# Paleozoic tectonic and metallogenetic evolution of pericratonic terranes in Yukon, northern British Columbia and eastern Alaska

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Project    Cordilleran Magmatic Evolution View project

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# Paleozoic tectonic and metallogenetic evolution of pericratonic terranes in Yukon, northern British Columbia and eastern Alaska[1]

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## Abstract
*The allochthonous, pericratonic Yukon-Tanana terrane (YTT) underlies much of southwest Yukon, easternmost Alaska and the Coast and Cassiar mountains of northern B.C. Data obtained through the Ancient Pacific Margin NATMAP Project (1998-2003) have substantially modified its extent, subdivided it into regional assemblages, and established*

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[1]Data Repository items *Nelson_DR1.xls* (Table DR1), *Nelson_DR2.xls* (Table DR2), *Nelson_DR3.xls* (Table DR3) and *Nelson_Appendix1.pdf* are available on the CD-ROM in pocket.

*distinct components of arc and back-arc affinity that define a west-facing Late Devonian to Early Permian arc. Most of the former YTT in Alaska is now considered parautochthonous.*

*Some aspects of YTT appear foreign to the continent: intense Devonian-Mississippian arc magmatism, and affiliations with the younger arc terranes of Quesnellia and Stikinia. A belt of Permian high-pressure rocks, a late Paleozoic marginal ocean terrane, and Jurassic thrust faults intervene between it and the miogeocline. However, Precambrian detrital zircon populations, εNd values and Pb isotopic ratios from Devonian-Mississippian syngenetic occurrences show a strong affinity for the northern miogeocline. VHMS mineralization associated with A-type and intraplate volcanism mark the YTT as a rifting frontal arc to continental back-arc during the Devonian-Mississippian. Simultaneously, the northwestern continent margin became a broad, extending back-arc region, with normal faulting, coarse clastic deposition, rift-related volcanism and syngenetic mineralization. Slab rollback drove regional extension, which culminated in the opening of the Slide Mountain marginal ocean between the YTT arc and North America.*

*The mid-Permian marked a transition to convergent tectonic style - the closure of the Slide Mountain basin by short-lived westward subduction under YTT. Within eastern (inboard) YTT, there was a brief phase of arc activity, east-vergent thrust faulting, exhumation of high P/T rocks and deposition of synorogenic clastic rocks. By the end of the Permian, YTT and its associated terranes, although still not accreted to their present locations, had once again become part of the North American margin.*

## Résumé

*Les roches allochtones péricratoniques du terrane de Yukon-Tanana (YTT) forment l'assise d'une grande partie du sud-ouest du Yukon, de l'extrême est de l'Alaska, et de la chaîne côtière et des monts Cassiar de la Colombie-Britannique. Les données obtenues par la réalisation du projet sur l'Ancienne marge du Pacifique de CARNAT (1998-2003) ont mené à une importante modification de son étendu, ont permis de le subdiviser en assemblages régionaux, et ont permis d'y définir des composants d'affinité d'arc et d'arrière-arc correspondant à un système d'arc orienté vers l'ouest du Dévonien supérieur au Permien inférieur. La majeure partie du YTT en Alaska est maintenant considérée comme parautochtone.*

*Certains aspects du YTT semblent étrangers au continent : un magmatisme d'arc intense du Dévonien au Mississipien et des affiliations avec les terranes d'arc plus jeunes de Quesnellia et de Stikinia. Une bande de roches de haute pression, un terrane de milieu océanique au Paléozoïque supérieur, ainsi que des failles de chevauchement du Jurassique entre celui-ci et le miogéocline. Cependant, l'existence de populations de zircons détritiques précambriens, de valeurs de εNd et de ratios isotopiques de Pb provenant d'indices minéralisés syngénétiques du Dévonien au Mississipien sont l'indication d'une affinité marquée avec le nord du miogéocline. Les minéralisations de SMSV associés au volcanisme d'intraplaque de type A sont l'indication que le milieu de constitution du YTT aurait été de type ouverture de fossé d'arc frontal à arrière-arc continental du Dévonien jusqu'au Mississipien. Simultanément, la marge nord-ouest du continent est devenue une grande région d'arrière-arc en extension, accompagnée de failles normales, de dépôts clastiques grossiers, d'un volcanisme de fossé tectonique, et d'une minéralisation syngénétique. La retraite de la plaque subduite a été le moteur d'une extension régionale, qui a culminée avec l'ouverture de l'océan de marge de Slide Mountain entre le YTT et l'Amérique du Nord. Le Permien moyen a été le moment d'une transition vers un style tectonique de convergence – la fermeture du bassin de Slide Mountain par l'effet d'une courte subduction vers l'ouest, sous le YTT. Dans la portion est (interne) du YTT, il y a eu une courte phase d'activité d'arc, l'action de failles de chevauchement de vergence est, l'exhumation de roches de hautes pressions et températures, et le dépôt de roches clastiques synorogéniques. Vers la fin du Permien, le YTT et ses terranes associés, faisaient de nouveau partie du continent nord-américain, bien qu'ils n'y aient pas été accrétés dans leurs positions actuelles.*

# INTRODUCTION

The Yukon-Tanana terrane (YTT) is a sprawling terrane of pericratonic affinity, located on both sides of the Tintina fault in the northern Canadian Cordillera and far eastern Alaska (Fig. 1). It was described by Mortensen (1992a) as one of the largest and most enigmatic terranes of the northern Canadian Cordillera, consisting mainly of a poorly exposed assemblage of polydeformed metamorphic rocks derived from a variety of igneous and sedimentary protoliths. Except for certain areas, very little was known at that time about its internal stratigraphy, and only limited radiometric and fossil dating of protoliths had been done.

In 1994-1997, a series of significant VHMS (volcanic-hosted massive sulphide) discoveries, Kudz Ze Kayah, Wolverine and Fyre Lake in the Finlayson Lake district northeast of the Tintina fault, sparked exploration interest in the YTT (Hunt, 1997, 1998). This in turn prompted provincial, territorial and federal government agencies to undertake geological mapping and related geoscience studies on regional scales. In 1999, these projects were incorporated into



**Figure 1.** *Regional setting of Yukon-Tanana terrane (YTT) in Canadian-Alaskan Cordillera; and summary of Devonian-Mississippian metallogeny, magmatism and tectonics of the northwestern North American margin and adjacent pericratonic terranes. The following abbreviations are used on Figures 1, 2 and 3: Ak = Alaska; AT = Alexander terrane; CA = Cassiar platform; CC = Cache Creek terrane; D = Dawson; E = Eagle; Fb = Fairbanks; Q = Quesnellia; ST = Stikinia; Wh = Whitehorse; WL = Watson Lake; WM = Windy-McKinley; YT = Yukon; YTT = Yukon-Tanana terrane.*

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the Ancient Pacific Margin NATMAP (National Mapping Program) project, a combined initiative between the Geological Survey of Canada, B.C. Ministry of Energy and Mines, Yukon Geological Survey and the United States Geological Survey in Alaska. Its goal was to arrive at a deeper understanding of the tectonic and metallogenetic evolution of the Paleozoic North American continental margin from Alaska to southern British Columbia, a story in which the YTT has played a key role.

