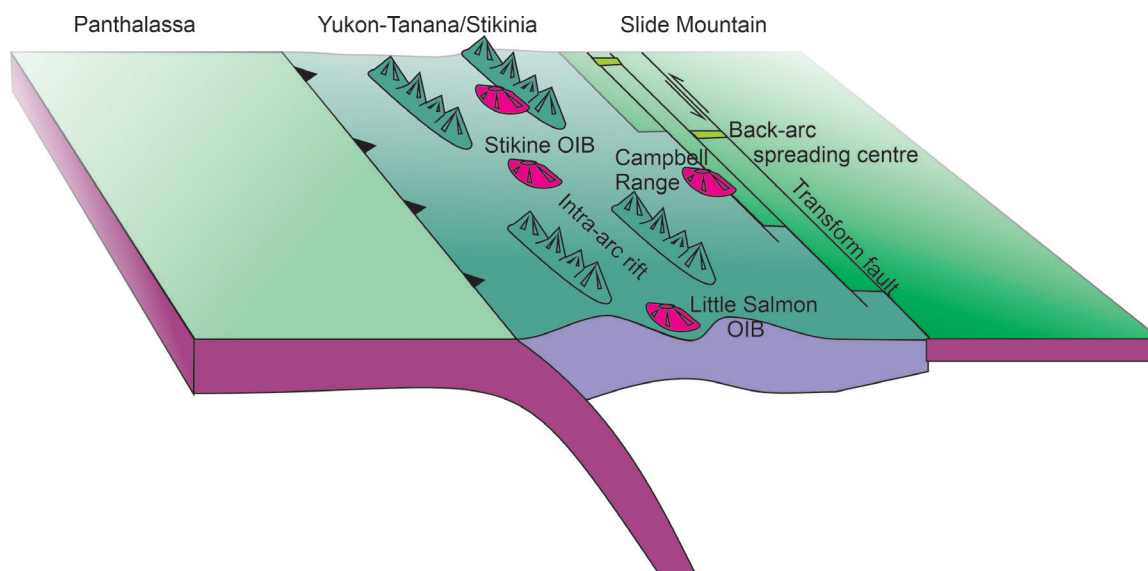
Paleozoic Stikinia has also been interpreted as an along-strike correlative of the Yukon-Tanana terrane, but founded on juvenile basement (e.g. Mortensen, 1992). Paleozoic Stikinia is characterized by predominantly island-arc tholeiite to calc-alkaline basalt magmatism in the Upper Devonian to Upper Carboniferous (Fig. 3e). The character of magmatism appears to change across the Carboniferous to Permian boundary, and Permian magmatism is characterized by eruption of ocean-island basalt (Fig. 3e), followed by general cessation of magmatism altogether (Logan et al., 2000; Gunning et al., 2006). Gunning et al. (2006) interpreted ocean-island basalt to have erupted in intra-arc rifts in a predominantly orogen-parallel transtensional arc system (Fig. 4).

The Paleozoic Cache Creek terrane has been interpreted as an entirely exotic terrane of oceanic affinity with no connection to other Intermontane terranes until the Late Triassic. The present investigations of the Cache Creek terrane indicate that it comprises two terranes of distinctly different provenance (Zagorevski et al., this volume). The younger Atlin terrane comprises Middle Permian to Middle Triassic ophiolites and rifted arc complexes that are characterized by island-arc tholeiite, boninite, calc-alkaline basalt, and back-arc basalt (Fig. 3f). Atlin terrane is similar to, but generally slightly younger than the Middle Permian island-arc tholeiite ophiolites in the Slide Mountain terrane. The older Cache Creek terrane is characterized by a voluminous carbonate platform that experienced episodic ocean-island basalt and EMORB magmatism throughout the Paleozoic (Fig. 3f; Monger, 1975; Mihalyuk and Cordey, 1997;

**Figure 3.** Summary of geochemistry from the Paleozoic parautochthonous **a)** Laurentia, **b)** Yukon-Tanana, **c)** Slide Mountain, **d)** Quesnellia, **e)** Stikinia, and **f)** Cache Creek and Atlin terranes (F). See Figure 2 for field labels and references. Normal mid-ocean ridge basalt (MORB), enriched mid-ocean ridge basalt (EMORB), and ocean-island basalt (OIB) are plotted for reference (Sun and McDonough, 1989). Blue field represents equivalent Nb/Y ratio (alkalinity index), pastel purple field represents mantle array equivalence. Quesnellia basement from southern British Columbia is plotted at 360 Ma for reference (Fig. 3d; from Massey and Dostal, 2013); CAB = calc-alkaline basalt, BAB = back-arc basalt, IAT = island-arc tholeiite.







**Figure 4.** Schematic model of ocean-island basalt (OIB) magmatism in the northern Cordillera (based on Simard et al., 2003, 2007; Gunning et al., 2006; Piercey et al., 2006, 2012).

Lapierre et al., 2003; Tardy et al., 2003). The association of within-plate magmatism with the carbonate platform that is characterized by warm water (i.e. “Tethyan”) fossils has been almost ubiquitously interpreted to indicate derivation of the Cache Creek terrane from a seamount chain or plateau in the western Panthalassa Ocean (i.e. Tethys; e.g. Monger and Ross, 1971; Monger, 1977; Orchard et al., 2001; Sano et al., 2001; Johnston and Borel, 2007); however, Cache Creek terrane ocean-island basalt and EMORB magmatism is coeval with ocean-island basalt and EMORB magmatism of the adjacent terranes (Fig. 3f).

### Within-plate magmatism in modern arc settings

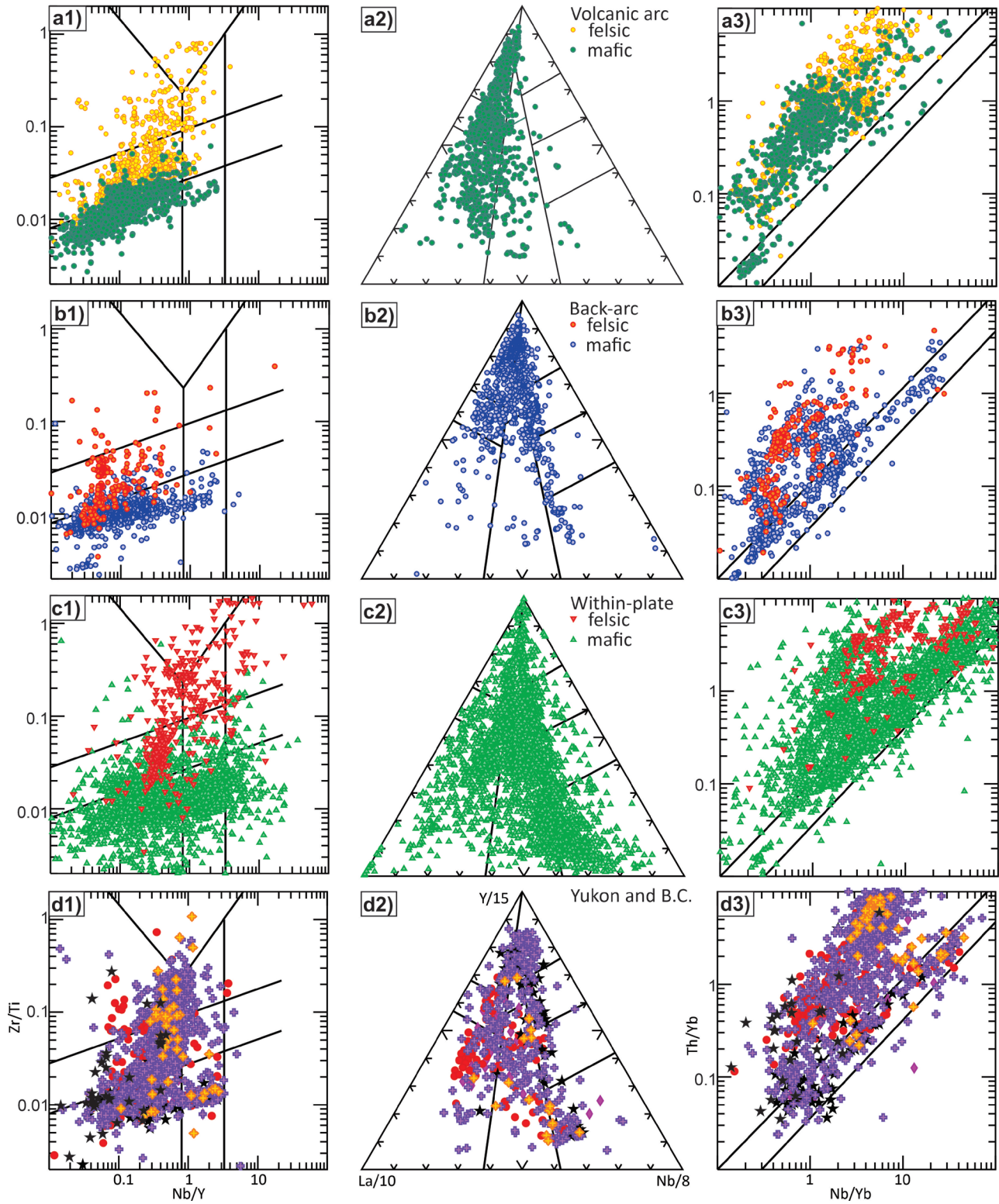
Within-plate magmatism, including ocean-island basalt, forms an integral part of development of most Intermontane terranes, except the newly defined Atlin terrane (Zagorevski et al., this volume). In this section, modern arc, back-arc,

and intraplate volcanic environments are briefly examined from a broad geochemical perspective. Then the setting of within-plate magmatism within arc–back-arc environments is targeted in order to elucidate key temporal and future stratigraphic relationships that can improve the understanding of development of Cordilleran terranes. Comparisons utilize data from <[www.earthchem.org/petdb](http://www.earthchem.org/petdb)>; download parameters are specified in Figure 5. Data were screened such that any samples that lacked Nb and rare-earth elements (REE) were eliminated. Data were subsequently classified as ‘mafic’ (<55% SiO<sub>2</sub>) and felsic (>55% SiO<sub>2</sub>). No parts of the data sets that appear to be misclassified were eliminated (e.g. volcanic-arc data includes some Yellowstone hot-spot related samples).

Volcanic-arc samples (Fig. 5a) are characterized by predominantly subalkaline compositions (Nb/Y<2), and plot predominantly in volcanic-arc tholeiite (= island-arc tholeiite) and calc-alkaline basalt fields. The vast majority of samples plot above the mantle array. Samples with elevated Nb/Y ratios are from ‘anomalous’ tectonic areas situated

**Figure 5.** Geochemical characteristics of volcanic rocks from different settings compared to Paleozoic Yukon-Tanana terrane (see Fig. 2 for field labels, number of samples varies between diagrams due to missing values). **a)** Modern volcanic arc (Mafic = 40–55% SiO<sub>2</sub>, Felsic = >55% SiO<sub>2</sub>; a1: n<sub>mafic</sub> = 1163, n<sub>felsic</sub> = 972; a2: n<sub>mafic</sub> = 1176, a3: n<sub>mafic</sub> = 980, n<sub>felsic</sub> = 831; downloaded from <[www.earthchem.org/petdb](http://www.earthchem.org/petdb)> [accessed 26 July 2019]; search parameter = volcanic arc). **b)** Modern back-arc setting (b1: n<sub>mafic</sub> = 989, n<sub>felsic</sub> = 252; b2: n<sub>mafic</sub> = 993, b3: n<sub>mafic</sub> = 802, n<sub>felsic</sub> = 239 downloaded from <[www.earthchem.org/petdb](http://www.earthchem.org/petdb)> [accessed 26 July 2019; search parameter = back-arc). **c)** Modern within plate settings (c1: n<sub>mafic</sub> = 3739, n<sub>felsic</sub> = 388; c2: n<sub>mafic</sub> = 4014, c3: n<sub>mafic</sub> = 3729, n<sub>felsic</sub> = 231; downloaded from <[www.earthchem.org/petdb](http://www.earthchem.org/petdb)> [accessed 26 July, 2019]; search parameters = continental rift, incipient rift, intra-plate craton, intraplate off-craton, oceanic plateau, oceanic island, and rift valley). **d)** Paleozoic parautochthonous Laurentia, Yukon-Tanana, Slide Mountain, Quesnellia, and Stikinia. Purple plus = Yukon-Tanana terrane, yellow plus = parautochthonous north America, black star = Slide Mountain, red circle = Stikinia, purple diamond = Quesnellia.





in the upper plate. These include Italy, a narrow sector of central American volcanic belt, and Yellowstone hotspot track.

Back-arc samples (Fig. 5b) are characterized by subalkaline to alkaline compositions and plot in the island-arc tholeiite and back-arc basalt fields with significant proportion of samples trending toward EMORB and ocean-island basalt fields. In contrast to the volcanic-arc samples, many back-arc samples plot along the mantle array, indicating a highly variable mantle source that ranges from depleted to enriched. Samples characterized by high Nb/Y ratio are predominantly from North Fiji Basin, South China Sea, Sea of Japan, northern Lau Basin, western Philippine Sea, and Shikoku Basin.

Within-plate samples (Fig. 5c) show the greatest diversity of magma types, including a large number of samples with elevated Nb/Y ratios. Mafic samples occupy all tectonic discrimination fields with a large number of samples plotting in the continental rift and ocean-island basalt fields. Within-plate samples overlap EMORB and ocean-island basalt portions of the mantle array with relatively few samples in the depleted part of the mantle array.

In order to evaluate the existing models of intra-arc and back-arc magmatism in the Intermontane terranes (Fig. 4), some modern analogues in the western Pacific (Fig. 6) are presented. The Sea of Japan has been previously proposed to be an analogue for the opening of the Slide Mountain Ocean and rift-related magmatism on the Laurentian margin, Yukon-Tanana terrane, and Quesnellia (e.g. Nelson, 1993; Creaser et al., 1999; Piercey et al., 2004). In the Sea of Japan, ocean-island basalt-like magmatism formed during the terminal rift stages (Late Miocene to Recent) of the opening of the Sea of Japan (Ulleung Basin, Ulleung Island, Oki Islands) and rifting on the Korean Peninsula (Cheju Island, Gueongsang Basin: Uto et al., 1994; Pouclet et al., 1995). Poorly documented Middle Miocene alkaline magmatism also formed a seamount in the Yamato Basin, following cessation of spreading (Pouclet et al., 1995). Although ocean-island basalt magmatism was coeval with arc magmatism, there is a clear association of ocean-island basalt magmatism with the back-arc regions and termination of spreading. This spatial and temporal association has several important implications for the expected tectono-stratigraphic relationships in ancient orogens. Primarily, ocean-island basalt magmatism does not occur along the magmatic front. Its position in the distal back-arc indicates that ocean-island basalt magmas are unlikely to be overlain or intruded by the active arc magmas unless there is a major plate reorganization. Additionally, ocean-island basalt magmatism appears to mark the terminal stages of back-arc development rather than initiation of spreading (Uto et al., 1994; Pouclet et al., 1995). Thus, the presence of ocean-island basalt-like magmatism in ancient Sea of Japan-like terranes should indicate either their position in extinct back arcs or remnant arcs, rather than arc fronts or nascent back arcs.