## Knowledge Base

This summary paper integrates observations and ideas on the evolution of the YTT that come from contributions to the Ancient Pacific Margin NATMAP project (Colpron *et al.*, this volume-a, b; Roots *et al.*, this volume; Murphy *et al.*, this volume; Dusel-Bacon *et al.*, 2004, this volume; Mihalynuk *et al.*, this volume) as well as important earlier and ongoing work by Mortensen (1990a, 1992a), Gehrels and co-workers (Gehrels *et al.,* 1991a, 1992; Gehrels and Kapp, 1998; Gehrels and Boghossian, 2000; Gehrels, 2000, 2001, 2002), Saleeby (2000), Simard *et al.* (2003), Foster (1992), Gordey and Stevens (1994), Werdon *et al.* (2001), Szumigala *et al.* (2002) and others. Figure 2 shows the areas in the main part of YTT covered by detailed recent mapping and focused studies, including those at 1:50,000-scale conducted during the Ancient Pacific Margin NATMAP project (1998-2003). The most extensive new map coverage, supported by U-Pb dating and igneous rock geochemistry, is in the Finlayson, Glenlyon and Wolf Lake-Jennings River areas in the Yukon and far northern B.C. Unfortunately, the three year Stewart River component project has published somewhat limited data to date (*cf.* Ryan *et al.*, 2003, and references therein).

Except for Stewart River in the Yukon Plateau of the western Yukon, these areas have moderate to high topographic relief, and both rock units and critical contacts are locally well exposed. Recent detailed studies in Alaska have provided a wealth of new U-Pb and geochemical data, particularly from important mineral districts (Fig. 2; Dusel-Bacon *et al.*, this volume). Pre-Mesozoic rock relationships in the southwestern part of YTT in the Yukon remain relatively undocumented, except for older-vintage regional maps.

The tectonic synthesis discussed here complements the stratigraphic overview of the pericratonic terranes of Colpron *et al.* (this volume-a), and the geochemical and isotopic synthesis of Piercey *et al.* (this volume). Colpron *et al.* (this volume-a) summarize the historical evolution of concepts and nomenclature with respect to the Yukon-Tanana and related terranes.

## GENERAL CONSIDERATIONS

The present YTT (as redefined in this paper; see below) consists of two separate pieces located on opposite sides of the Tintina fault (Figs. 1, 2). Restored plutonic belts and structural features show that dextral offset on the Tintina fault was 430 km, probably mostly during the Eocene (Gabrielse *et al.*, in press). Figure 3 is a restoration of YTT and the continent margin prior to the offset on this regional fault system. Plate 1 (in pocket) is a detailed compilation of the geology of pericratonic assemblages and terranes of the northern Cordillera, from the Finlayson belt and Sylvester allochthon in the

south, to Fairbanks, Alaska in the north (equivalent to Plate 1 in Colpron *et al.*, this volume-a; also refer to Figure 2 for locations). It is based on contributions to this volume, along with interpreted older mapping.

The YTT includes, within its presently defined borders, all of the pericratonic assemblages of the northern Canadian Cordillera and adjacent easternmost Alaska that are considered far-travelled with respect to the North American continental margin (Figs. 1, 2; Plate 1). Three other related terranes shown on Figure 1, the late Paleozoic Slide Mountain terrane, and the long-lived arc terranes of Quesnellia and Stikinia, also share parts of its geologic history. In Canada, the allochthonous relationship of the YTT to ancestral North America is clearly shown by the regional Jurassic thrust faults that separate them. In the Finlayson Lake area northeast of the Tintina fault, this structure is called the Inconnu thrust fault (Fig. 3, Plate 1; Murphy *et al.*, this volume). Along with pericratonic assemblages, there are late Paleozoic oceanic strata of Slide Mountain terrane and Permian high P/T facies metamorphic rocks in its hanging wall; and Upper Triassic and older North American strata in its footwall (Murphy *et al.*, this volume; Erdmer *et al.*, 1998). Structures equivalent to the Inconnu thrust are widespread in Yukon and northern B.C., forming the demarcation between autochthonous and allochthonous rocks in numerous klippen. In some localities, such as the Sylvester allochthon and Nina Creek area of central B.C., the Slide Mountain terrane alone forms the immediate hanging wall panel above the fundamental, master thrust fault (Figs. 1, 3; Ferri, 1997; Nelson and Friedman, 2004). The Inconnu thrust and its equivalents represent the base of a post-Early Jurassic accretionary wedge made up of the combined allochthons, YTT, Slide Mountain and Quesnel terranes, including a suite of Early Jurassic plutons in Quesnellia and YTT, which is absent on the autochthonous North American margin (Figs. 1, 3; Plate 1).

Overall, the geology of YTT is that of a large continental margin fragment, substrate to magmatic arcs and back arcs of Devonian-Mississippian, Pennsylvanian and Permian age. Early Jurassic batholiths and a myriad of smaller bodies represent much later, superimposed arcs, shared with Quesnellia and Stikinia. A frequency plot of U/Pb ages (Fig. 4; data in Table DR1 [see footnote 1]) shows Paleozoic YTT magmatism beginning at about 385 Ma (Middle Devonian), a strong magmatic peak in Early Mississippian time, and smaller peaks in the Late Mississippian and Late Permian. The Devonian-Mississippian magmatic episodes were continentally influenced, dominated by crustally-derived rhyolite and enriched basalt that interfingered with siliciclastic strata. By contrast, magmatic arc volcanic products in the later, overlapping Pennsylvanian-Early Permian Klinkit assemblage (Plate 2) were predominantly andesitic, with a comparatively more primitive isotopic character (Simard *et al.,* 2003; Piercey *et al.,* this volume). Flows and tuffs are interbedded with locally thick limestone bodies and chert-argillite-epiclastic successions. The apparent frequency low in Figure 4 from Pennsylvanian through Early Permian is because the mainly intermediate sequences have yielded few zircons, and are primarily dated by macrofossils and conodonts. In contrast, the Late Permian arc of the Klondike assemblage is largely felsic in composition, with minor

mafic rocks, and associated VHMS occurrences have a very radiogenic isotopic character (Mortensen *et al.*, this volume).

The Slide Mountain terrane comprises latest Devonian to mid-Permian marginal basin strata and, in some localities, oceanic lithosphere. It occupies a series of thrust panels structurally between YTT and North America in the Sylvester allochthon (Figs. 1, 3;