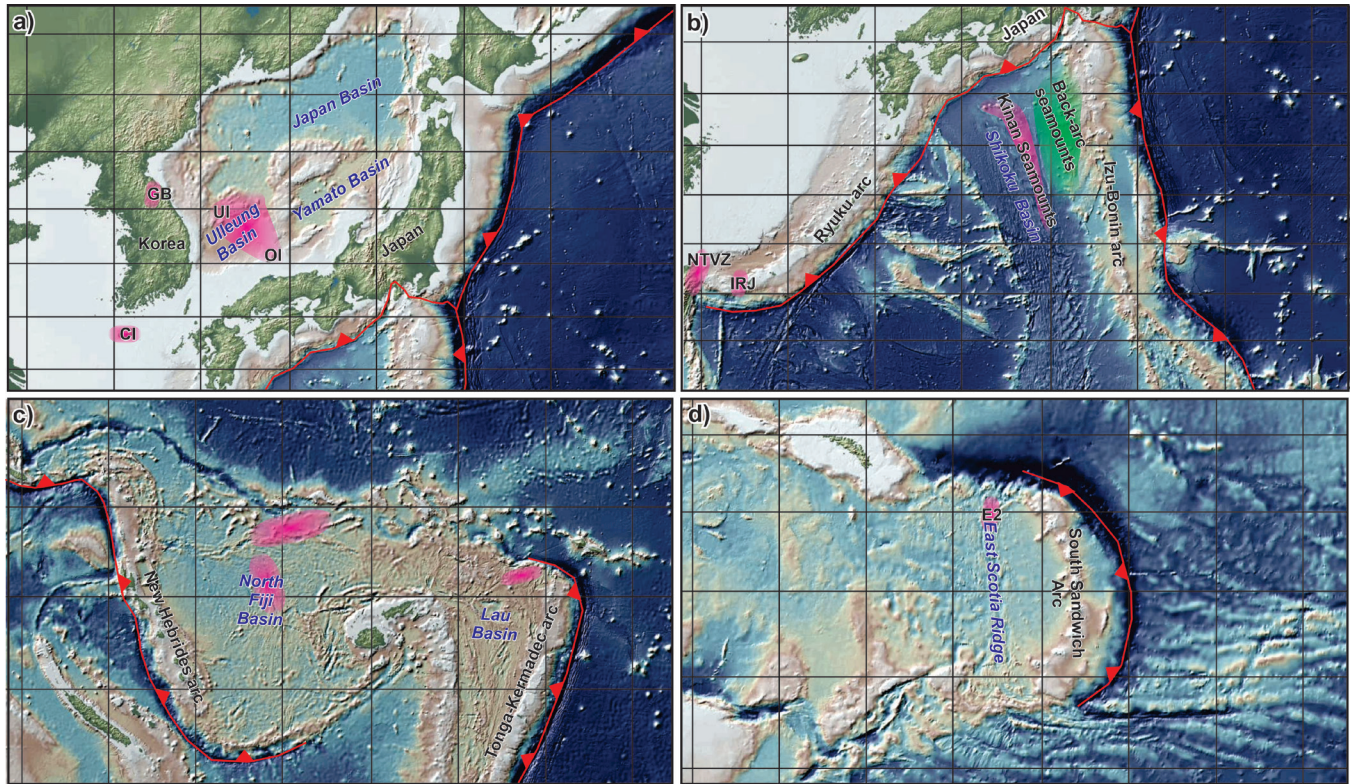
Ocean-island basalt magmatism also occurs in the Shikoku Basin, which formed as a 27 Ma to 15 Ma back arc to the Izu-Bonin Arc (Ishizuka et al., 2009). Cessation of spreading in the Shikoku Basin was followed by emplacement of the Kinan seamount chain ocean-island basalt (15 Ma to 7 Ma: Ishizuka et al., 2009), which formed seamounts on the extinct back-arc ridge. Similar to the Sea of Japan, ocean-island basalt magmatism in the Shikoku Basin occurs in the back arc, postdates back-arc spreading, and has no chance of being intercalated with the volcanic rocks along the Izu-Bonin-Marianna Arc unless there is a major plate reorganization.

The New Hebrides–Solomon Arc and the North Fiji Basin have a somewhat different setting of ocean-island basalt compared to the Sea of Japan and Shikoku Basin. Ocean-island basalt magmatism in the North Fiji Basin is contemporaneous with back-arc ridge spreading (Fig. 6c; Eissen et al., 1994; Nohara et al., 1994); however, the position of the ocean-island basalt magmatism in the distal back-arc means that these ocean-island basalts have no chance of being intercalated with volcanic-arc rocks of the New Hebrides–Solomon Arc.

The Tonga–Kermadec and the northern Lau Basin back arc show a similar relationship to the North Fiji Basin. The northern Lau Basin ocean-island basalts are located within the distal Lau back-arc basin along the northern termination of the Tonga–Kermadec Arc (Fig. 6c). Their petrogenesis, however, has been in part linked to flow of Samoan plume components around the slab edge (Price et al., 2016). Similarly, the northern segment of the East Scotia Ridge has a significant plume-related component on-strike with back-arc magmatism (Fig. 6d; E2 back-arc segment in Fretzdorff et al., 2002). This plume component has been related to flow of Bouvet plume-related mantle around the slab edge (Fretzdorff et al., 2002). In both of these cases, plume components coincide with a slab edge, are erupted in the back arc, and are thus localized features within the back-arc system.

Lastly, ocean-island basalt lavas are present at the southern termination of the Ryuku Arc (Fig. 6a). Magmatism on Iriomote-jima (IR) and in the northern Taiwan volcanic zone (NTVZ) formed during opening of the South China Sea as a consequence of India–Asia collision (Chung et al., 1994). Although some models also link this spreading to Pacific subduction (Hall, 2002), these enriched magmas were far removed from the present Ryuku subduction zone (Chung et al., 1994; Shinjo, 1999). Its current position along the southern termination of the Ryuku magmatic front is a product of propagation of the edge of the Ryuku subduction zone to the southwest. These ocean-island basalts can be on-lapped by arc–back-arc magmatism related to the Ryuku arc and Okinawa trough; however, this is a rather unique tectonic scenario where subduction propagates toward a continental rift unrelated to the approaching subduction zone. In such scenario, ocean-island basalt sequences are unrelated





**Figure 6.** Setting of ocean-island basalt (OIB) magmatism (purple) in selected areas. Background image is generated from <http://www.geomapapp.org> [accessed July 30, 2019]. **a)** Ocean-island basalt magmatism in Sea of Japan and Korea is concentrated in the back-arc area and formed during the latest stages of back-arc development (Uto et al., 1994; Pouclet et al., 1995). Without major plate reorganization this magmatism has no potential of being onlapped by active arc magmas. CI = Cheju Island, GB = Gueongsang Basin, OI = Oki Islands, UI = Ulleung Island. **b)** Ocean-island basalt magmatism at the southern termination of Ryukyu Arc and Shikoku Basin. Magmatism on Iriomote-jima (IRJ) and in the northern Taiwan volcanic zone (NTVZ) formed during continental extension that was far-removed from Ryukyu subduction (Chung et al., 1994; Shinjo, 1999). Its current position along the Ryukyu magmatic front is a product of propagation of the edge of the Ryukyu subduction zone to the west. These ocean-island basalts can be onlapped by arc magmatism. In the Izu-Bonin-Mariana Arc, the Kinan seamount chain (Shikoku Basin) formed following cessation of spreading in the Shikoku Basin (Ishizuka et al., 2009). These ocean-island basalts have no potential of being onlapped by active arc magmas without plate re-organization, or accretion along the Ryukyu Arc. **c)** Ocean-island basalts in North Fiji Basin (Nohara et al., 1994) is far removed from the active subduction zone magmatism. Ocean-island basalt magmatism in the northern Lau Basin is related to flow of mantle around the slab edge (Price et al., 2016). **d)** Plume component in E2 segment of the East Scotia Ridge is related to flow of mantle around the slab edge (Fretzdorff et al., 2002). Red line = subduction zone boundary, teeth on upper plate.

to arc development, but can be diachronously on-lapped by arc magmatism as the subduction propagates along the continental margin.

## Evaluation of Intermontane terranes

Enriched magmatism forms a minor, but important contribution to modern back-arc settings (Fig. 6). The relatively restricted occurrence of enriched magmatism in arc-back-arc settings can be used to aid and evaluate tectonic reconstructions of the northern Cordillera. Enriched magmatism, and specifically ocean-island basalt, should generally mark back-arc regions far away from the arc front in ancient arc terranes and either be coeval with an active back-arc ridge (e.g. North Fiji Basin); overlap an extinct back-arc ridge (e.g. Shikoku Basin); erupt onto rifted continental or

arc crust in the back-arc basin (about broadly equivalent to a remnant arc: Sea of Japan); and/or be unrelated to arc magmatism.

Ocean-island basalt and/or EMORB magmatism is preserved in all Intermontane terranes (Fig. 3). With the exception of the Cache Creek terrane, these Intermontane terranes were generally interpreted to have formed in an arc (Yukon-Tanana, Stikinia, Quesnellia) and back-arc (Slide Mountain) settings (Fig. 4; Nelson et al., 2013). From the perspective of modern examples (*see* ‘Within-plate magmatism in modern arc settings’), only the Paleozoic Stikinia seems to fit the expected evolution of a rifting arc system. Stikinia is characterized by Carboniferous calc-alkaline Stikine assemblage magmatism followed by Permian alkaline, ocean-island basalt-like magmatism (Fig. 3c), cessation of magmatism altogether, and development of a Permian carbonate platform (e.g. Logan et al., 2000; Gunning et al.,

2006). Although Stikine assemblage ocean-island basalt magmatism was previously interpreted as representing intra-arc rifts (Fig. 4; Gunning et al., 2006), the evolution of the Stikine assemblage strongly suggests that the Carboniferous Stikine assemblage formed along the arc front (e.g. Logan et al., 2000; Gunning et al., 2006; Zagorevski et al., 2012), but developed into a remnant-arc ridge by the Permian. This implies that by the Permian, the Stikine assemblage remnant arc was separated from the active Permian arc by a back-arc basin. This active Permian arc has not been identified in any of the existing tectonic models.

Mesozoic Stikinia and Quesnellia are generally considered to be correlative (e.g. Logan and Mihalynuk, 2014); however, their Paleozoic basement appears to have experienced markedly different histories (Fig. 3d). The Late Paleozoic Quesnellia in southern British Columbia is characterized by ocean-island basalt and EMORB magmatism as well as arc-back-arc magmatism (Fig. 3d; Massey and Dostal, 2013). Younger magmatism in Paleozoic Quesnellia is mostly characterized by arc-like characteristics. The overall temporal evolution of magmatism from ocean-island basalt-rich to arc (Fig. 3d) is the opposite of what is expected to occur in a rifting arc-back-arc-remnant-arc system (*see* 'Within-plate magmatism in modern arc settings' section). As previously suggested by Massey and Dostal (2013), Paleozoic Quesnellia includes several widely separated blocks of arc, back-arc, remnant-arc, and other crustal settings. As such, it is a composite terrane.

The Yukon-Tanana and Slide Mountain terranes have also undergone several episodes of ocean-island basalt magmatism contemporaneous with calc-alkaline basalt, island-arc tholeiite, and boninite magmatism (e.g. Simard et al., 2003, 2007; Piercey et al., 2006). The separation of the Yukon-Tanana from the Slide Mountain terrane in part recognizes that these terranes formed in distinctly different settings; however, both have stratigraphic successions that include several episodes of ocean-island basalt and rift magmatism (e.g. Piercey et al., 2001, 2006, 2012; Murphy et al., 2006). In general, the complex tectonostratigraphy and often confusing geological constraints make it extremely difficult to evaluate the evolution of the Yukon-Tanana and Slide Mountain terranes. Overall, the occurrence of ocean-island basalt magmatism throughout the whole history of the Yukon-Tanana terrane is much more similar to continental rifts and continental magmatic provinces (e.g. Edwards and Russell, 2000) rather than to an extensional arc system (Fig. 5). In continental rift systems, calc-alkaline magmatism is often associated with ocean-island basalt-like magmatism, but does not require active subduction to drive it (Fig. 5). These calc-alkaline magmas can be derived by melting of previously metasomatized mantle or continental crust (e.g. Hawkesworth et al., 1995; Hooper et al., 1995). Similarly, application of the tectonomagmatic evolution of the Sea of Japan to the Yukon-Tanana terrane still requires that it represents a distal back arc or remnant arc, rather than an episodically active arc front. For example, ocean-island

basalt containing tectonostratigraphic units such as the Klinkit Group (Simard et al., 2007) likely mark the terminal stages of remnant-arc and back-arc development (Fig. 6a, b) rather than active arc magmatism.

In contrast to parts of the Yukon-Tanana terrane, the presence of Middle Permian suprasubduction zone (back-arc or intra-arc) spreading centres in the Slide Mountain terrane indicates a much closer proximity to the Middle Permian active arc (van Staal et al., 2018; Parsons et al., 2019). Although these ophiolites were previously included in the Slide Mountain terrane, they are distinctly different and should be separated from older Permian to Carboniferous volcano-sedimentary successions, especially those that contain ocean-island basalt. Existing relationships seem to indicate that both the Yukon-Tanana and Slide Mountain terranes are composite in themselves and comprise distinct tectonic elements that have undergone different geological history and were subsequently juxtaposed by faults (Harms and Murchey, 1992; van Staal et al., 2018; Parsons et al., 2019).

## Implications for Cordilleran terrane definitions and reconstructions

Identification of distinct arc, back-arc, and remnant-arc terranes within a single, upper plate magmatic (arc) system may seem like a largely academic exercise of overcomplicating the existing terrane framework; however, systematic re-evaluation of the existing terrane framework can have a fundamental impact on the understanding of the stratigraphy, structural stacking, as well as temporal and spatial distribution of mineral deposits. For example, this study's re-evaluation of the 'oceanic' rocks in northern British Columbia and southern Yukon led to recognition of two distinct terranes that experienced distinctly different histories (*see* Zagorevski et al., this volume). Specifically, the newly defined Atlin terrane ophiolites are in part coeval with ophiolites that have been traditionally included in the Slide Mountain terrane.

Re-evaluation of the Stikine assemblage as a Permian remnant arc also has important regional implications as it requires that the Permian arc axis migrated away from this remnant arc. An active Permian arc and back-arc basin have not been properly considered in previous models, but these may well be represented by the Middle Permian to Middle Triassic elements of the Atlin terrane (formerly part of the Cache Creek terrane: *see* Zagorevski et al., this volume). If this assertion is correct, then it implies a west-dipping, retreating subduction beneath Paleozoic Stikinia.

This new framework allows proper evaluation of terrane linkages through time as it dispenses with the traditionally held, but often poorly supported notions of where terrane boundaries are located. For example, existing models entirely dismiss any connection between Cache Creek and



other Intermontane terranes on the basis of presence of warm-water fossils and presumed seamount or plateau origin of the volcanic rocks (Monger and Ross, 1971; Monger, 1977; Monger et al., 1991; *see* Zagorevski et al., this volume); however, the Cache Creek terrane ocean-island basalt and EMORB magmatism is actually coeval with ocean-island basalt and EMORB magmatism in the Yukon Tanana, Slide Mountain, and Stikinia terranes (Fig. 3). This may be entirely coincidental, or it may reflect a more southerly derivation of Cache Creek terrane within the same ocean-island basalt-rich rift system which changes facies from siliciclastic-dominated to the north, to carbonate-dominated in the south. Although paleo-longitudinal transport of the Cache Creek terrane is the currently preferred model (e.g. Johnston and Borel, 2007), paleolatitudinal transport of the Cache Creek terrane was deemed more likely in the past (Monger and Ross, 1971) and is supported by recent re-evaluation of conodont faunas (Golding, 2018).