Plate 1; Nelson, 1993; Nelson and Friedman, 2004). It lies between YTT and North American strata in the Finlayson Lake district and Glenlyon area, and locally occupies structural windows in YTT - the Big Campbell window in the Finlayson Lake district and the Clinton Creek window west of Dawson (Plate 1; Abbott, 1983; Murphy *et al.*, 2001; Colpron *et al.*, this volume-b; Mortensen, 1988). The history
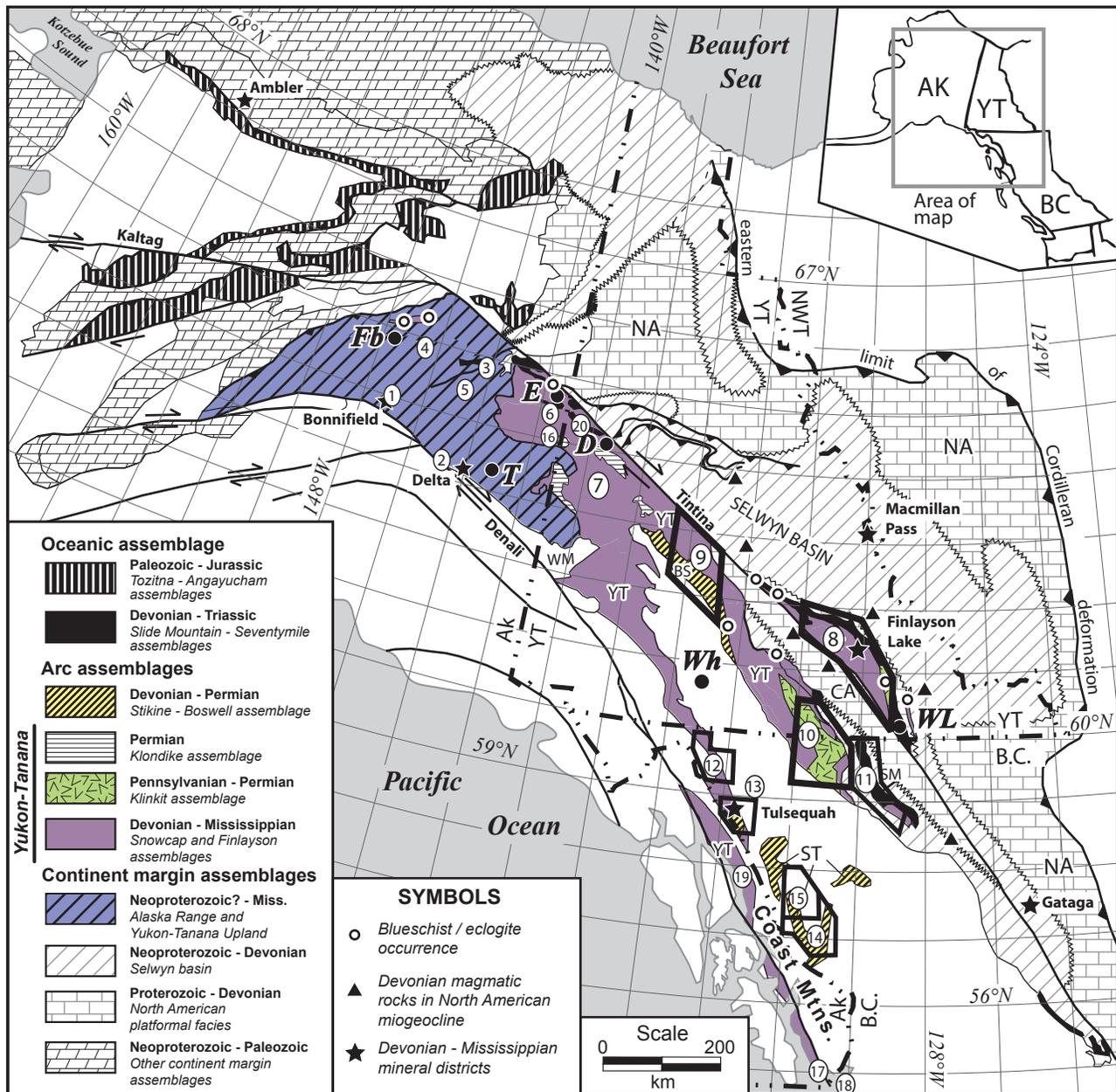


**Figure 2.** *Locations of detailed recent mapping projects and other projects that form the basis of this synthesis.* <u>Numbered projects</u>: *(1-5) Dusel-Bacon* et al. *(2004, this volume); (6-7) Dusel-Bacon* et al. *(this volume); Stewart River area, S. Gordey and J. Ryan, unpublished data; (8) Finlayson Lake belt, Murphy* et al. *(this volume); (9) Glenlyon area, Colpron* et al. *(2002, this volume -b); (10) Wolf Lake- Jennings River area, Roots* et al. *(this volume); Mihalynuk* et al., *(this volume); (11) Sylvester allochthon, Nelson and Bradford (1993); Nelson and Friedman (2004); (12) Tagish Lake area, Mihalynuk (1999); (13) Tulsequah area, Mihalynuk* et al. *(1994a); (14) Iskut River area, Logan* et al. *(2000); Gunning* et al. *(this volume); (15) Scud River area, Brown* et al. *(1991); (16) Eagle quadrangle, Werdon* et al. *(2001) and Szumigala* et al. *(2002); (17) Rubin and Saleeby (1991); Saleeby (2000); (18) Gehrels (2002); (19) Gehrels* et al. *(1991); (20) Klondike area, Mortensen (1990a); Dusel-Bacon* et al. *(this volume). Symbols as on Figure 1.*

of the Slide Mountain terrane spans the same time period as arcs in the YTT. Later arguments will show that most likely they developed together as an arc and back-arc pair. The Paleozoic and Mesozoic arc terranes of Quesnellia and Stikinia show evidence of development contiguous with and on top of YTT (Roots *et al.*, this volume; Simard *et al.*, 2003, Nelson and Friedman, 2004, Jackson *et al.*, 1991; McClelland, 1992; Mihalynuk *et al.*, 1994a; Mihalynuk, 1999;

Gunning *et al.*, this volume). Where relevant to the Paleozoic history of YTT, they are also included in this synthesis.

YTT, with its clear allochthonous relationship to the continent margin, contrasts with the pericratonic Kootenay terrane in southern British Columbia (Fig. 1). The Kootenay terrane, like the YTT, includes Late Devonian arc strata with associated VHMS deposits (Paradis *et al.*, this volume), that lie on older siliciclastic, carbonate
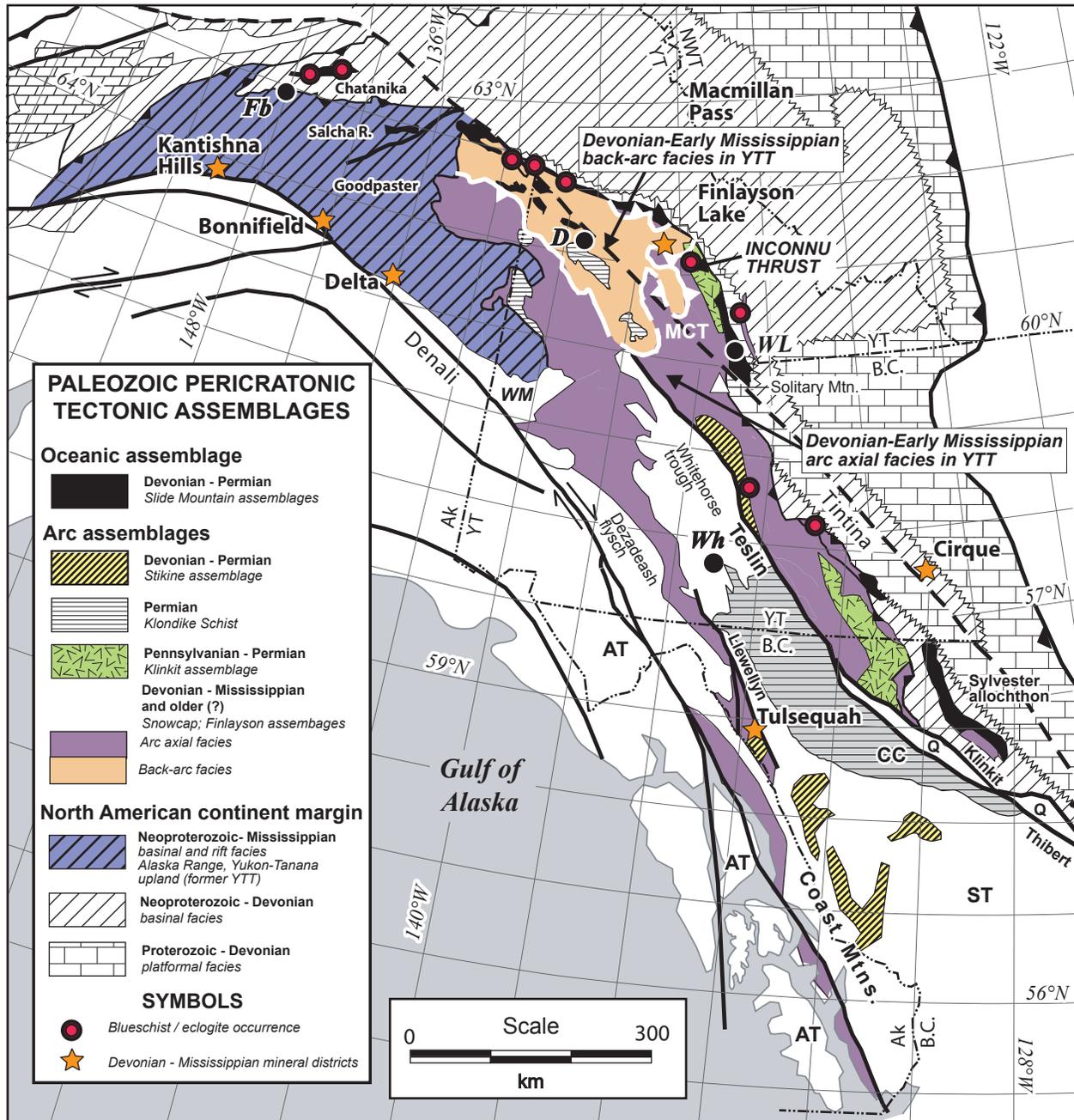