Re-evaluation of the tectonic framework will also facilitate a broader understanding of tectonic processes and related magmatism. For example, although Stikinia, Quesnellia, and Yukon-Tanana terranes are generally interpreted as segments of the same arc-back-arc system (e.g. Mortensen, 1992; Mihalynuk et al., 1994; Nelson and Colpron, 2007; Nelson et al., 2013), there seems to be a broad indication that the peak of ocean-island basalt magmatism, and presumably termination of spreading in the distal back arc is diachronous in Intermontane terranes (Fig. 3). These differences may indicate significant diachroneity of tectonic processes or may be an artifact of improperly defined terranes. The latter is particularly salient because terranes such as Stikinia and Quesnellia are largely defined and correlated on the basis of the Late Triassic overlap assemblages (*see* Logan and Mihalynuk, 2014) that were deposited on already deformed basement (e.g. Monger et al., 1991; Logan et al., 2000). This deformed and often poorly exposed basement may, in itself, comprise several distinct terranes.

## PALEOZOIC KLONDIKE ARC — IS IT REALLY AN ARC?

The Middle to Late Permian Klondike assemblage preserves the youngest magmatism in the Yukon-Tanana terrane (Fig. 3, 7; ca. 269–253 Ma; Nelson et al., 2006). Similar to other Paleozoic magmatic assemblages in the Yukon-Tanana terrane, the Klondike assemblage is interpreted as a continental arc (e.g. Piercey et al., 2006), and generally referred to as the Klondike arc. The purpose of this section is to evaluate the evidence for an arc origin of the Klondike assemblage and to identify recent analogues of the Middle to Late Permian Yukon-Tanana terrane.

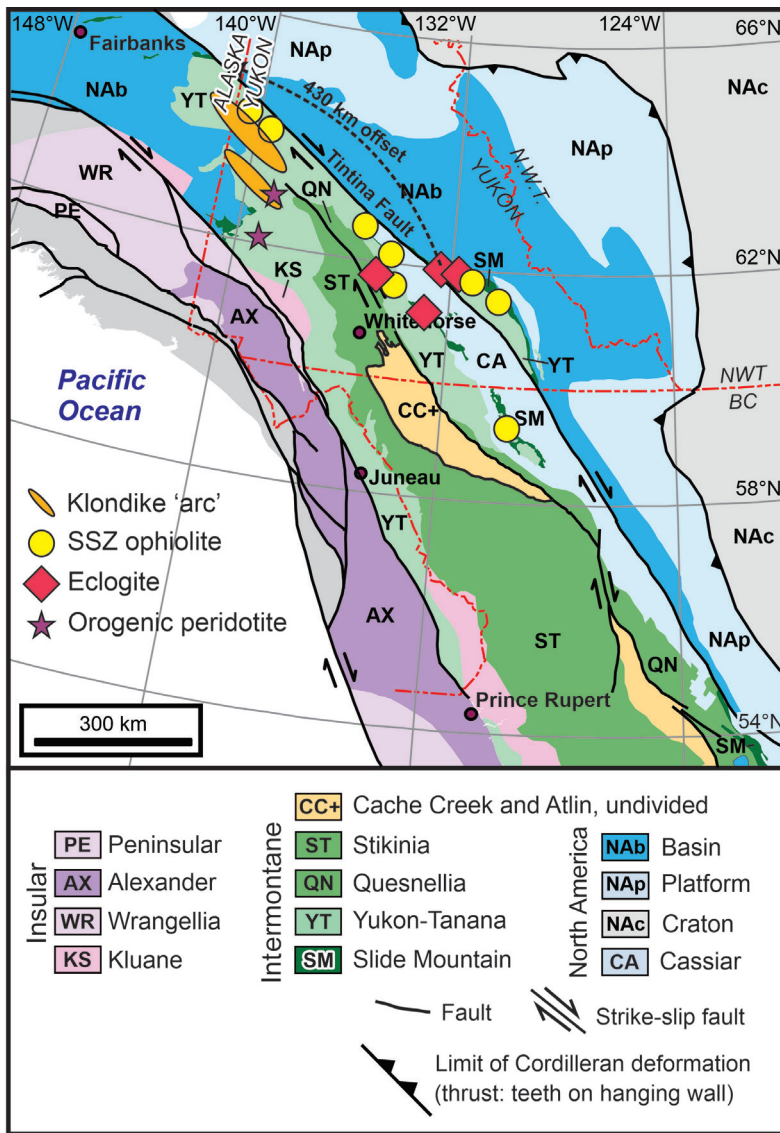
The Klondike assemblage is mostly restricted to the central-western Yukon and eastern Alaska (Fig. 7), and comprises the Sulphur Creek plutonic suite and the Klondike schist volcanic rocks (e.g. Mortensen, 1992; Ryan and Gordey, 2004;

Beranek and Mortensen, 2011; Ryan et al., 2013a, b, 2014, this volume). The Sulphur Creek suite comprises variably deformed, amphibolite-facies, K-feldspar porphyritic monzogranite to syenogranite (Fig. 8a), K-feldspar augen gneiss, and schist. The Sulphur Creek suite intrudes into the Late Devonian and older metasedimentary Snowcap assemblage mica schist, quartzite, and marble. The coeval Klondike schist comprises variably deformed (sub)greenschist-facies phyllonite and schist derived from felsic and mafic volcanic and hypabyssal rocks (Fig. 8b). Felsic rocks are by far the most abundant and are locally preserved as felsic lapilli tuff and breccia (Ryan et al., 2014, this volume). Stratigraphic relationships between the Klondike schist and the Snowcap assemblage basement are not well exposed. Instead, the volcanic rocks of the Klondike schist are generally overthrust by the distinctly higher metamorphic grade Snowcap assemblage, though both are intruded by the Sulphur Creek suite (Ryan et al., 2014).

Felsic plutonic rocks of the Klondike assemblage area display variable trace-element signatures, ranging from variably LREE-enriched to relatively MREE- and HREE-depleted (Piercey et al., 2006; Ruks et al., 2006; Milidragovic et al., 2016). Felsic volcanic rocks are characterized by strong LREE-enrichment characteristic of calc-alkaline suites (Fig. 8c). Felsic plutonic and volcanic rocks plot above the upper crust in the Th/Yb-Nb/Yb plot (Fig. 8d), consistent with their evolved nature and significant crustal component in their petrogenesis (Piercey et al., 2006; Ruks et al., 2006). Relatively sparse mafic volcanic and plutonic rocks show very diverse geochemical signatures, ranging from volcanic arc tholeiite to calc-alkaline basalt (Fig. 8e, f). Some volcanic and plutonic rocks are characterized by small Nb anomaly relative to La, typical of rift-related enriched magmas that were contaminated by crust (e.g. Piercey et al., 2006).

The Klondike assemblage is broadly coeval and co-spatial with Middle Permian orogenic peridotite(s) which were structurally exhumed into the Snowcap assemblage during extension (Fig. 7; Buffalo Pitts: Canil et al., 2003; Johnston et al., 2007; Ryan et al., 2014; N. Joyce, unpub. data, 2020; Schist Creek: Ryan et al., 2016). Layered pyroxenite from the Middle Permian Buffalo Pitts orogenic peridotite (Fig. 7) is characterized by highly enriched LREE and Nb, indicating derivation from a highly enriched non-arc magma source, probably ocean-island basalt-like. Gabbro from the Middle Permian Schist Creek mafic-ultramafic complex is characterized by calc-alkaline geochemistry.

The voluminous Klondike assemblage felsic plutons, predominantly felsic volcanic rocks and Middle Permian orogenic peridotites, were emplaced during a rather enigmatic period during the development of the Yukon-Tanana terrane. Although the Permian Yukon-Tanana terrane is accepted to be a continental arc, parts of it were metamorphosed to eclogite facies between 271 Ma and 252 Ma (Philippot et al., 2001; Gilotti et al., 2017). This eclogite-facies metamorphism is poorly understood, but has been attributed to

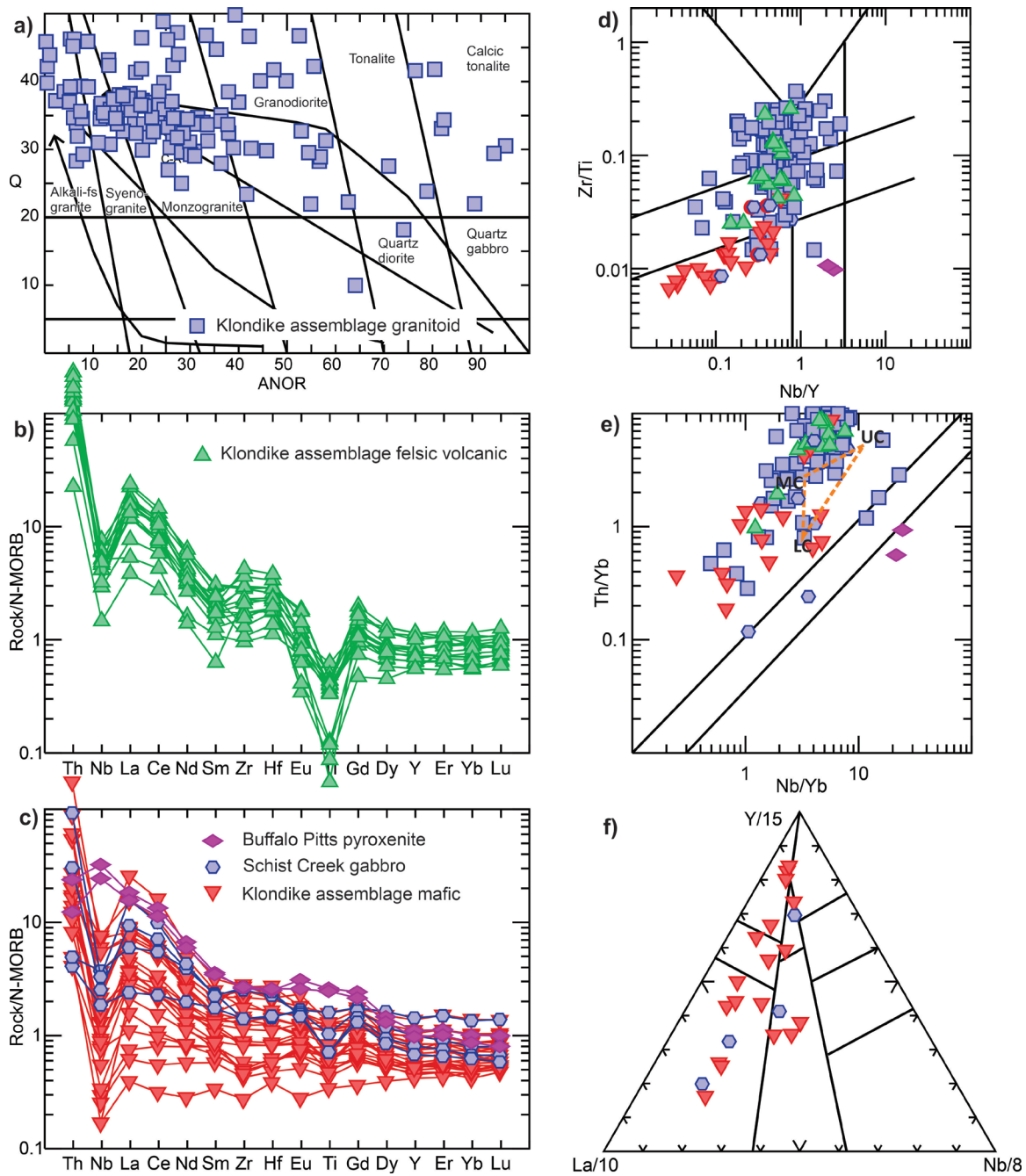


**Figure 7.** Lithotectonic map of northern Cordillera (Colpron and Nelson, 2011), showing distribution of the Middle to Late Permian Klondike assemblage, eclogites, suprasubduction zone (SSZ) ophiolites, and orogenic peridotites. Tintina Fault has about 430 km of offset.

underthrusting of the Yukon-Tanana terrane upper plate as a result of subduction erosion during subduction of the Slide Mountain Ocean (Creaser et al., 1999; Gilotti et al., 2017). The spatial distribution of ophiolitic rocks of the Slide Mountain terrane and high-pressure rocks to the east, and the Klondike assemblage magmatism to the west has been interpreted by most workers as a paired metamorphic belt (Fig. 7; Nelson et al., 2006; Piercey et al., 2006); that is, the Klondike assemblage has been interpreted to represent an arc, whereas the high-pressure rocks and the Slide Mountain terrane ophiolitic rocks were interpreted to mark the accretionary complex and paleotrench to the east (e.g. Nelson et al., 2006; Gilotti et al., 2017).

Slide Mountain terrane ophiolitic rocks were previously interpreted to form part of the Slide Mountain Ocean that was subducting beneath the Klondike arc. Investigations of Clinton Creek, Midnight Dome, and Dunite Peak ophiolite complexes indicate that these Permian ophiolites did not

form part of the subducting plate as they are characterized by suprasubduction-zone magmatism ranging from ca. 260 Ma to 285 Ma (Fig. 7; Colpron et al., 2005; van Staal et al., 2018; Parsons et al., 2019; Zagorevski et al., this volume). Thus, an extensional arc was developing in the Slide Mountain Ocean (van Staal et al., 2018; Parsons et al., 2019), broadly at the same time as the adjacent, eastern edge of the Yukon-Tanana terrane was undergoing eclogite-facies metamorphism (Philippot et al., 2001; Gilotti et al., 2017). This requires that either there were two distinct arcs in the Slide Mountain Ocean, possibly with a Molucca Sea-style configuration (e.g. Bader et al., 1999) and/or more simply, the Yukon-Tanana terrane was situated on the subducting plate and was partly subducted to eclogite facies beneath this arc. In order to reconcile the seemingly conflicting relationships between the Klondike magmatism, eclogite-facies metamorphism of parts of the



**Figure 8.** Geochemical characteristics of the Klondike assemblage. **a)** Q-ANOR plot of the Sulphur Creek plutonic suite granitoid rocks (Whalen and Frost, 2013). Fs = feldspar **b)** Felsic volcanic rocks of the Klondike schist (N-MORB normalization factor from Sun and McDonough, 1989). **c)** Mafic volcanic and plutonic rocks of the Klondike assemblage, Buffalo Pitts, and Schist Creek complexes. **d), e)** Nb/Y-Zr/Ti and Nb/Yb-Th/Yb plots, respectively, showing diversity of the Klondike assemblage (Pearce, 1996). **f)** Mafic volcanic and plutonic rocks of the Klondike assemblage (Cabanis and Lecolle, 1989).



Yukon-Tanana terrane, orogenic peridotite exhumation, and formation of a juvenile arc along the presumed paleotrench, the present authors re-examine the generally accepted arc origin of the Klondike assemblage.