**Figure 3.** *Yukon-Tanana terrane, its relationships to other terranes and the regional faults which bound and transect it. Eocene dextral motion of 430 kilometres on Tintina fault (black dashed line) is restored. Thick white line separates Early Mississippian arc-axis from back-arc facies rocks; for details see text. Ak = Alaska; AT = Alexander terrane; CC = Cache Creek terrane; D = Dawson; Fb = Fairbanks; MCT = Money Creek thrust; Q = Quesnellia; ST = Stikinia; WL = Watson Lake; Wh = Whitehorse; WM = Windy-McKinley terrane, YT = Yukon; YTT = Yukon-Tanana terrane.*
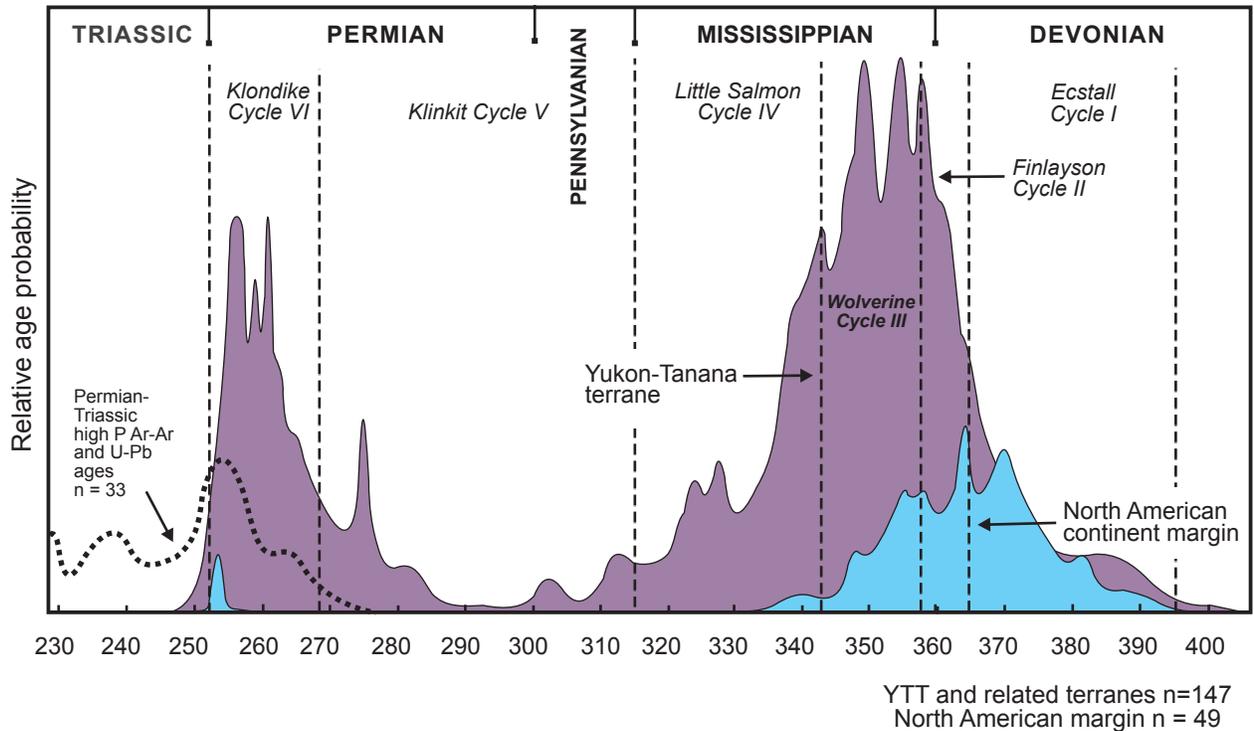
**Figure 4.** *Frequency diagram for Devonian-Permian magmatism and high-pressure metamorphism in YTT, related terranes and autochthonous and parautochthonous North America. Stage boundaries from Okulitch (2002). Cycle boundaries discussed in text. Data from Breitsprecher* et al. *(2002, 2004); and contributions to this volume (Tables DR 1, DR2, DR3 [see footnote 1]).*

and mafic volcanic strata. Logan and Colpron (this volume) document depositional ties between the Kootenay terrane and Lower Cambrian units of the autochthonous miogeocline. Moreover, the Kootenay terrane lies inboard of a structurally emplaced Slide Mountain terrane succession, the Fennell Formation (Schiarizza and Preto, 1987).

## REVISION OF TERRANE BOUNDARIES AND EXTENTS

One key outcome of this project is a set of significant modifications, both additions and subtractions, to the previous spatial extent of YTT. The proposed changes are summarized here; for additional details see Colpron *et al.* (this volume-a). YTT shares a bimodal Devonian-Early Mississippian igneous suite with the continental margin, consisting of coeval continentally-derived felsic to intermediate bodies, enriched and MORB basalts, and volcanic rocks of magmatic arc affinity such as are found in the Kootenay terrane. However YTT, in addition to its structurally allochthonous relationship to North America, contains well-developed Late Mississippian, Pennsylvanian, Permian and Early Jurassic arc assemblages that have no autochthonous equivalents: this set of characteristics forms the criteria that can be used to evaluate the terrane affinities and allochthonous *vs.* parautochthonous status of pericratonic tracts in the northern Cordillera.