## Klondike assemblage as a continental rift

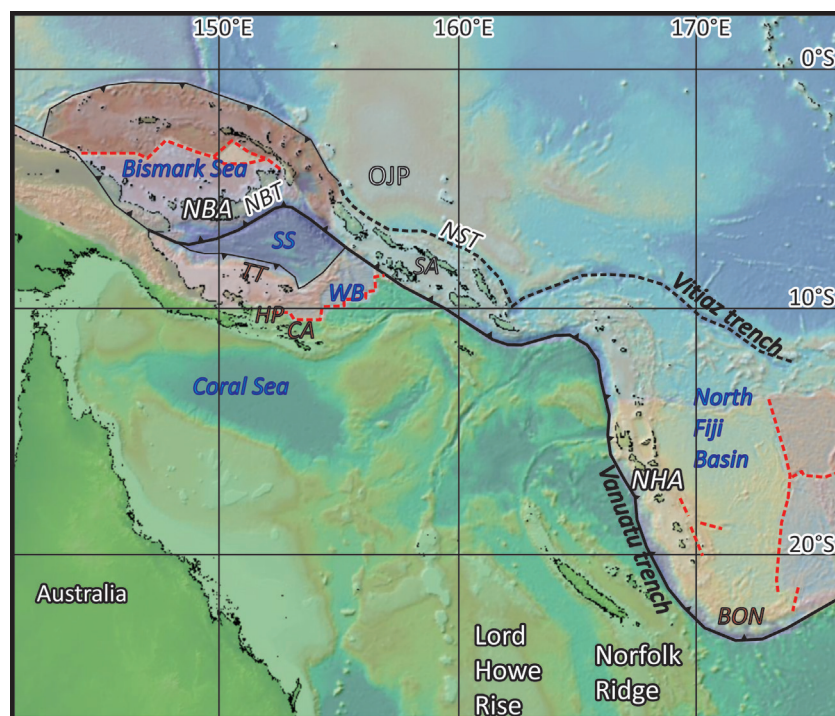
From a geochemical perspective, the Klondike assemblage is characterized by: volumetrically minor, but geochemically highly variable mafic magmatism; a component of rift-related mafic magmatism including emplacement of highly enriched mafic magmas; and voluminous evolved felsic magmatism with significant crust involvement (Piercey et al., 2006). None of these characteristics are indicative of an arc setting. Moreover, the highly diverse rift-like mafic magmatism, crustal derivation of voluminous felsic magmatism, extensive preservation of pre-arc sedimentary basement, structural exhumation of orogenic peridotite, and restricted distribution of the Klondike assemblage magmatic rocks (Fig. 7) are much more consistent with a continental rift setting (e.g. Canil et al., 2003; Johnston et al., 2007; van Staal et al., 2018).

Development of the Klondike assemblage in a Middle Permian continental rift rather than an arc setting can explain some of the enigmatic aspects of current tectonic models such as structural exhumation of orogenic peridotites, roughly coeval with eclogite-facies metamorphism of supposedly upper plate rocks, and formation of coeval suprasubduction zone ophiolites. Within this context, the Middle Permian Yukon-Tanana terrane and the Klondike assemblage are probably best interpreted as the subducting

plate below a juvenile Middle Permian arc that is largely represented by the Middle Permian suprasubduction zone ophiolites (Dunite Peak arc of Parsons et al., 2019). The coincidence of rift-related magmatism and eclogite-facies, subduction-related metamorphism of the Yukon-Tanana terrane is obviously unusual; however, there are several recent analogues to this process in the western Pacific Ocean.

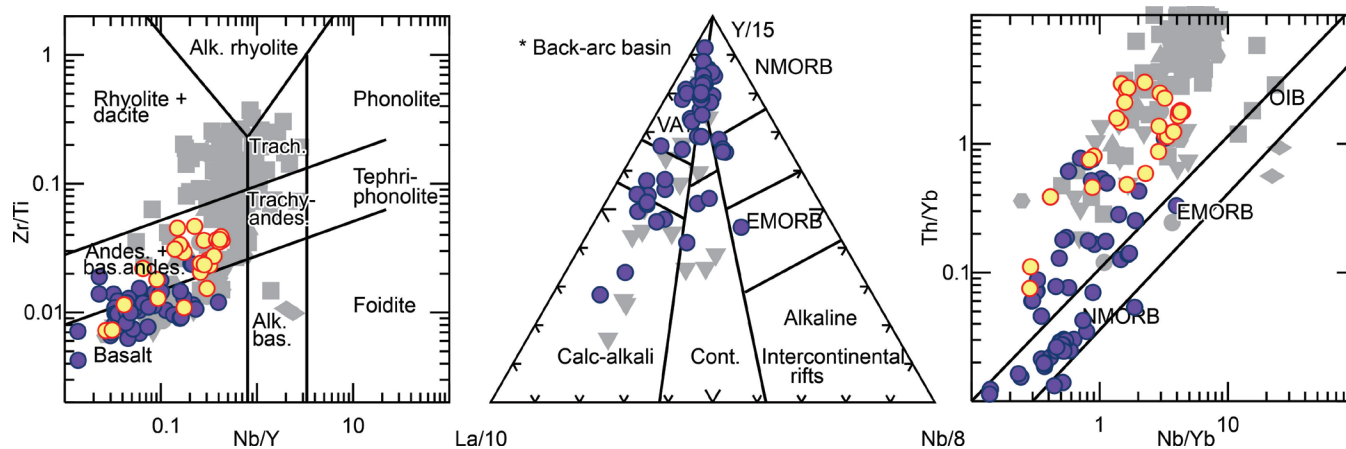
The highly diachronous interaction of the New Britain Arc–Solomon Arc with the Australian margin and associated opening of the Woodlark Basin in Papua New Guinea provides a potential analogue for the various complex relationships recognized in the Yukon-Tanana–Slide Mountain terranes. Pertinent is that the downgoing Australian plate that subducts beneath the New Britain Arc–Solomon Arc contains an active rift (Woodlark Basin; Fig. 9; Baldwin et al., 2012). The tectonics of this area are very complex; as such the present authors address only the salient points that are considered most relevant to interpreting the Klondike assemblage.

The Australian margin, which is undergoing active continental rifting on the Papuan Peninsula, transitions to fully oceanic spreading in the Woodlark Basin (e.g. Abers et al., 1997; Taylor et al., 1999). Rifting is accompanied by extensional faulting; exhumation of metamorphic core complexes, including the youngest-known eclogites on Earth; and rift-related magmatism (Perfit et al., 1987; Stolz et al., 1993; Abers et al., 1997; Little et al., 2011). Rift-related magmatism is very diverse and is characterized by peralkaline to calc-alkaline magmatism on the margin, transitioning to predominantly tholeiitic in the Woodlark Basin (Fig. 10; Perfit et al., 1987; Stolz et al., 1993; Park et al., 2018). The Woodlark Basin taps into previously metasomatized mantle



**Figure 9.** Australia-Pacific plate boundary provides a good example of interaction of New Hebrides–Solomon–New Britain extensional arc system (equivalent to Slide Mountain suprasubduction zone ophiolites) with an active Woodlark Basin that is propagating as a continental rift into the Australian continental margin (possible analogue of the Klondike assemblage magmatism); *modified from* van Staal et al. (2018); background image is generated from <http://www.geomapp.org> [accessed July 30, 2019]. NBA = New Britain Arc, NBT = New Britain Trench, NHA = New Hebrides Arc, NST = Northern Solomon Trench, OJP = Ontong-Java Plateau, SA = Solomon Arc, SS = Solomon Sea, TT = Trobriand Trough, WB = Woodlark Basin; BON = boninite, CA = calc-alkaline and peralkaline magmatism, HP = exhumed high pressure rocks





**Figure 10.** Geochemical characteristics the Woodlark Basin (<[www.earthchem.org/petdb](http://www.earthchem.org/petdb)> [accessed 31 January 2020]; search parameter = polygon containing Woodlark Basin and eastern Papuan Peninsula). Yellow symbols = >55 wt.%  $\text{SiO}_2$ , purple symbols = <55 wt.%  $\text{SiO}_2$ , grey symbols = Klondike assemblage (see also Fig. 8 for comparison) alk = alkali, trach = trachyte, andes = andesite, bas = basalt, cont. = continental.

sources and is locally characterized by arc and back-arc-like magmatism (e.g. Perfit et al., 1987; Park et al., 2018). Hence, ancient analogues of such a setting could be easily mistaken for an arc setting. Australian continental lithospheric mantle has not been described in the Woodlark Basin; however, orogenic peridotites occur in other continental rifts (e.g. Bonatti et al., 1986) and form likely analogues for the Middle Permian orogenic peridotites in the Yukon-Tanana terrane (Canil et al., 2003; Johnston et al., 2007).

This region also preserves several analogues where continental rifting and eclogite-facies metamorphism occur within the same plate. Specifically, the Australian continental margin is colliding with, and was partially subducted beneath, the overriding Bismark Arc–New Britain Arc (e.g. Abbott et al., 1994). Continued subduction of the active Woodlark Basin under the Solomon Arc will eventually result in subduction of the extended Australian margin (Fig. 9). An alternative analogue to the coincidence of eclogite-facies metamorphism and continental rifting is exposed at the western tip of the Woodlark Basin in the active continental rift. In this area, eclogites are being exhumed as a consequence of the continental rifting that propagated through an older collision zone (Little et al., 2011). In these analogues, the Middle Permian Slide Mountain ophiolites are likely equivalent to the New Britain–Solomon–New Hebrides arcs and their respective back arcs. Exhumation of eclogites in a continental rift requires that the Yukon-Tanana terrane experienced previous collisions, a possibility that is supported by the presence of Mississippian eclogites (e.g. Devine et al., 2006).

The collision of the Luzon Arc with Asia forms another potential analogue of broadly coeval eclogite-facies metamorphism and continental rift-related magmatism. The collision terminated rift-related magmatism in the South China Sea (Chung et al., 1994), subducted continental crust beneath the Luzon Arc, and resulted in Luzon fore-arc block

subduction (McIntosh et al., 2005). Deformation front extends about 100 km from the suture into the continental margin. The Luzon Arc is diachronously emplaced (obducted) onto the subducted continental margin; however, the Luzon Arc itself remains extremely well preserved with virtually no evidence of penetrative deformation (McIntosh et al., 2005; Huang et al., 2006), which is indicative of a soft collision. In this analogue, the Permian Klondike assemblage may be equivalent to the South China Sea continental margin, eclogite-facies Yukon-Tanana terrane may form part of the subducted extended continental crust, whereas the Middle Permian Slide Mountain terrane suprasubduction zone ophiolites are broadly equivalent to the Luzon Arc.

These analogues indicate that most of the enigmatic characteristics of the Middle Permian Yukon-Tanana terrane and the Klondike assemblage can be explained in terms of a partial subduction of an actively rifting Yukon-Tanana terrane; however, this requires a major re-evaluation of the existing models for the Paleozoic evolution of the Yukon-Tanana and Slide Mountain terranes (e.g. van Staal et al., 2018; Parsons et al., 2019).

## MID-CRETACEOUS MAGMATISM AND HIGH-FLUX MAGMATIC EPISODES

Voluminous mid-Cretaceous plutonic rocks and associated volcanic rocks were emplaced throughout the North American Cordillera from the Peninsular Ranges Batholith in California, through the Coast Mountain and Cassiar batholiths in British Columbia, and to the various plutonic suites in Yukon and Alaska (Fig. 11). The emplacement of these plutonic rocks marks one of the most voluminous high-flux magmatic episodes in the Cordillera (DeCelles et al., 2009).

Despite the volume and areal extent of magmatism, there is no consensus on the origin of the Middle Cretaceous magmatism and high-flux magmatic episodes in general.

The tectonic setting of the mid-Cretaceous magmatism has been explained by several contradictory models. Broadly, these tectonic models include elements of: widespread arc and back-arc magmatism (e.g. Hart et al., 2004; Allan et al., 2013; Nelson et al., 2013); crustal thickening followed by anatexis (Rubin et al., 1990; Selby et al., 1999; Driver et al., 2000) and/or delamination (DeCelles et al., 2009) and/or late-syn- to postcollisional magmatism (Gehrels et al., 2009; Hildebrand, 2013; Rusmore et al., 2013; Hildebrand and Whalen, 2017); and transtension during strike-slip or postcollisional extension (Miller and Hudson, 1991; Pavlis et al., 1993; Dusel-Bacon et al., 2002; Umhoefer, 2003; Staples et al., 2013). All of these models are confounded by significant orogen-parallel displacement of crustal blocks in mid-Cretaceous to Recent along an extensive network of strike-slip faults. These faults accommodated about 800 km cumulative dextral offset (Gabrielse et al., 2006), although paleomagnetic studies indicate up to 2000 km of displacement (Enkin et al., 2006). Although the intricate details of these models are beyond the scope of this overview, the nature of the mid-Cretaceous magmatism in Yukon (e.g. Driver et al., 2000; Ryan et al., 2013a, b, 2016, 2018; Pigage et al., 2014; Klöcking et al., 2016) does shed light on the nature of the Cordilleran Orogen in Yukon and eastern Alaska. Specifically, existing data can be used to evaluate whether magmatism occurred in an arc–back-arc setting, in an over-thickened orogen, or during extension.

## Mid-Cretaceous arc?

Analyses of Cretaceous plutonic suites in the northern Cordillera emphasized significant across-strike differences from oxidized, I-type granitoid rocks to the southwest to generally reduced, S-type and slightly younger alkalic granitoid rocks to the northeast, and attributed these to arc axis and back-arc settings, respectively (Hart et al., 2004; Allan et al., 2013; Nelson et al., 2013; Rasmussen, 2013). Within these analyses, the arc axis is broadly coincident with the Whitehorse Plutonic Suite in Yukon (Fig. 11). If the Whitehorse plutonic suite does indeed represent the arc axis, then it is likely about 100–150 km inboard of the closest possible trench which could be represented by the Gravina-Nutzotin basins, or more than 250 km if the trench was located outboard of Insular terranes (Fig. 11). Although not emphasized in many models, mid-Cretaceous I-type granitoid rocks are also common further inboard in the

Cassiar batholith (Woodsworth et al., 1991), the Tay River Suite (Pigage et al., 2014), and Tombstone Suite (Anderson, 1983), as far as 350 km farther inboard of the Whitehorse plutonic suite (Fig. 11). I-type magmas are commonly interpreted to mark the magmatic axes of arcs where melting is generally controlled by dehydration reactions in the down-going slab and generally leads to relatively narrow (~50 km) volcanic fronts (e.g. Grove et al., 2012). In contrast, the mid-Cretaceous I-type magmatism has a total across-strike width of more than 450 km.