We propose that a large tract of the former YTT in the western Yukon-Tanana Upland, extending from the latitude of Fairbanks (Plate 1) to the northern strand of the Denali fault in the central Alaska Range, and including the Mt. Hayes, Tanacross, Big Delta and northern Eagle quadrangles, is a parautochthonous part of the North American continent margin. This interpretation is based on the exclusively Devonian-Early Mississippian ages; the bimodal composition and non-magmatic arc, within-plate tectonic affinities of most meta-igneous rocks, and, northwest of the Shaw Creek fault (Plate 1), a structural position below (originally inboard of) slivers of oceanic crust equivalent to the Slide Mountain terrane (Figs. 1, 3; Plate 1; Dusel-Bacon *et al.*, 2004, this volume). This parautochthonous tract includes Devonian-Mississippian assemblages hosting the Bonnifield and Delta VHMS camps in the Alaska Range, and SEDEX (sedimentary exhalative sulphide) occurrences in the Chena slate belt of the northern Big Delta quadrangle. Stratigraphic correlations between the volcanic units that host VHMS deposits in the Delta mineral belt and those in the Bonnifield district are uncertain (Dashevsky *et al.,* 2003). Although the timing of magmatism in the Delta and Bonnifield districts overlap, magmatism in the former was more intermediate in composition, as opposed to bimodal in the latter, suggesting a possible coeval arc-continental margin pair (Dusel-Bacon *et al.*, this volume). Parts of the Tanacross and Big Delta quadrangles (Plate 1) are underlain by the Lake George assemblage, a metasiliciclastic unit intruded by large Devonian-

Mississippian augen orthogneiss bodies (Dusel-Bacon *et al.* 2004, this volume). The Lake George assemblage extends eastward to the Yukon border, and includes the Fiftymile batholith in the western Stewart River area (Dusel-Bacon *et al.*, this volume; Plate 1); although approximately coeval plutonic rocks are interpreted to lie within allochthonous YTT farther east (J. Ryan, personal communication, 2005). The parautochthonous Lake George rocks are interpreted to lie in the footwall of a Cretaceous extensional fault (Hansen and Dusel-Bacon, 1998). These arguments are expanded upon later, particularly in the discussion of the period between 357 and 342 Ma, when the geological history of the YTT began to diverge significantly from that of the parautochthonous Yukon-Tanana Upland and Alaska Range (see discussion below).

The former Dorsey terrane on the B.C.-Yukon border in the Wolf Lake-Jennings River map areas (Wheeler *et al.*, 1991; see #10, Fig. 2) and its correlative, the former Rapid River tectonite in the Sylvester allochthon (Harms, 1990) are now included within YTT (Roots *et al.*, this volume; Nelson and Friedman, 2004). So, too, is the belt of pericratonic rocks in the Coast Mountains of southeastern Alaska and northwestern B.C. (Fig. 1), including the former Nisling and part of the Taku terrane, based on close stratigraphic and isotopic similarities (Gehrels and Kapp, 1998; Gehrels and Boghossian, 2000; Gehrels, 2000a, 2002; Rubin and Saleeby, 1991; Saleeby, 2000). This includes the Ecstall belt south of Prince Rupert (Fig. 1), which hosts several Devonian VHMS occurrences (Gareau and Woodsworth, 2000; Alldrick *et al.*, 2001).

## THE YTT AS A COHERENT, STRATIFIED PERICRATONIC ARC TERRANE

Detailed mapping conducted during the Ancient Pacific Margin NATMAP project has borne out earlier depictions of the YTT as fundamentally an integral, internally stratified geological province (Mortensen, 1992a). The distillation of a set of stratigraphic columns representing each of the study areas (Colpron *et al.*, this volume-a; Plate 2, in pocket) forms the basis for understanding and interpreting the evolution of the terrane. These columns depict the nature of YTT, its essential pericratonic character, with superimposed Devonian-Mississippian and younger felsic to mafic igneous units in multiple, unconformity-bounded sequences. Overall, the picture is one of surprising stratigraphic continuity, given the vast extent of the terrane.

The YTT is far from a tectonic mélange or a collage of unrelated structural slivers. Elements that are indicative of plate margin settings — oceanic crust, melange, blueschist-eclogite — are confined to its edges (*e.g.*, Permian blueschist) and structural base (*e.g.*, Slide Mountain terrane) and top (*e.g.*, Seventymile terrane [Dusel-Bacon *et al.*, this volume] and Mississippian eclogites [Devine *et al.*, 2004, this volume]). Mafic sequences in the Finlayson Lake area — the so-called 'Anvil assemblage', correlated with Slide Mountain terrane and previously considered to be structurally imbricated with YTT — have been redefined as mafic strata in depositional contact with YTT (Murphy *et al.*, this volume).

Internally, YTT shows a coherence in Paleozoic tectonic facies that invites paleogeographic reconstruction. An excellent, terrane-wide example of this is the pairing of distinct Early Mississippian igneous suites of continent-margin arc and back-arc affinity, distinguished by the thick white lines on Figure 3, which have been identified on geological, geochemical and isotopic grounds (Piercey *et al.*, 2001, 2003, 2004, this volume). Arc facies include the Fortymile River assemblage (formerly termed the Taylor Mountain assemblage) in eastern Alaska and western Yukon (Dusel-Bacon *et al.*, this volume), intrusions in the Snowcap and Dorsey complexes in southeastern YTT (Colpron *et al.*, this volume-b; Roots *et al.*, this volume), the Little Kalzas formation in the Glenlyon area (Colpron *et al.*, this volume-b), the Simpson Range plutonic suite, and tentatively the Waters Creek and Tuchitua River formations in the Finlayson Lake district (Murphy *et al.*, this volume). Back-arc facies rocks include the Grass Lakes and Wolverine Lake groups and cogenetic plutons in the Finlayson Lake district (Piercey *et al.*, 2001, 2002, 2003, this volume; Murphy *et al.*, this volume) and the Nasina assemblage in easternmost Alaska and western Yukon (Dusel-Bacon *et al.*, this volume). Transitional units are rare. One example is in the Fire Lake formation in the Finlayson Lake district (Piercey *et al.*, this volume; Murphy *et al.*, this volume). In general, arc and back-arc facies are juxtaposed across faults: the Early Permian Money Creek thrust in the Finlayson Lake belt (Murphy, 2004; Murphy *et al.*, this volume) and the unnamed fault at the base of the Fortymile River assemblage in eastern Alaska - western Yukon. On Figure 3, assumed connections between and extensions of these faults into poorly mapped areas are shown as thick white broken lines, which correspond to approximate Early Mississippian arc/back-arc boundaries, restored prior to 430 km of dextral displacement on the Tintina fault.

## STRUCTURAL SETTING OF YTT AND RELATIONSHIP TO CONTIGUOUS TERRANES

Figure 3 shows the YTT as a vast region shaped somewhat like an old-fashioned clothes pin. Its northern core includes the Yukon-Tanana Upland portion near Dawson and the Finlayson Lake belt. The southeastern prong includes the Glenlyon and Wolf Lake-Jennings River areas. The southwestern prong extends along the Coast Mountains into northwest B.C. and southeast Alaska, as far south as the Ecstall belt (Fig. 1). This complex geometry brings YTT into contact with many other major terranes of the Canadian-Alaskan Cordillera (Fig. 1). Besides the North American margin, these include: (1) the Slide Mountain terrane to the east; (2) Mesozoic Quesnellia and the Cache Creek terrane on the inner (western) side of the southeastern prong; (3) Stikinia on the inner (eastern) side of the southwestern prong; and (4) the Windy-McKinley terrane and rocks of the Insular superterrane (Alexander terrane, Wrangellia and the Dezadeash flysch and its metamorphosed equivalents) to the west. Contacts between YTT and other terranes include thrust faults related to terrane accretion with North America, Cache Creek and Insular superterrane; strike-slip faults; and fault-modified facies

boundaries and onlaps in the case of Slide Mountain terrane, Quesnellia and Stikinia.