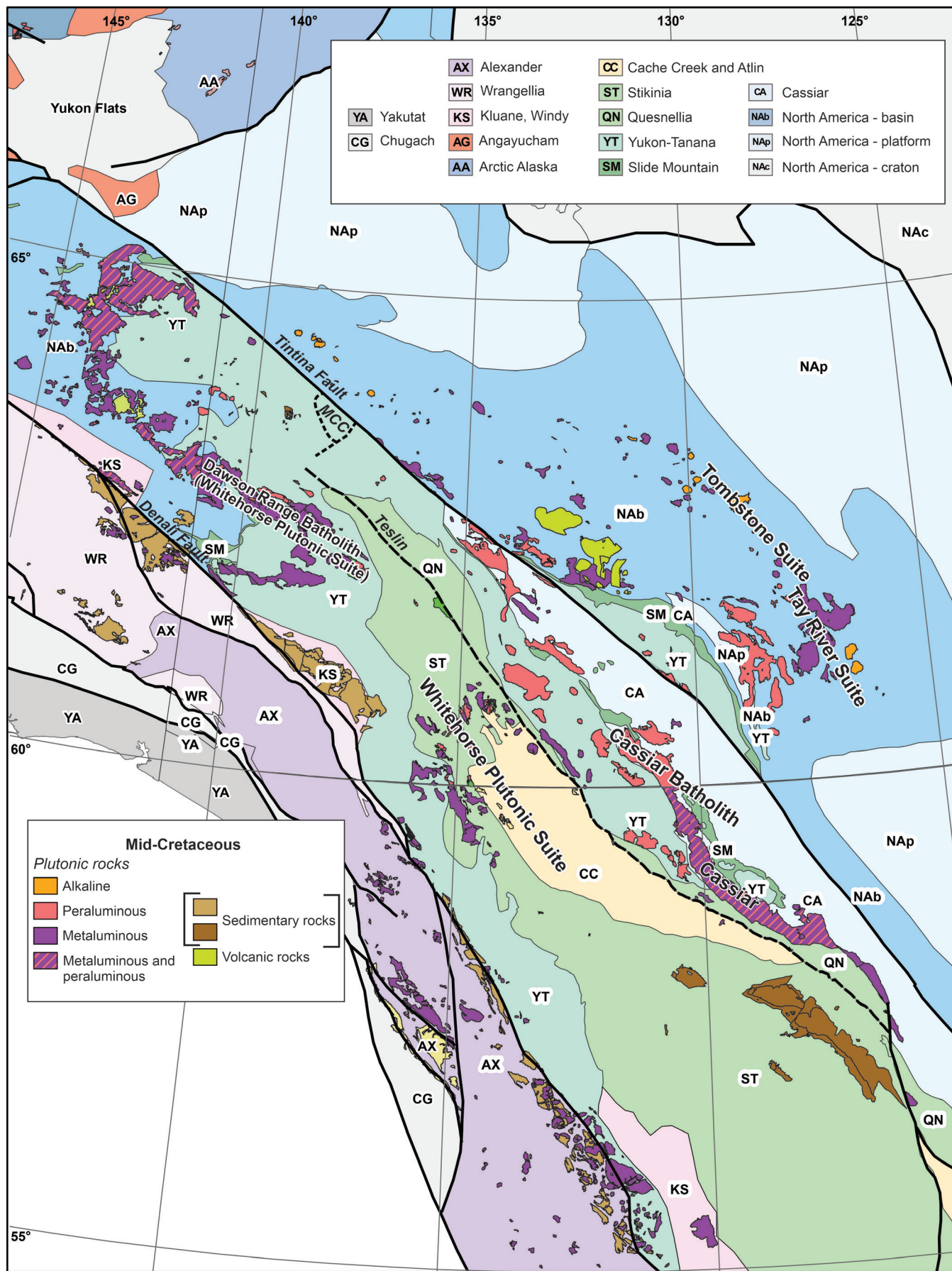
Hart et al. (2004) attributed the inboard ilmenite-bearing I-type suites to back-arc extension, where decompression and melting of the mantle facilitated advection of heat to the crust and resulted in crustal anatexis. A problem with this explanation is the arbitrary separation of the compositionally similar arc axis and back-arc magmatism (e.g. Selby et al., 1999; Driver et al., 2000), especially since age-equivalent magmas also intrude the Insular terranes (Fig. 11; e.g. Gehrels et al., 2009). Whatever model is used to explain mid-Cretaceous magmatism, it needs to account for a very wide belt of I-type magmatism, which is not characteristic of modern arc settings.

## Overthickened Cretaceous orogen?

In contrast to the back-arc extension model, a compressional, Andean-style mid-Cretaceous orogen has been invoked by many tectonic models (Selby et al., 1999; Driver et al., 2000; Gabrielse et al., 2006; Mair et al., 2006; Evenchick et al., 2007; Monger, 2014). Contractual crustal duplication is also thought to be a pre-requisite for high-flux magmatic episodes (DeCelles et al., 2009) and has been invoked to explain northeasterly migration of plutonic suites (e.g. Johnston, 2008). Selby et al. (1999) and Driver et al. (2000) inferred that the Yukon Whitehorse plutonic suite and Cassiar batholith were generated as a result of partial melting of crust related to overthickening of North American margin. This interpretation was in part based on the presence of high-grade metamorphic rocks, isotopic evidence for significant involvement of continental crust, perceived lack of coeval mantle-derived mafic rocks, and possible coeval thrusting (Mair et al., 2006).

Local preservation of Barrovian metamorphism in the basement led Driver et al. (2000) to interpret the mid-Cretaceous evolution of the Cordillera as representing an overthickened orogen. Whereas the presence of high-grade rocks does suggest crustal thickening prior to the mid-Cretaceous (e.g. Staples et al., 2014), high-grade rocks were

**Figure 11.** Regional distribution of Middle Cretaceous magmatism in Northwestern Cordillera (geology: Colpron and Nelson, 2011; Wilson et al., 2015; Colpron et al., 2016; Cui et al., 2017). MCC = Mid-Cretaceous metamorphic core complex (Staples et al., 2013)





exhumed in metamorphic core complexes prior to emplacement of the Cassiar batholith requiring extension (Fig. 11; Staples et al., 2013, 2014). In addition, presence of andalusite in its contact aureole (Driver et al., 2000) supports emplacement of the Cassiar batholith at shallow crustal depth. The evident upper crustal setting of the batholith and exhumation of high-grade metamorphic core complexes prior to intrusion does not require or support an overthickened orogen model during the mid-Cretaceous high-flux magmatic episode.

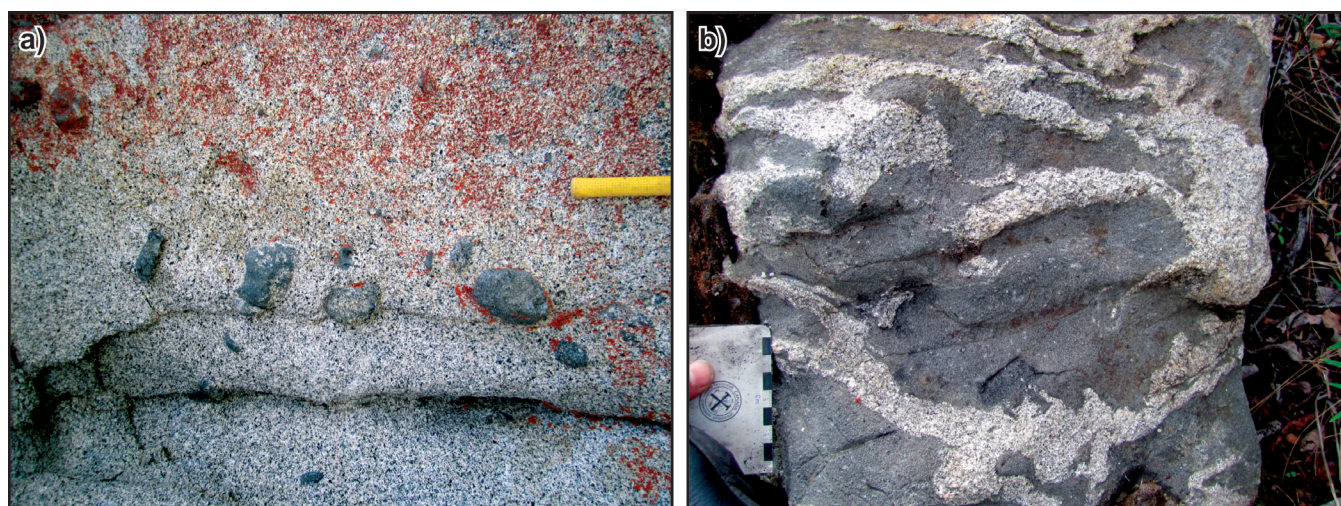
Similarly, the Whitehorse plutonic suite in the Dawson Range area was interpreted as anatectic melt related to crustal thickening (Selby et al., 1999). It was also emplaced at upper crustal levels as indicated by rapid cooling indicated by similarity of Ar-Ar and U-Pb ages, barometry (McCausland et al., 2006), and preservation of comagmatic volcanic and hypabyssal rocks (e.g. Klöcking et al., 2016). Mapping by the present authors indicates that the Dawson Range phase magmatism did include a significant volume of mafic to intermediate juvenile melts, which were disaggregated in and hybridized with the more evolved magmas (Fig. 12; Ryan et al., 2013a, b). Generation of these mafic to intermediate melts through crustal thickening is difficult and generally requires either a direct mantle source or emplacement of mantle-derived, high-temperature magmas that facilitate melting of the more refractory lower crust (e.g. Thompson et al., 1999). Identification of a mantle-derived source during the mid-Cretaceous magmatism does not discount thickening; however, it does eliminate the need for thickening to drive anatexis that is implicit in the Selby et al. (1999) model.

Shallow melting and shallow emplacement of mid-Cretaceous magmas, formation of coeval extensional marine basins (Miller and Hudson, 1991; Bassett and Kleinspehn,

1997), subdued mid-Cretaceous landscape (Lowey and Hills, 1988; Long et al., 2001) and exhumation of metamorphic core complexes (Pavlis et al., 1993; Dusel-Bacon et al., 2002; Murphy, 2004; Staples et al., 2013) do not support or require an Andean-style orogen. Combining these observations with preservation of Jurassic Ar-Ar and He-apatite cooling ages in the basement (Bineli Betsi and Bennett, 2010; Joyce et al., 2015) suggest that there has been limited exhumation of the basement rocks since the Middle Jurassic. Overall, these provide a compelling argument against an Andean-style mid-Cretaceous orogen at the latitude of northern British Columbia, Yukon, and Alaska.

## Extended orogen?

In contrast to the lack of evidence for an overthickened or compressional orogen, thinned crust at least immediately prior to Whitehorse plutonic suite and/or Cassiar Batholith magmatism is indicated by several lines of data. Exhumation of metamorphic core complexes along extensional shear zones is documented immediately prior to and during early stages of the mid-Cretaceous magmatism (Pavlis et al., 1993; Murphy, 2004; Staples et al., 2013, 2016). Continued mid-Cretaceous extension is a viable mechanism to advect heat into the crust through mantle-derived mafic underplating and resultant crustal anatexis. Rather than a compressional orogen or a normal arc-back-arc setting, a wide zone of extension and mafic underplating is more consistent with the broad extents of magmatic belts displaying both I- and S-type magmatism. In addition, younger alkaline plutons can be explained in this context by progressive rifting (e.g. Hawkesworth et al., 1995; Hooper et al., 1995). The composition of the mantle-derived input may be controlled by the subduction signature inherited from subduction-zone modified sublithospheric mantle, which can be remarkably



**Figure 12.** Representative photographs of the Whitehorse plutonic suite in the Dawson Range area. **a)** Train of diorite inclusions derived from a co-magmatic diorite dyke in Dawson Range phase granodiorite; hammer handle for scale is 3.5 cm wide. NRC photo 2019-736. **b)** Pillowed diorite in Dawson Range phase monzogranite indicates mingling of mafic and felsic magmas. NRC photo 2019-735. Photographs by A. Zagorevski.



persistent (Robertson, 2007; Park et al., 2018), or by hybridization with crustal melts which are characterized by arc-like Nb depletion (e.g. Rudnick and Fountain, 1995).

Crustal extension has been previously proposed for the mid-Cretaceous in Alaska, where basins accumulated up to 12 km of marine sediments, coeval with formation of extensional detachments and exhumation of high-grade rocks (Miller and Hudson, 1991; Pavlis et al., 1993; Dusel-Bacon et al., 2002). Evidence for Mid-Cretaceous marine sedimentation is sparse in Yukon. Volcanic rocks of the Mount Nansen Group locally contain pillow basalt (Carbon Hill volcanic rocks of Hart, 1996) characteristic of subaqueous eruptions, though not necessarily a marine setting. The Indian River Formation sedimentary rocks were reported to contain marine palynomorphs (Lowey and Hills, 1988), but subsequent studies failed to replicate or identify any additional localities; however, depofacies do suggest a relatively subdued landscape characterized by fan-delta plains and marshes (Lowey and Hills, 1988; Long et al., 2001).

Mid-Cretaceous magmatism in the Yukon was immediately followed by development of a (?)marine basin represented by the Late Cretaceous Kluane Schist that was derived from the adjacent Whitehorse plutonic suite and its basement (Israel et al., 2011). The Kluane Schist is locally intercalated with ca. 202 Ma ultramafic rocks that Canil et al. (2015) argued were exhumed into the basin. In this context, the easiest mechanism for exhumation of these rocks is by extension. The Kluane Basin was inverted and metamorphosed by ca. 82 Ma (Israel et al., 2011), significantly later than the mid-Cretaceous magmatism described above. Since active dextral strike-slip faulting has been documented throughout, the overall mid-Cretaceous tectonic regime in the northern Cordillera was most likely transtensional.

## SUMMARY AND FUTURE RESEARCH DIRECTIONS

This study's evaluation of the Paleozoic magmatism in the Intermontane terranes, Permian magmatism in the Yukon-Tanana terrane, and mid-Cretaceous magmatism in Yukon indicates that existing tectonic models are supported by neither the existing data nor modern analogues. The evaluated magmatic episodes are best interpreted as products of broad lithospheric extension, rather than being controlled by subduction-zone processes. In the case of the Paleozoic ocean-island basalt magmatism, modern analogues indicate that ocean-island basalt magmatism should not be forming along the arc fronts. Hence, parts of the Intermontane terranes have been misinterpreted as Paleozoic arc centres. In the case of the Middle Permian Yukon-Tanana terrane, continental rift magmatism was likely misidentified as arc magmatism. Mid-Cretaceous magmatism is also unlikely to represent a compressional orogen or a normal arc-back-arc system. Rather, it is likely a product of broad lithospheric extension. Although the present evaluation of these magmatic

episodes is cursory, it does indicate that Cordilleran models will be significantly improved through targeted schematic studies that integrate multidisciplinary data sets. Ultimately, these studies will improve the tectonic framework and establish much more realistic and predictive models for the origin and distribution of mineral deposits.

## ACKNOWLEDGMENTS

This project was funded by the Geo-mapping for Energy and Minerals program. This manuscript was reviewed and improved by M. Mihalynuk and N. Rogers.

## REFERENCES

- Abbott, L.D., Silver, E.A., and Galewsky, J., 1994. Structural evolution of a modern arc-continent collision in Papua New Guinea; *Tectonics*, v. 13, no. 5, p. 1007–1034. <https://doi.org/10.1029/94TC01623>
- Abers, G.A., Mutter, C.Z., and Fang, J., 1997. Shallow dips of normal faults during rapid extension: earthquakes in the Woodlark-D'Entrecasteaux rift system, Papua New Guinea; *Journal of Geophysical Research*, v. 102, no. B7, p. 15 301–15 317. <https://doi.org/10.1029/97JB00787>
- Allan, M.M., Colpron, M., Mortensen, J.K., Hart, C.J.R., Bailey, L.A., Sanchez, M.G., Ciolikiewicz, W., McKenzie, G.G., Creaser, R.A., Bissig, T., Rusk, B.G., and Thompson, J.F.H., 2013. Magmatic and metallogenic framework of west-central Yukon and eastern Alaska; *Society of Economic Geologists, Special Publication*, v. 17, p. 111–168.
- Anderson, R.G., 1983. Selwyn plutonic suite and its relationship to tungsten skarn mineralization, southeastern Yukon and District of Mackenzie; in *Current Research, Part B; Geological Survey of Canada, Paper 83-1B*, p. 151–163. <https://doi.org/10.4095/109319>
- Bader, A.G., Pubellier, M., Rangin, C., Deplus, C., and Louat, R., 1999. Active slivering of oceanic crust along the Molucca Ridge (Indonesia-Philippine); implication for ophiolite incorporation in a subduction wedge; *Tectonics*, v. 18, no. 4, p. 606–620. <https://doi.org/10.1029/1999TC900004>
- Baldwin, S.L., Fitzgerald, P.G., and Webb, L.E., 2012. Tectonics of the New Guinea region; *Annual Review of Earth and Planetary Sciences*, v. 40, p. 495–520. <https://doi.org/10.1146/annurev-earth-040809-152540>
- Bassett, K.N. and Kleinspehn, K.L., 1997. Early to Middle Cretaceous paleogeography of north-central British Columbia; stratigraphy and basin analysis of the Skeena Group; *Canadian Journal of Earth Sciences*, v. 34, no. 12, p. 1644–1669. <https://doi.org/10.1139/c17-132>
- Beranek, L.P. and Mortensen, J.K., 2011. The timing and provenance record of the Late Permian Klondike Orogeny in northwestern Canada and arc-continent collision along western North America; *Tectonics*, v. 30, issue 5, cit. no. TC5017. <https://doi.org/10.1029/2010TC002849>

- Bineli Betsi, T. and Bennett, V., 2010. New U-Pb age constraints at Freegold Mountain: evidence for multiple phases of polymetallic mid- to Late Cretaceous mineralization; *in* Yukon Exploration and Geology 2009, (ed.) K.E. MacFarlane, L.H. Weston, and L.R. Blackburn; Yukon Geological Survey, p. 57–84.
- Bonatti, E., Ottonello, G., and Hamlyn, P.R., 1986. Peridotites from the island of Zabargad (St. John), Red Sea; petrology and geochemistry; *Journal of Geophysical Research*, v. 91, no. B1, p. 599–631. <https://doi.org/10.1029/JB091iB01p00599>
- Cabanis, B. and Lecolle, M., 1989. Le diagramme La/10-Y/15-Nb/8; un outil pour la discrimination des séries volcaniques et la mise en évidence des processus de mélange et/ou de contamination crustale. The La/10-Y/15-Nb/8 diagram; a tool for distinguishing volcanic series and discovering crustal mixing and/or contamination; *Comptes Rendus de l'Académie des Sciences, Serie 2, Mécanique, Physique, Chimie, Sciences de l'Univers; Sciences de la Terre*, v. 309, no. 20, p. 2023–2029.
- Canil, D., Johnston, S.T., Evers, K., Shellnutt, J.G., and Creaser, R.A., 2003. Mantle exhumation in an early Paleozoic passive margin, northern Cordillera, Yukon; *The Journal of Geology*, v. 111, no. 3, p. 313–327. <https://doi.org/10.1086/373971>
- Canil, D., Johnston, S.T., d'Souza, R.J., and Heaman, L.M., 2015. Protolith of ultramafic rocks in the Kluane Schist, Yukon, and implications for arc collisions in the northern Cordillera; *Canadian Journal of Earth Sciences*, v. 52, no. 7, p. 431–443. <https://doi.org/10.1139/cjes-2014-0138>
- Chung, S.-L., Sun, S.-s., Tu, K., Chen, C.-H., and Lee, C.-y., 1994. Late Cenozoic basaltic volcanism around the Taiwan Strait, SE China; product of lithosphere-asthenosphere interaction during continental extension; *Chemical Geology*, v. 112, no. 1–2, p. 1–20. [https://doi.org/10.1016/0009-2541\(94\)90101-5](https://doi.org/10.1016/0009-2541(94)90101-5)
- Colpron, M. and Nelson, J.L. (ed.), 2006. Paleozoic evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera; Geological Association of Canada, Special Paper 45, 528 p.
- Colpron, M. and Nelson, J.L., 2011. A Digital Atlas of Terranes for the Northern Cordillera; British Columbia Ministry of Energy and Mines, British Columbia Geological Survey GeoFile 2011-11.
- Colpron, M., Gladwin, K., Johnston, S.T., Mortensen, J.K., and Gehrels, G.E., 2005. Geology and juxtaposition history of the Yukon-Tanana, Slide Mountain, and Cassiar Terranes in the Glenlyon area of central Yukon; *Canadian Journal of Earth Sciences*, v. 42, no. 8, p. 1431–1448. <https://doi.org/10.1139/e05-046>
- Colpron, M., Nelson, J.L., and Murphy, D.C., 2006. A tectonostratigraphic framework for the pericratonic terranes of the northern Canadian Cordillera; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 1–23.
- Colpron, M., Israel, S., Murphy, D., Pigage, L., and Moynihan, D., 2016. Yukon bedrock geology map; Yukon Geological Survey, Open File 2016-1, scale 1:1 000 000.
- Creaser, R.A., Goodwin-Bell, J.-A.S., and Erdmer, P., 1999. Geochemical and Nd isotopic constraints for the origin of eclogite protoliths, northern Cordillera; implications for the Paleozoic tectonic evolution of the Yukon-Tanana Terrane; *Canadian Journal of Earth Sciences*, v. 36, no. 10, p. 1697–1709. <https://doi.org/10.1139/e99-070>
- Cui, Y., Miller, D., Schiarizza, P., and Diakow, L.J., 2017. British Columbia digital geology; British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2017-8, 9 p.
- Currie, L.D., 1994. The geology and Mid-Jurassic amalgamation of Tracy Arm Terrane and Stikinia of northwestern British Columbia; Ph.D. thesis, Carleton University, Ottawa, Ontario, 416 p.
- 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*, v. 109, no. 11, p. 1402–1420. [https://doi.org/10.1130/0016-7606\(1997\)109%3c1402:PAMROS%3e2.3.CO%3b2](https://doi.org/10.1130/0016-7606(1997)109%3c1402:PAMROS%3e2.3.CO%3b2)
- DeCelles, P.G., Ducea, M.N., Kapp, P., and Zandt, G., 2009. Cyclicity in Cordilleran orogenic systems; *Nature Geoscience*, v. 2, no. 4, p. 251–257. <https://doi.org/10.1038/ngeo469>
- Devine, F., Colpron, M., Carr, S.D., Murphy, D.C., Davis, W.J., Smith, S., Villeneuve, M., and Nelson, J.L., 2006. Geochronological and geochemical constraints on the origin of the Klatsa metamorphic complex: implications for early Mississippian high-pressure metamorphism within Yukon-Tanana Terrane; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 107–130.
- Driver, L.A., Creaser, R.A., Chacko, T., and Erdmer, P., 2000. Petrogenesis of the Cretaceous Cassiar Batholith, Yukon-British Columbia, Canada; implications for magmatism in the North American Cordilleran interior; *Geological Society of America Bulletin*, v. 112, no. 7, p. 1119–1133. [https://doi.org/10.1130/0016-7606\(2000\)112%3c1119:POTCCB%3e2.0.CO%3b2](https://doi.org/10.1130/0016-7606(2000)112%3c1119:POTCCB%3e2.0.CO%3b2)
- Dusel-Bacon, C., Lanphere, M.A., Sharp, W.D., Layer, P.W., and Hansen, V.L., 2002. Mesozoic thermal history and timing of structural events for the Yukon-Tanana Upland, East-Central Alaska;  $^{40}\text{Ar}/^{39}\text{Ar}$  Ar data from metamorphic and plutonic rocks; *Canadian Journal of Earth Sciences*, v. 39, no. 6, p. 1013–1051. <https://doi.org/10.1139/e02-018>
- Dusel-Bacon, C., Colpron, M., Hopkins, M.J., Mortensen, J.K., Dashevsky, S.S., Bressler, J.R., Day, W.C., and Nelson, J.L., 2006. Paleozoic tectonic and metallogenic evolution of the pericratonic rocks of east-central Alaska and adjacent Yukon; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 25–74.

- Edwards, B.R. and Russell, J.K., 2000. Distribution, nature, and origin of Neogene-Quaternary magmatism in the northern Cordilleran volcanic province, Canada; Geological Society of America Bulletin, v. 112, no. 8, p. 1280–1295. [https://doi.org/10.1130/0016-7606\(2000\)112%3c1280:DNAOON%3e2.0.CO%3b2](https://doi.org/10.1130/0016-7606(2000)112%3c1280:DNAOON%3e2.0.CO%3b2)
- Eissen, J.-P., Auzende, J.-M., Nohara, M., Cotten, J., Hirose, K., and Urabe, T., 1994. North Fiji Basin basalts and their magma sources; Part I, incompatible element constraints; Marine Geology, v. 116, no. 1-2, p. 153–178. [https://doi.org/10.1016/0025-3227\(94\)90174-0](https://doi.org/10.1016/0025-3227(94)90174-0)
- English, J.M., Mihalynuk, M.G., and Johnston, S.T., 2010. Geochemistry of the northern Cache Creek Terrane and implications for accretionary processes in the Canadian Cordillera; Canadian Journal of Earth Sciences, v. 47, no. 1, p. 13–34. <https://doi.org/10.1139/E09-066>
- Enkin, R.J., Johnston, S.T., Larson, K.P., and Baker, J., 2006. Paleomagnetism of the 70 Ma Carmacks Group at Solitary Mountain, Yukon, confirms and extends controversial results; further evidence for the Baja British Columbia model; in Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements, (ed.) J.W. Haggart, R.J. Enkin, and J.W.H. Monger; Geological Association of Canada, Special Paper 46, p. 221–232.
- Evenchick, C.A., Sears, J.W., McMechan, M.E., McNicoll, V.J., Carr, S.D., Harms, T.A., and Evenchick, C.A., 2007. A synthesis of the Jurassic-Cretaceous tectonic evolution of the central and southeastern Canadian Cordillera; exploring links across the orogen; Geological Society of America Special Paper, v. 433, p. 117–145.
- Ferri, F., 1997. Nina Creek Group and Lay Range Assemblage, north-central British Columbia; remnants of late Paleozoic oceanic and arc terranes; Canadian Journal of Earth Sciences, v. 34, no. 6, p. 854–874. <https://doi.org/10.1139/c17-070>
- Fretzdorff, S., Livermore, R.A., Devey, C.W., Leat, P.T., and Stoffers, P., 2002. Petrogenesis of the back-arc East Scotia Ridge, South Atlantic Ocean; Journal of Petrology, v. 43, no. 8, p. 1435–1467. <https://doi.org/10.1093/petrology/43.8.1435>
- Gabrielse, H., Haggart, J.W., Murphy, D.C., Mortensen, J.K., Enkin, R.J., and Monger, J.W.H., 2006. Cretaceous and Cenozoic dextral orogen-parallel displacements, magmatism, and paleogeography, north-central Canadian Cordillera; in Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements, (ed.) J.W. Haggart, R.J. Enkin, and J.W.H. Monger; Geological Association of Canada, Special Paper 46, p. 255–276.
- Gehrels, G.E., Rusmore, M., Woodsworth, G.J., Crawford, M., Andronicos, C., Hollister, L., Patchett, J., Ducea, M., Butler, R., Klepeis, K., Davidson, C., Friedman, R., Haggart, J.W., Mahoney, B., Crawford, W., Pearson, D., and Girardi, J., 2009. U-Th-Pb geochronology of the Coast Mountains Batholith in north-coastal British Columbia: constraints on age and tectonic evolution; Geological Society of America Bulletin, v. 121, no. 9-10, p. 1341–1361. <https://doi.org/10.1130/B26404.1>
- Gilotti, J.A., McClelland, W.C., van Staal, C.R., and Petrie, M.B., 2017. Detrital zircon evidence for eclogite formation by basal subduction erosion: an example from the Yukon-Tanana composite arc, Canadian Cordillera; Geological Society of America Special Paper, v. 526, p. 173–189. [https://doi.org/10.1130/2017.2526\(09\)](https://doi.org/10.1130/2017.2526(09))
- Golding, M., 2018. Heterogeneity of conodont faunas in the Cache Creek Terrane, Canada; significance for tectonic reconstructions of the North American Cordillera; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 506, p. 208–216. <https://doi.org/10.1016/j.palaeo.2018.06.038>
- Gordey, S.P., 2013. Evolution of the Selwyn Basin region, Sheldon Lake and Tay River map areas, central Yukon; Geological Survey of Canada, Bulletin 599, 190 p. <https://doi.org/10.4095/293034>
- Grove, T.L., Till, C.B., and Krawczynski, M.J., 2012. The role of H<sub>2</sub>O in subduction zone magmatism; Annual Review of Earth and Planetary Sciences, v. 40, p. 413–439. <https://doi.org/10.1146/annurev-earth-042711-105310>
- Gunning, M.H., Colpron, M., Hodder, R.W., Nelson, J.L., and Nelson, J.L., 2006. Contrasting volcanic styles and their tectonic implications for the Paleozoic Stikine Assemblage, western Stikine Terrane, northwestern British Columbia; in Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 201–227.
- Hall, R., 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations; Journal of Asian Earth Sciences, v. 20, no. 4, p. 353–431. [https://doi.org/10.1016/S1367-9120\(01\)00069-4](https://doi.org/10.1016/S1367-9120(01)00069-4)
- Harms, T.A. and Murchey, B.L., 1992. Setting and occurrence of late Paleozoic radiolarians in the Sylvester Allochthon, part of a proto-Pacific ocean floor terrane in the Canadian Cordillera; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 96, no. 1-2, p. 127–139. [https://doi.org/10.1016/0031-0182\(92\)90063-B](https://doi.org/10.1016/0031-0182(92)90063-B)
- Hart, C.J.R., 1996. Magmatic and tectonic evolution of the Intermontane Superterrane and Coast Plutonic Complex in southern Yukon Territory; M.Sc. thesis, University of British Columbia, Vancouver, British Columbia, 198 p.
- Hart, C.J.R., Goldfarb, R.J., Lewis, L.L., and Mair, J.L., 2004. The northern cordilleran mid-Cretaceous plutonic province: ilmenite/magnetite-series granitoids and intrusion-related mineralisation; Resource Geology, v. 54, p. 253–280. <https://doi.org/10.1111/j.1751-3928.2004.tb00206.x>
- Hawkesworth, C., Turner, S., Gallagher, K., Hunter, A., Bradshaw, T., and Rogers, N., 1995. Calc-alkaline magmatism, lithospheric thinning and extension in the Basin and Range; Journal of Geophysical Research, v. 100, no. B6, p. 10 271–10 286. <https://doi.org/10.1029/94JB02508>
- Hildebrand, R.S., 2013. Mesozoic assembly of the North American Cordillera; Geological Society of America Special Paper, v. 495, 167 p.