A counterclockwise tour of the YTT, beginning with its eastern side, illustrates its external relationships in detail. On Figure 3 and Plate 1, the eastern side of YTT is bounded by thrust faults and later strike-slip faults against the North American miogeocline, except where the Slide Mountain terrane intervenes. In the Finlayson Lake belt, Devonian to Early Permian rocks of the YTT are juxtaposed with the Fortin Creek group of the Slide Mountain terrane across the steep, northwesterly-striking transcurrent(?) Jules Creek fault, which in turn is overlapped by mid-Permian basalts of the Campbell Range formation (Plate 1; Murphy *et al.*, this volume). The Fortin Creek group forms the immediate hanging wall of the post-Triassic Inconnu thrust. Farther west, Triassic strata, lying on top of Slide Mountain greenstone and ultramafites, are exposed below YTT in the Big Campbell window in the middle of the Finlayson Lake belt (Plate 1). The Tummel fault zone in the Glenlyon area, a series of steeply-dipping, imbricate thrust faults, possibly modified by later strike-slip faulting, is probably a southern continuation of the Inconnu thrust. Along its trace, multiple slivers of Slide Mountain terrane oceanic rocks and synorogenic clastic rocks lie between YTT and North America (Cassiar terrane; Colpron *et al.*, 2005, this volume-b).

In the Wolf Lake area in southernmost Yukon, YTT rocks are separated from parautochthonous North American strata (Cassiar terrane), including probable Triassic units, by the Ram Creek fault, which also may have accommodated later strike-slip motion. To the south in the Jennings River area of northern British Columbia, the Cottonwood thrust fault is a gently-dipping shear zone, analogous to the Inconnu thrust, which places Mississippian arc rocks on top of distal North American strata (Roots *et al.*, this volume). In the Sylvester allochthon, panels of YTT (the Dorsey Complex) and Mississippian to Permian arc strata lie in thrust contact above imbricated Slide Mountain terrane and its Triassic cover rocks; these in turn are thrust over the North American miogeocline (Nelson and Friedman, 2004). The pre-Mississippian Dorsey Complex overrides upper Paleozoic units on the Hidden Lake thrust fault in the Wolf Lake-Jennings River area and on the Beale Mountain thrust fault in the Sylvester allochthon; these are probably equivalent structures, and may be of mid-Permian, earliest accretionary age (Roots *et al.*, this volume; Nelson and Friedman, 2004).

In western Yukon, mafic and ultramafic rocks of the Slide Mountain terrane and Triassic sedimentary strata are exposed structurally below the YTT in the Clinton Creek window (Mortensen, 1998), in a structural setting analogous to that of the Campbell Creek window in the Finlayson district, and to that in the Sylvester allochthon. After restoration of motion on the Tintina fault, the Jules Creek fault in the Finlayson Lake district is approximately aligned with the Slide Mountain-equivalent American Creek and Mt. Sorensen ophiolitic bodies in eastern Alaska (Fig. 3; Plate 1; see also Dusel-Bacon *et al.*, this volume, Fig. 2 and discussion of the Seventymile terrane). Further west, in the Salcha River area near the Shaw Creek fault in northeast Big Delta quadrangle, lithologically similar peridotite and associated mafic and sedimentary rocks of the Seventymile terrane structurally overlie the parautochthonous rocks along a low-angle fault (see Dusel-Bacon *et al.*, this volume).

Timing of displacement on the faults that separate the allochthonous terranes from North America in the northern Cordillera is constrained to be between the Early Jurassic and mid-Cretaceous, based on the age of the youngest intrusive bodies restricted to the hanging wall, and cross-cutting igneous bodies such as the Orchay batholith (*ca.* 106 Ma; Pigage, 2004) that cuts the Inconnu thrust (Gordey and Makepeace, 2000), the Cassiar batholith (*ca.* 110 Ma) that pierces the entire structural stack in the Sylvester allochthon (Nelson and Friedman, 2004), and the Glenlyon batholith (*ca.* 105 Ma) with a contact aureole that extends across the Tummel fault (Gladwin *et al.*, 2003; Colpron *et al.*, 2005).

The western limit of YTT in eastern Alaska is obscured by normal faults, Cretaceous plutons and thick Quaternary cover. It runs roughly southerly, from the western end of the non-carbonaceous Nasina assemblage (Dusel-Bacon *et al.*, this volume) underlying the Mt. Sorensen ophiolitic body, to the area south of Taylor Mountain, where it is defined by a gently-dipping detachment fault with parautochthonous Lake George assemblage rocks in its footwall (Fig. 3, Plate 1; Dusel-Bacon *et al.*, this volume). This detachment structure was identified by Hansen and Dusel-Bacon (1998, and references therein), based on differences in lithologies, structural histories and, most notably, in metamorphic cooling ages and the age of intrusions, *i.e.,* Cretaceous in the footwall *vs.* Early Jurassic in the hanging wall. New information about differences in Devonian-Mississippian igneous history accords with their model (see below; also Dusel-Bacon *et al.*, this volume). In addition, the absence of Slide Mountain terrane panels along this detachment suggests that structural section was eliminated, which is compatible with a low-angle normal fault origin. An isolated western outlier of allochthonous terranes, the Chatanika schist, forms two klippe structurally above the parautochthonous Fairbanks schist northeast of Fairbanks (Plate 1). In it, eclogitic rocks are intercalated with amphibolite, impure marble, phyllitic schist and glaucophane-bearing schist (Swainbank and Forbes, 1975; Brown and Forbes, 1986; Laird *et al.*, 1984).

The southwestern boundary of YTT enters the Yukon within the southern Stewart River map area (Plate 1), although its exact trajectory is still unclear and a matter of continuing debate (Dusel-Bacon *et al.*, this volume; J. Ryan, personal communication, 2004). From there it continues into the southwest Yukon (Figs. 1, 3), where no recent or detailed mapping has been done. The nature of its contacts with the Windy-McKinley terrane and metamorphosed Dezadeash flysch rocks(?) (Gordey and Makepeace, 2000) of the Kluane schist are unknown. Near the Yukon-B.C. border, the YTT is truncated against the Denali fault, a dextral strike-slip fault with an estimated 400 km of Cenozoic displacement (Nokleberg *et al.*, 1985; Lowey, 1998).

Within the Coast Mountains of southeastern Alaska and coastal British Columbia, the YTT has been subdivided into a stratigraphic succession of three units - the Devonian and older Tracy Arm, Devonian Endicott Arm and late Paleozoic Port Houghton assemblages (Gehrels *et al.*, 1992). Rubin and Saleeby (1991) defined two

units within the Taku terrane near Ketchikan, Alaska: the Devonian and older Kah Shakes sequence, and the upper Paleozoic to lower Mesozoic Alava sequence. In the Coast Mountains, YTT is in fault contact with rocks of the exotic Alexander terrane to the west. Many of the faults are west-vergent thrusts related to mid-Cretaceous crustal thickening, but locally the YTT lies above the Alexander terrane on a refolded, low-angle thrust fault onlapped by Upper Jurassic - Lower Cretaceous Gravina belt strata (Saleeby, 2000). This represents the original terrane suture, which has been extensively overprinted by later faulting, folding and metamorphism (Saleeby, 2004).