- Hildebrand, R.S. and Whalen, J.B., 2017. The tectonic setting and origin of Cretaceous batholiths within the North American Cordillera; the case for slab failure magmatism and its significance for crustal growth; Geological Society of America Special Paper, v. 532, 113 p.
- Hooper, P.R., Bailey, D.G., and McCarley Holder, G.A., 1995. Tertiary calc-alkaline magmatism associated with lithospheric extension in the Pacific Northwest; Journal of Geophysical Research, v. 100, no. B6, p. 10 303–10 319. <https://doi.org/10.1029/94JB03328>
- Huang, C.-Y., Yuan, P.B., and Tsao, S.-J., 2006. Temporal and spatial records of active arc-continent collision in Taiwan; a synthesis; Geological Society of America Bulletin, v. 118, no. 3-4, p. 274–288. <https://doi.org/10.1130/B25527.1>
- Ishizuka, O., Yuasa, M., Taylor, R.N., and Sakamoto, I., 2009. Two contrasting magmatic types coexist after the cessation of back-arc spreading; Chemical Geology, v. 266, no. 3-4, p. 274–296. <https://doi.org/10.1016/j.chemgeo.2009.06.014>
- Israel, S., Murphy, D., Bennett, V., Mortensen, J., and Crowley, J., 2011. New insights into the geology and mineral potential of the Coast Belt in southwestern Yukon; in Yukon Exploration and Geology 2010, (ed.) K.E. MacFarlane, L.H. Weston, and C. Relf; Yukon Geological Survey, p. 101–123.
- Johnston, S.T., 2008. The Cordilleran ribbon continent of North America; Annual Review of Earth and Planetary Sciences, v. 36, p. 495–530. <https://doi.org/10.1146/annurev.earth.36.031207.124331>
- Johnston, S.T. and Borel, G.D., 2007. The odyssey of the Cache Creek Terrane, Canadian Cordillera; implications for accretionary orogens, tectonic setting of Panthalassa, the Pacific Superswell, and break-up of Pangea; Earth and Planetary Science Letters, v. 253, p. 415–428. <https://doi.org/10.1016/j.epsl.2006.11.002>
- Johnston, S.T., Canil, D., and Heaman, L.H., 2007. Permian exhumation of the Buffalo Pitts orogenic peridotite massif, northern Cordillera, Yukon; Canadian Journal of Earth Sciences, v. 44, no. 3, p. 275–286. <https://doi.org/10.1139/e06-078>
- Joyce, N.L., Ryan, J.J., Colpron, M., Hart, C.J.R., and Murphy, D.C., 2015. A compilation of  $^{40}\text{Ar}/^{39}\text{Ar}$  age determinations for igneous and metamorphic rocks, and mineral occurrences from central and southeast Yukon; Geological Survey of Canada, Open File 7924, 229 p. <https://doi.org/10.4095/297446>
- Klöcking, M., Mills, L., Mortensen, J., and Roots, C., 2016. Geology of mid-Cretaceous volcanic rocks at Mount Nansen, central Yukon, and their relationship to the Dawson Range batholith; Yukon Geological Survey, Open File 2016-25, 37 p.
- Lapierre, H., Bosch, D., Tardy, M., and Struik, L.C., 2003. Late Paleozoic and Triassic plume-derived magmas in the Canadian Cordillera played a key role in continental crust growth; Chemical Geology, v. 201, p. 55–89. [https://doi.org/10.1016/S0009-2541\(03\)00224-9](https://doi.org/10.1016/S0009-2541(03)00224-9)
- Little, T.A., Hacker, B.R., Gordon, S.M., Baldwin, S.L., Fitzgerald, P.G., Ellis, S., and Korchinski, M., 2011. Diapiric exhumation of Earth's youngest (UHP) eclogites in the gneiss domes of the D'Entrecasteaux Islands, Papua New Guinea; Tectonophysics, v. 510, no. 1-2, p. 39–68. <https://doi.org/10.1016/j.tecto.2011.06.006>
- Logan, J.M. and Mihalynuk, M.G., 2014. Tectonic controls on early Mesozoic paired alkaline porphyry deposit belts (Cu-Au + or - Ag-Pt-Pd-Mo) within the Canadian Cordillera; Economic Geology and the Bulletin of the Society of Economic Geologists, v. 109, no. 4, p. 827–858. <https://doi.org/10.2113/econgeo.109.4.827>
- Logan, J.M., Drobe, J.R., and McClelland, W.C., 2000. Geology of the Forrest Kerr-Mess Creek area, northwestern British Columbia (NTS 104B/10,15 & 104G/2 & 7W); British Columbia Ministry of Energy and Mines, Energy and Minerals Division, Geological Survey Branch, Bulletin, v. 104, 163 p.
- Long, D.G.F., Lowey, G.W., and Sweet, A.R., 2001. Age and setting of dinosaur trackways, Ross River area, Yukon Territory (105F/15); in Yukon Exploration and Geology 2000, Exploration and Geological Services Division, (ed.) D.S. Emond and L.H. Weston; Indian and Northern Affairs Canada, Yukon, p. 181–198.
- Lowey, G.W. and Hills, L.V., 1988. Lithofacies, petrography and environments of deposition, Tantalus Formation (Lower Cretaceous), Indian River area, west-central Yukon; Bulletin of Canadian Petroleum Geology, v. 36, no. 3, p. 296–310.
- Mair, J.L., Hart, C.J.R., and Stephens, J.R., 2006. Deformation history of the northwestern Selwyn Basin, Yukon, Canada; implications for orogen evolution and Mid-Cretaceous magmatism; Geological Society of America Bulletin, v. 118, no. 3-4, p. 304–323. <https://doi.org/10.1130/B25763.1>
- Massey, N.W.D. and Dostal, J., 2013. Geochemistry of metabasalts from the Knob Hill complex and Anarchist Group in the Paleozoic basement to southern Quesnellia; in Geological Fieldwork 2012; British Columbia Ministry of Energy, Mines and Natural Gas, British Columbia Geological Survey, Paper 2013-1, p. 45–52.
- McCausland, P.J.A., Haggart, J.W., Symons, D.T.A., Hart, C.J.R., Blackburn, W.H., Enkin, R.J., and Monger, J.W.H., 2006. Assembly of the northern Cordillera; new paleomagnetic evidence for coherent, moderate Jurassic to Eocene motion of the Intermontane Belt and Yukon-Tanana terranes; in Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements, (ed.) J.W. Haggart, R.J. Enkin, and J.W.H. Monger; Geological Association of Canada, Special Paper 46, p. 147–170.
- McGoldrick, S., Zagorevski, A., and Canil, D., 2017. Geochemistry of volcanic and plutonic rocks from the Nahlin ophiolite with implications for a Permo-Triassic arc in the Cache Creek terrane, northwestern British Columbia; Canadian Journal of Earth Sciences, v. 54, no. 12, p. 1214–1227. <https://doi.org/10.1139/cjes-2017-0069>
- McIntosh, K., Nakamura, Y., Wang, T.K., Shih, R.C., Chen, A., and Liu, C.S., 2005. Crustal-scale seismic profiles across Taiwan and the western Philippine Sea; Tectonophysics, v. 401, no. 1-2, p. 23–54. <https://doi.org/10.1016/j.tecto.2005.02.015>

- Mihalynuk, M.G., and Cordey, F., 1997. Potential for Kutcho Creek volcanogenic massive sulphide mineralization in the northern Cache Creek Terrane: a progress report; British Columbia Geological Survey, Geological Fieldwork 1996, p. 157–170.
- Mihalynuk, M.G., Nelson, J., and Diakow, L.J., 1994. Cache Creek Terrane entrapment: oroclinal paradox within the Canadian Cordillera; *Tectonics*, v. 13, no. 3, p. 575–595. <https://doi.org/10.1029/93TC03492>
- Milidragovic, D., Ryan, J.J., Zagorevski, A., and Piercey, S.J., 2016. Geochemistry of Permian rocks of the Yukon-Tanana Terrane, western Yukon: GEM 2 Cordillera Project; Geological Survey of Canada, Open File 8170, 21 p. <https://doi.org/10.4095/299484>
- Miller, E.L. and Hudson, T.L., 1991. Mid-Cretaceous extensional fragmentation of a Jurassic-Early Cretaceous compressional orogen, Alaska; *Tectonics*, v. 10, no. 4, p. 781–796. <https://doi.org/10.1029/91TC00044>
- Monger, J., 1975. Upper Paleozoic rocks of the Atlin Terrane, northwestern British Columbia and south-central Yukon; Geological Survey of Canada, Paper 74-47, 73 p. <https://doi.org/10.4095/102554>
- Monger, J.W.H., 1977. Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran evolution; *Canadian Journal of Earth Sciences*, v. 14, no. 8, p. 1832–1859. <https://doi.org/10.1139/e77-156>
- Monger, J., 2014. Seeking the suture: the Coast-Cascade conundrum; *Geoscience Canada*, v. 41, p. 379–398. <https://doi.org/10.12789/geocanj.2014.41.058>
- Monger, J.W.H. and Ross, C.A., 1971. Distribution of fusulinaceans in the western Canadian Cordillera; *Canadian Journal of Earth Sciences*, v. 8, p. 259–278. <https://doi.org/10.1139/e71-026>
- Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C. J., Gehrels, G. E., and O'Brien, J., 1991. Cordilleran terranes; Part B in Chapter 8 of *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 281–327 (also *Geological Society of America, The Geology of North America*, v. G-2, p. 281–327). <https://doi.org/10.4095/134091>
- Mortensen, J.K., 1992. Pre-mid-Mesozoic tectonic evolution of the Yukon-Tanana Terrane, Yukon and Alaska; *Tectonics*, v. 11, no. 4, p. 836–853. <https://doi.org/10.1029/91TC01169>
- Murphy, D.C., 2004. Devonian-Mississippian metavolcanic stratigraphy, massive sulphide potential and structural re-interpretation of Yukon-Tanana Terrane south of the Finlayson Lake massive sulphide district, southeastern Yukon (105G/1, 105H/3,4,5); in *Yukon Exploration and Geology 2003*, (ed.) D.S. Emond and L.L. Lewis; Yukon Geological Survey, p. 157–175.
- Murphy, D.C., Colpron, M., Mortensen, J.K., Piercey, S.J., Orchard, M.J., Gehrels, G.E., and Nelson, J.L., 2006. Mid-Paleozoic to early Mesozoic tectonostratigraphic evolution of Yukon-Tanana and Slide Mountain terranes and affiliated overlap assemblages, Finlayson Lake massive sulphide district, southeastern Yukon; in *Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America*, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 75–105.
- Nelson, J.L., 1993. The Sylvester Allochthon; upper Paleozoic marginal-basin and island-arc terranes in northern British Columbia; *Canadian Journal of Earth Sciences*, v. 30, no. 3, p. 631–643. <https://doi.org/10.1139/e93-048>
- Nelson, J.L. and Colpron, M., 2007. Tectonics and metallogeny of the British Columbia, Yukon and Alaskan Cordillera, 1.8 Ga to the present; in *Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces and Exploration Methods*, (ed.) W.D. Goodfellow; Geological Association of Canada, Mineral Deposits Division, Special Publication no. 5, p. 755–791.
- Nelson, J. and Friedman, R., 2004. Superimposed Quesnel (late Paleozoic-Jurassic) and Yukon-Tanana (Devonian-Mississippian) arc assemblages, Cassiar Mountains, northern British Columbia; field, U-Pb, and igneous petrochemical evidence; *Canadian Journal of Earth Sciences*, v. 41, no. 10, p. 1201–1235. <https://doi.org/10.1139/e04-028>
- Nelson, J.L., Colpron, M., Colpron, M., Piercey, S.J., Dusel-Bacon, C., Murphy, D.C., Roots, C.F., and Nelson, J.L., 2006. Paleozoic tectonic and metallogenetic evolution of pericratonic terranes in Yukon, northern British Columbia and eastern Alaska; in *Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America*, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 323–360.
- Nelson, J.L., Colpron, M., and Israel, S., 2013. The Cordillera of British Columbia, Yukon, and Alaska: tectonics and metallogeny; in *Tectonics, Metallogeny, and Discovery: The North American Cordillera and Similar Accretionary Settings*, (ed.) M. Colpron, T. Bissig, B.G. Rusk, and J.F.H. Thompson; Society of Economic Geologists, Special Publication, v. 17, p. 53–109.
- Nohara, M., Auzende, J.-M., Hirose, K., Eissen, J.P., Urabe, T., Joshima, M., and Urabe, T., 1994. The North Fiji Basin basalts and their magma sources; Part II, Sr-Nd isotopic and trace element constraints; *Marine Geology*, v. 116, no. 1-2, p. 179–195. [https://doi.org/10.1016/0025-3227\(94\)90175-9](https://doi.org/10.1016/0025-3227(94)90175-9)
- Orchard, M.J., Struik, L.C., Cordey, F., Rui, L., Bamber, E.W., Mamet, B., Struik, L.C., Sano, H., Taylor, H.J., and MacIntyre, D.G., 2001. Biostratigraphic and biogeographic constraints on the Carboniferous to Jurassic Cache Creek Terrane in central British Columbia; *Canadian Journal of Earth Sciences*, v. 38, p. 551–578. <https://doi.org/10.1139/e00-120>
- Park, S.-H., Michael, P.J., Kamenov, G.D., Lee, S.-M., Hauff, F., and Lee, K.Y., 2018. Petrogenesis of basalts along the eastern Woodlark spreading center, equatorial western Pacific; *Lithos*, v. 316-317, p. 122–136. <https://doi.org/10.1016/j.lithos.2018.07.003>