The inner (eastern) margin of the southwestern prong of YTT against Stikinia is generally defined by high-angle faults, such as those of the Llewellyn system in northern British Columbia (Fig. 3; Mihalynuk, 1999; Mihalynuk *et al.*, 1994a). Evidence of long-standing linkages and commonalities between northwestern Stikinia and YTT (Jackson *et al.*, 1991; Mihalynuk *et al.*, 1994a; Alldrick, 2003) suggests that these faults may be superimposed on original facies boundaries. The configuration of YTT assemblages in the Coast Mountains, a narrow belt that extends 500 km south of the main YTT, could be interpreted as a set of fault slivers, based on its narrow, elongate outcrop pattern (Figs. 1, 3); alternatively, it may simply represent an uptilted western margin of the Stikine terrane.

The inner (western) margin of the southeastern YTT prong is defined partly by thrust faults that juxtapose it with rocks of Quesnellia and possibly Stikinia, and partly by high-angle faults. The Klinkit thrust fault in northern British Columbia (Fig. 3; Gabrielse, 1985) and unnamed faults in southern Yukon (Gordey and Stevens, 1994) separate it from early Mesozoic Quesnellia and Whitehorse trough arc and clastic strata. In Glenlyon area, the Needlerock thrust fault (Plate 1) emplaces a YTT siliciclastic sequence southward on top of Carboniferous volcanic and plutonic rocks of the Boswell block (Colpron *et al.*, 2002, this volume-b; M. Colpron and J.K. Mortensen, unpublished U-Pb data, 2003). All of these faults are cut off by high angle faults of the Teslin system, which juxtaposes the combined YTT, Mesozoic Quesnellia and Boswell block with the exotic, oceanic Cache Creek terrane and Mesozoic Whitehorse trough strata to the southwest (Fig. 3, Plate 1).

As imaged on the crustal transect shown by SNORCLE (Slave-Northern Cordillera Lithospheric Evolution) line 3, the Teslin fault (Figs. 3, 5), dips steeply northeastwards (Cook *et al.*, 2004). As part of its early history, this fault may have been a hinterland feature associated with mid-Jurassic deformation during the closing of the Cache Creek ocean and its emplacement on top of Stikinia (Mihalynuk *et al.*, 2004). At the only known outcrop locality of the Teslin fault, early ductile shear fabrics, consistent with sinistral transpression, are overprinted by fabrics in which shear sense indicators show dextral displacement (de Keijzer *et al.*, 2000).

Dextral Cretaceous-Tertiary offset on the Teslin-Thibert fault system is well constrained by displacement of Jurassic and Cretaceous plutons and other unit boundaries (Gabrielse, 1985; Gabrielse *et al.*, in press). At its maximum in central B.C., total displacement across the fault system is about 300 km, with individual strands such as the Finlay, Kutcho and Cassiar accommodating 40 to 200 km (Fig. 5; Gabrielse, 1985). The Teslin fault projects northerly into the heart of YTT southeast of Dawson (Fig. 3), but north of 63°N in the Stewart River area, it disappears as a mappable feature (J. Ryan, personal communication, 2004). The more northerly-trending strands appear to be horsetails that partition movement. Because they cut across regional strike, displacements on these fault splays are well constrained. In Glenlyon area, various strands such as the Tadru, Big Salmon and Bearfeed faults total approximately 80 km of offset (Plate 1; Colpron *et al.*, 2003). The map pattern of faults like these, and also the Finlay and Cassiar faults (see Gabrielse, 1985), suggest that they partitioned motion northwards off the main Teslin fault, lessening the total motion across it towards the north (Figs. 3, 5). This could explain why offset on the Teslin fault system apparently dwindles to insignificance in the Stewart River area.

Restoration of Cretaceous-Tertiary offsets on the Teslin fault system (Fig. 5) does not greatly modify the outline of the southeastern YTT prong, except to reduce its present attenuation. In Figure 5, pre-Cretaceous restoration of motion on the Tintina and Teslin fault systems places the Finlayson Lake belt adjacent to the YTT in the Dawson area, and reduces the overall strike extent of southeast YTT by about 200 km. Perhaps the most important result is to show that prior to this displacement, the YTT in the Wolf Lake-Jennings River area may have been contiguous with the upper Paleozoic Lay Range assemblage of central Quesnellia, with which it shares key stratigraphic elements (Simard *et al.*, 2003).

## RELEVANCE OF CRETACEOUS PALEOMAGNETIC DATA TO YUKON-TANANA RECONSTRUCTIONS

The prevalence of anomalously shallow paleomagnetic inclinations observed at Cretaceous sites throughout the Canadian Cordillera has raised the possibility of large-scale dextral displacement of terranes, the so-called "Baja BC" hypothesis (*cf.* Irving *et al.*, 1996) - a possibility which should be taken into account in modelling pre-Cretaceous terrane configurations and relationships (Wyld *et al.*, 2004). In the past, discrepancies between coastal and interior sites have been interpreted to require major displacement on intra-Cordilleran faults such as the Coast Shear Zone (Hollister and Andronicos, 1997), which transects the YTT in the Coast Mountains. Recently, however, Enkin *et al.* (in press) have established an anomalously shallow paleomagnetic inclination in the *ca.* 70 Ma Carmacks Group volcanic rocks at Solitary Mountain, located within the eastern YTT 3 km southwest of the Tummel fault (Fig. 3; Plate 1). The Solitary Mountain pole, averaged with other data from the Carmacks Group, requires 1950 ± 600 km of northward translation (Enkin *et al.*, in press). The hornfelsed contact aureole of the *ca.* 105 Ma Glenlyon batholith extends across the Tummel fault, limiting any significant motion between YTT and adjacent North American strata to pre-mid-Cretaceous (Gladwin *et al.*, 2003; Colpron *et al.*, 2005). Enkin (in press), in a thorough and insightful review of the entire northern Cordilleran paleomagnetic data set for the Cretaceous, shows that the entire set of well-constrained, tilt-corrected poles

averages about 2000 km in latitudinal discrepancy from the North American pole. Interestingly, the Solitary Mountain and other Carmacks poles are as anomalously shallow as those from sites located south of the Denali fault in Alaska (Lake Clark and McColl Ridge sites): the paleomagnetic data set is uniformly discordant, and



**Figure 5.** *Restoration of Cretaceous-Eocene motion on faults that transect southeastern YTT; after Gabrielse (1985) and M. Colpron (unpublished data) in the Glenlyon-Quiet Lake area.*

does not reflect offset on any of the known Cretaceous-Tertiary great faults of the Cordillera. Instead, Enkin (in press) proposes that the locus of motion must have been within the Selwyn basin, and possibly even within the southern Rocky Mountains, where some anomalously shallow inclinations have also been determined. The geological framework of this well-studied region fails to support Late Cretaceous displacements of the order of 2000 km: counterevidence includes stratigraphic continuity, continuity of transverse structures and of mid-Cretaceous plutonic suites, and - unlike the western Cordillera - the lack of mapped major transcurrent faults. Thus the conflict between the geologic and paleomagnetic data sets has not abated, but only changed its ground; the Baja BC dilemma has been reframed from an intra-Cordilleran problem, to one focused on the foreland fold and thrust belt. As such, it does not affect the immediate configuration of, or paleogeographic reconstructions within, the YTT, only the latitudinal location of the entire northern Cordilleran orogen in Cretaceous time.