- Parsons, A.J., Zagorevski, A., Ryan, J.J., McClelland, W.C., Van Staal, C.R., Coleman, M.J., and Golding, M.L., 2019. Petrogenesis of the Dunite Peak Ophiolite, south-central Yukon, and the distinction between upper-plate and lower-plate settings: a new hypothesis for the late Paleozoic-early Mesozoic tectonic evolution of the Northern Cordillera; *Geological Society of America Bulletin*, v. 131, no. 1-2, p. 274–298. <https://doi.org/10.1130/B31964.1>
- Pavlis, T.L., Sisson, V.B., Foster, H.L., Nokleberg, W.J., and Plafker, G., 1993. Mid-Cretaceous extensional tectonics of the Yukon-Tanana Terrane, Trans-Alaska Crustal Transect (TACT), east-central Alaska; *Tectonics*, v. 12, no. 1, p. 103–122. <https://doi.org/10.1029/92TC00860>
- Pearce, J.A., 1996. A user's guide to basalt discrimination diagrams; in *Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration*, (ed.) D.A. Wyman; Geological Association of Canada, Short Course Notes, v. 12, p. 79–113.
- Pearce, J.A., 2014. Immobile element fingerprinting of ophiolites; *Elements*, v. 10, no. 2, p. 101–108. <https://doi.org/10.2113/gselements.10.2.101>
- Pearce, J.A., Dilek, Y., and Ernst, R.E., 2008. Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust; *Lithos*, v. 100, no. 1-4, p. 14–48. <https://doi.org/10.1016/j.lithos.2007.06.016>
- Perfit, M.R., Taylor, B., Langmuir, C.H., Baekisapa, M., Chappell, B.W., Johnson, R.W., Staudigel, H., Taylor, S.R., and Exon, N.F., 1987. Geochemistry and petrology of volcanic rocks from the Woodlark Basin: addressing questions of ridge subduction; in *Marine Geology, Geophysics and Geochemistry of the Woodlark Basin – Solomon Islands*, (ed.) B. Taylor and N. Exon; Circum-Pacific Earth Science Series, v. 7, p. 113–154.
- Philippot, P., Blichert-Toft, J., Perchuk, A., Costa, S., Gerasimov, V., and Arnaud, N.M., 2001. Lu-Hf and Ar-Ar chronometry supports extreme rate of subduction zone metamorphism deduced from geospeedometry; *Tectonophysics*, v. 342, no. 1-2, p. 23–38. [https://doi.org/10.1016/S0040-1951\(01\)00155-X](https://doi.org/10.1016/S0040-1951(01)00155-X)
- Piercey, S.J., Murphy, D.C., Mortensen, J.K., and Paradis, S., 2001. Boninitic magmatism in a continental margin setting, Yukon-Tanana Terrane, southeastern Yukon, Canada; *Geology*, v. 29, no. 8, p. 731–734. [https://doi.org/10.1130/0091-7613\(2001\)029%3c0731:BMIACM%3e2.0.CO%3b2](https://doi.org/10.1130/0091-7613(2001)029%3c0731:BMIACM%3e2.0.CO%3b2)
- Piercey, S.J., Murphy, D.C., Mortensen, J.K., and Creaser, R.A., 2004. Mid-Paleozoic initiation of the northern Cordilleran marginal backarc basin; geologic, geochemical, and neodymium isotope evidence from the oldest mafic magmatic rocks in the Yukon-Tanana Terrane, Finlayson Lake District, southeast Yukon, C; *Geological Society of America Bulletin*, v. 116, no. 9-10, p. 1087–1106. <https://doi.org/10.1130/B25162.1>
- Piercey, S.J., Colpron, M., Nelson, J.L., Colpron, M., Dusel-Bacon, C., Simard, R.-L., Roots, C.F., and Nelson, J.L., 2006. Paleozoic magmatism and crustal recycling along the ancient Pacific margin of North America, northern Cordillera; in *Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera*, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, v. 45, p. 281–322.
- Piercey, S.J., Murphy, D.C., and Creaser, R.A., 2012. Lithosphere-asthenosphere mixing in a transform-dominated late Paleozoic backarc basin: implications for northern Cordilleran crustal growth and assembly; *Geosphere*, v. 8, p. 716–739. <https://doi.org/10.1130/GES00757.1>
- Pigage, L.C., Crowley, J.L., Roots, C.F., and Abbott, J.G., 2014. Geochemistry and U-Pb zircon geochronology of mid-Cretaceous Tay River suite intrusions in southeast Yukon; in *Yukon Exploration and Geology 2014*, (ed.) K.E. MacFarlane, M.G. Nordling, and P.J. Sack; Yukon Geological Survey, p. 169–194.
- Pouclet, A., Lee, J.-S., Vidal, P., Cousens, B., and Bellon, H., 1995. Cretaceous to Cenozoic volcanism in South Korea and in the Sea of Japan: magmatic constraints on the opening of the back-arc basin; in *Volcanism Associated with Extension at Convergent Plate Margins*, (ed.) J.L. Smellie; Geological Society, London, Special Publication no. 81, p. 169–191.
- Price, A.A., Jackson, M.G., Blichert-Toft, J., Blusztajn, J., Conatser, C.S., Konter, J.G., Koppers, A.A.P., and Kurz, M.D., 2016. Geochemical evidence in the northeast Lau Basin for subduction of the Cook-Austral volcanic chain in the Tonga Trench; *Geochemistry Geophysics Geosystems*, v. 17, no. 5, p. 1694–1724. <https://doi.org/10.1002/2015GC006237>
- Rasmussen, K.L., 2013. The timing, composition, and petrogenesis of syn- to post-accretionary magmatism in the Northern Cordilleran Miogeocline, eastern Yukon and southwestern Northwest Territories; Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 810 p.
- Robertson, A.H.F., 2007. Evidence of continental breakup from the Newfoundland rifted margin (Ocean Drilling Program Leg 210): Lower Cretaceous seafloor formed by exhumation of subcontinental lithosphere and the transition to seafloor spreading; *Proceedings of the Ocean Drilling Program, Scientific Results*, v. 210, p. 1–69.
- Rubin, C.M., Saleeby, J.B., Cowan, D.S., Brandon, M.T., and McGroder, M.F., 1990. Regionally extensive mid-Cretaceous west-vergent thrust system in the northwestern Cordillera; implications for continent-margin tectonism; *Geology*, v. 18, no. 3, p. 276–280. [https://doi.org/10.1130/0091-7613\(1990\)018%3c0276:REMCWV%3e2.3.CO%3b2](https://doi.org/10.1130/0091-7613(1990)018%3c0276:REMCWV%3e2.3.CO%3b2)
- Rudnick, R.L. and Fountain, D.M., 1995. Nature and composition of the continental crust: a lower crustal perspective; *Reviews of Geophysics*, v. 33, no. 3, p. 267–309. <https://doi.org/10.1029/95RG01302>



- Ruhs, T.W., Piercey, S.J., Ryan, J.J., Villeneuve, M.E., and Creaser, R.A., 2006. Mid- to late Paleozoic K-feldspar augen granitoids of the Yukon-Tanana Terrane, Yukon, Canada; implications for crustal growth and tectonic evolution of the northern Cordillera; *Geological Society of America Bulletin*, v. 118, no. 9-10, p. 1212–1231. <https://doi.org/10.1130/B25854.1>
- Rusmore, M.E., Bogue, S.W., and Woodsworth, G.J., 2013. Paleogeography of the Insular and Intermontane terranes reconsidered: Evidence from the southern Coast Mountains Batholith, British Columbia; *Lithosphere*, v. 5, no. 5, p. 521–536. <https://doi.org/10.1130/L288.1>
- Ryan, J.J., and Gordey, S.P., 2004. Geology, Stewart River area (parts of 115 N/1, 2, 7, 8 and 115 O/2-12), Yukon Territory; Geological Survey of Canada, Open File 4970, scale 1:250 000. <https://doi.org/10.4095/221149>
- Ryan, J.J., Zagorevski, A., Williams, S.P., Roots, C., Ciolkiewicz, W., Hayward, N., and Chapman, J.B., 2013a. Geology, Stevenson Ridge (northeast part), Yukon; Geological Survey of Canada, Canadian Geoscience Map 116 (second preliminary edition), scale 1:100 000. <https://doi.org/10.4095/292407>
- Ryan, J.J., Zagorevski, A., Williams, S.P., Roots, C., Ciolkiewicz, W., Hayward, N., and Chapman, J.B., 2013b. Geology, Stevenson Ridge (northwest part), Yukon; Geological Survey of Canada, Canadian Geoscience Map 117 (second preliminary edition), scale 1:100 000. <https://doi.org/10.4095/292408>
- Ryan, J.J., Zagorevski, Z., Roots, C.F., and Joyce, N., 2014. Paleozoic tectonostratigraphy of the northern Stevenson Ridge area, Yukon; Geological Survey of Canada, Current Research 2014-4, 16 p. <https://doi.org/10.4095/293924>
- Ryan, J.J., Westberg, E.E., Williams, S.P., and Chapman, J.B., 2016. Geology, Mount Nansen-Nisling River area, Yukon; Geological Survey of Canada, Canadian Geoscience Map 292 (preliminary edition), scale 1:100 000. <https://doi.org/10.4095/298835>
- Ryan, J.J., Zagorevski, A., and Piercey, S.J., 2018. Geochemical data of Yukon-Tanana and Slide Mountain Terranes and their successor rocks in Yukon and northern British Columbia; Geological Survey of Canada, Open File 8500, 11 p. <https://doi.org/10.4095/313250>
- Sano, H., Struik, L.C., Rui, L., and MacIntyre, D.G., 2001. Facies interpretation of Middle Carboniferous to Lower Permian Pope succession limestone of Cache Creek Group, Fort St. James, central British Columbia; *Canadian Journal of Earth Sciences*, v. 38, p. 535–550. <https://doi.org/10.1139/e01-009>
- Selby, D., Creaser, R.A., and Nesbitt, B.E., 1999. Major and trace element compositions and Sr-Nd-Pb systematics of crystalline rocks from the Dawson Range, Yukon, Canada; *Canadian Journal of Earth Sciences*, v. 36, no. 9, p. 1463–1481. <https://doi.org/10.1139/e99-058>
- Shinjo, R., 1999. Geochemistry of high Mg andesites and the tectonic evolution of the Okinawa Trough-Ryukyu Arc system; *Chemical Geology*, v. 157, no. 1-2, p. 69–88. [https://doi.org/10.1016/S0009-2541\(98\)00199-5](https://doi.org/10.1016/S0009-2541(98)00199-5)
- Simard, R.-L., Dostal, J., and Roots, C.F., 2003. Development of late Paleozoic volcanic arcs in the Canadian Cordillera; an example from the Klunkit Group, northern British Columbia and southern Yukon; *Canadian Journal of Earth Sciences*, v. 40, no. 7, p. 907–924. <https://doi.org/10.1139/e03-025>
- Simard, R.-L., Dostal, J., and Colpron, M., 2007. Rifting of a Mississippian continental arc system; Little Salmon Formation, Yukon-Tanana Terrane, northern Canadian Cordillera; *Canadian Journal of Earth Sciences*, v. 44, no. 9, p. 1267–1289. <https://doi.org/10.1139/e07-022>
- Soucy La Roche, R. and Zagorevski, A., 2018. Origin of the Florence Range, Boundary Ranges and Whitewater metamorphic suites, Yukon-Tanana terrane, northwestern British-Columbia; Yukon Geoscience Forum, Whitehorse, Yukon, poster.
- Staples, R.D., Gibson, H.D., Berman, R.G., Ryan, J.J., and Colpron, M., 2013. A window into the early to mid-Cretaceous infrastructure of the Yukon-Tanana Terrane recorded in multi-stage garnet of west-central Yukon, Canada; *Journal of Metamorphic Geology*, v. 31, no. 7, p. 729–753. <https://doi.org/10.1111/jmg.12042>
- Staples, R.D., Murphy, D.C., Gibson, H.D., Colpron, M., Berman, R.G., and Ryan, J.J., 2014. Middle Jurassic to earliest Cretaceous mid-crustal tectono-metamorphism in the northern Canadian Cordillera: Recording foreland-directed migration of an orogenic front; *Geological Society of America Bulletin*, v. 126, no. 11-12, p. 1511–1530. <https://doi.org/10.1130/B31037.1>
- Staples, R.D., Gibson, H.D., Colpron, M., and Ryan, J.J., 2016. An orogenic wedge model for diachronous deformation, metamorphism, and exhumation in the hinterland of the northern Canadian Cordillera; *Lithosphere*, v. 8, no. 2, p. 165–184. <https://doi.org/10.1130/L472.1>
- Stolz, A.J., Davies, G.R., Crawford, A.J., and Smith, I.E.M., 1993. Sr, Nd and Pb isotopic compositions of calc-alkaline and peralkaline silicic volcanics from the D'Entrecasteaux Islands, Papua New Guinea, and their tectonic significance; *Mineralogy and Petrology*, v. 47, no. 2-4, p. 103–126. <https://doi.org/10.1007/BF01161562>
- Sun, S.S. and McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts; implications for mantle composition and processes; *Geological Society Special Publications*, v. 42, p. 313–345. <https://doi.org/10.1144/GSL.SP.1989.042.01.19>
- Tardy, M., Struik, L.C., Lapierre, H., Struik, L.C., Bosch, D., Brunet, P., and MacIntyre, D.G., 2001. The influence of mantle plume in the genesis of the Cache Creek oceanic igneous rocks; implications for the geodynamic evolution of the inner accreted terranes of the Canadian Cordillera; *Canadian Journal of Earth Sciences*, v. 38, p. 515–534. <https://doi.org/10.1139/e00-104>
- Tardy, M., Lapierre, H., Bosch, D., Cadoux, A., Narros, A., Struik, L.C., and Brunet, P., 2003. Le terrane de Slide Mountain (Cordillères canadiennes) : une lithosphère océanique marquée par des points chauds; *Canadian Journal of Earth Sciences*, v. 40, no. 6, p. 833–852. <https://doi.org/10.1139/e03-010>

- Taylor, B., Goodliffe, A.M., and Martinez, F., 1999. How continents break up; insights from Papua New Guinea; *Journal of Geophysical Research*, v. 104, no. B4, p. 7497–7512. <https://doi.org/10.1029/1998JB900115>
- Thompson, A.B., Castro, A., Fernandez, C., and Vigneresse, J.L., 1999. Some time-space relationships for crustal melting and granitic intrusion at various depths; *Geological Society Special Publications*, v. 168, p. 7–25. <https://doi.org/10.1144/GSL.SP.1999.168.01.02>
- Umhoefer, P., 2003. A model for the North America Cordillera in the Early Cretaceous: tectonic escape related to arc collision of the Guerrero Terrane and a change in North America plate motion; *in* *Tectonic evolution of northwestern Mexico and the Southwestern USA*, (ed.) S.E. Johnson, S.R. Paterson, J.M. Fletcher, G.H. Girty, D.L. Kimbrough, and A. Martin-Barajas; *Geological Society of America, Special Paper 374*, p. 117–134.
- Uto, K., Sato, H., Takahashi, E., Nakamura, E., Kaneoka, I., Misra, K.C., and Fujimaki, H., 1994. Geochronology of alkali volcanism in Oki-Dogo Island, Southwest Japan; geochemical evolution of basalts related to the opening of the Japan Sea; *Geochemical Journal*, v. 28, no. 6, p. 431–449. <https://doi.org/10.2343/geochemj.28.431>
- van Staal, C.R., Zagorevski, A., McClelland, W.C., Escayola, M., Ryan, J., Parsons, A.J., and Proenza, J.A., 2018. Age and setting of Permian Slide Mountain terrane ophiolitic ultramafic-mafic complexes in the Yukon: Implications for late Paleozoic-early Mesozoic tectonic models in the northern Canadian Cordillera; *Tectonophysics*, v. 744, p. 458–483. <https://doi.org/10.1016/j.tecto.2018.07.008>
- Whalen, J. and Frost, C., 2013. The Q-ANOR diagram: A tool for the petrogenetic and tectonomagmatic characterization of granitic suites; *Geological Society of America Abstracts with Programs*, v. 45, no. 3, p. 24.
- Wilson, F.H., Hults, C.P., Mull, C.G., and Karl, S.M., 2015. Geologic map of Alaska; U.S. Geological Survey, Scientific Investigations Map 3340, scale 1:1 584 000.
- Winchester, J.A. and Floyd, P.A., 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements; *Chemical Geology*, v. 20, no. 4, p. 325–343. [https://doi.org/10.1016/0009-2541\(77\)90057-2](https://doi.org/10.1016/0009-2541(77)90057-2)
- Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L., 1991. Plutonic regimes; Chapter 15 *in* *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; *Geological Survey of Canada, Geology of Canada*, no. 4, p. 491–531 (*also* *Geological Society of America, The geology of North America*, v. G-2, p. 491–531). <https://doi.org/10.1130/DNAG-GNA-G2.491>
- Yukon Geological Survey, 2019. Yukon Digital Bedrock Geology, Volume 2019, Yukon Geological Survey. <[http://www.geology.gov.yk.ca/update\\_yukon\\_bedrock\\_geology\\_map.html](http://www.geology.gov.yk.ca/update_yukon_bedrock_geology_map.html)> [accessed June 24, 2021]
- Zagorevski, A., 2018. Geochemical data of the northern Cache Creek, Slide Mountain, and Stikine Terranes and their overlap assemblages, British Columbia and Yukon; *Geological Survey of Canada, Open File 8395*, 12 p. <https://doi.org/10.4095/308496>
- Zagorevski, A., 2020. Whole-rock geochemical data compilation supporting Geo-mapping for Energy and Minerals Cordillera syntheses, British Columbia and Yukon; *Geological Survey of Canada, Open File 8674*, 5 p. <https://doi.org/10.4095/323678>
- Zagorevski, A., Mihalynuk, M.G., and Logan, J.M., 2012. Geochemical characteristics of Mississippian to Pliensbachian volcanic and hypabyssal rocks in the Hoodoo Mountain area (NTS 104B/14E); *in* *Geological Fieldwork 2011*; *British Columbia Ministry of Energy, Mines and Natural Gas, British Columbia Geological Survey Paper 2012-01*, p. 121–134.