## THE NORTHWESTERN LAURENTIAN 'HOMELAND' OF YTT

The YTT shows a characteristic pericratonic signature throughout, expressed obviously as thick quartzite and grit units (Colpron *et al.*, this volume-a), and more subtly in the common presence of Precambrian cores in igneous zircons. This signature, combined with its allochthonous relationship to the miogeocline, suggests that it was an island continent, rifted from a larger mass. The preponderance of evidence suggests that the rifted continental margin in question was that of North America itself. This idea was first proposed by Tempelman-Kluit (1979), and elaborated and defended by Hansen (1990) and Hansen *et al.* (1991). Relevant arguments can be summarized as follows. Stratigraphic similarities exist in Early Mississippian and older successions. The oldest recognized unit in the YTT, the Snowcap assemblage, contains quartzites, metasiliciclastic schists and metabasites with N-MORB (normal mid-ocean ridge basalt) to OIB (ocean island, intraplate, basalt) signatures (Colpron *et al.*, this volume-a, b). It resembles poorly dated lower Paleozoic successions on the outer margin such as the Snowshoe Group (Ferri and Schiarizza, this volume), pre-Devonian units of the Eagle Bay assemblage (Schiarizza and Preto, 1987; Paradis *et al.*, this volume), the Lardeau Group (Logan and Colpron, this volume), as well as the Upper Proterozoic Windermere Supergroup (Ross, 1991; Sevigny, 1988). Furthermore, the compositions of the mafic rocks in the Snowcap assemblage are identical to those in lower Paleozoic successions of the North American margin (Goodfellow *et al.*, 1995; Logan and Colpron, this volume; Paradis *et al.*, this volume). YTT and the continental margin share a Late Devonian-earliest Mississippian arc to back-arc magmatic event with accompanying crustal extension (Fig. 2; Nelson *et al.,* 2002). Although Devonian-Mississippian magmatic products are not as voluminous on the continent margin as in YTT, examples occur throughout the outer miogeocline, particularily in the Selwyn basin, the Cassiar platform and Kootenay terrane of southern B.C., and in the parautochthonous Yukon-Tanana Upland and Alaska Range of eastern
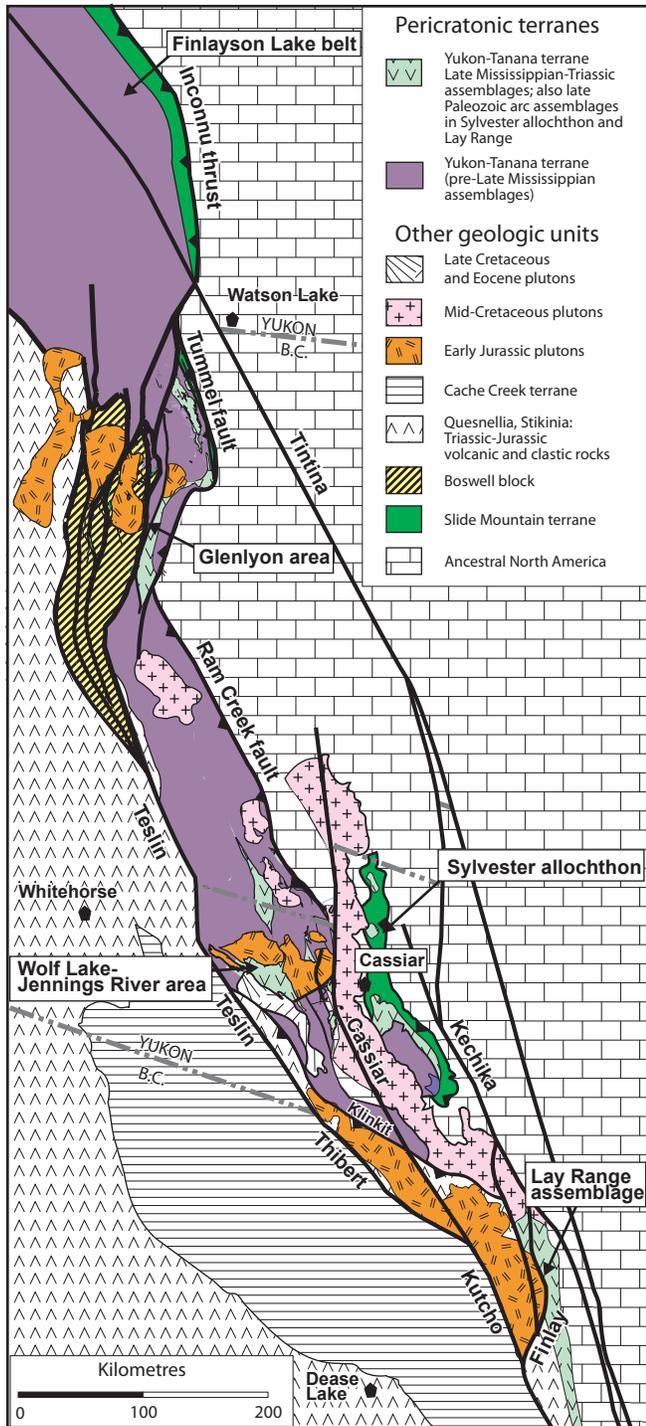
Alaska (Dusel-Bacon *et al.*, 2004, this volume). The age probability plot shows that lesser igneous activity commenced on the North American margin at the same time as in YTT (Fig. 4). Black to dark grey, carbonaceous basinal sedimentary strata form a characteristic and distinctive part of both miogeoclinal (Earn Group, Lardeau Group) and YTT (Nasina, back-arc facies of Finlayson assemblage of Colpron *et al.*, this volume-a) units of this age, as well as in the intervening Early Mississippian sequences in the Slide Mountain terrane; at sites of felsic volcanism they form a sombre backdrop to creamy quartz-sericite schists.

Beginning in Early Mississippian time, the stratigraphic/tectonic record of YTT diverged sharply from that of North America. The cause of such a profound shift is discussed in later sections of this paper.

Arguments for early dissimilarities between YTT and adjacent North America point to the comparative paucity of Devonian igneous activity on the continent margin. Although minor, it is widespread, from rhyolite near the Marg VHMS deposit in northern Selwyn basin to the Exshaw tuff in southern B.C. (Fig. 1); and a suite of plutons that intrude the outer margin, including the Quesnel Lake, Mt. Fowler and other unnamed bodies (see ages in Table DR2 [see footnote 1]). Although most autochthonous igneous rocks are of non-arc, A-type (anorogenic/crustally derived) and alkaline character, arc geochemical signatures are present in the Eagle Bay assemblage of the Kootenay terrane (Paradis *et al.*, this volume). A-type and alkalic igneous suites are found in the YTT in the Finlayson district, where they are interpreted as of back-arc origin (Piercey *et al.*, 2001, 2003, this volume). The recent re-assignment of former YTT rocks in Alaska to the parautochthonous North American margin (Fig. 2) strengthens the argument for early ties, as this area includes many large Late Devonian plutons and extensive tracts of felsic and mafic metavolcanic rocks (Dusel-Bacon *et al.*, 2004, this volume).

Common Devonian-Mississippian tectonics and metallogeny provide another key link between YTT and particularily the northern part of the continent margin. Both experienced extensional tectonics and accompanying syngenetic mineralization throughout that time. The Earn Group in the Selwyn basin, Kechika trough and Cassiar terrane of northern B.C. and Yukon is well known for its Late Devonian-Early Mississippian rift-controlled sedimentation, local coarse conglomerates and growth-fault-bounded sub-basins (Gordey *et al.*, 1987; McClay *et al.*, 1989). SEDEX-type syngenetic sulphide deposits outweigh VHMS deposits in the relatively volcanic-poor miogeocline, whereas VHMS outweigh SEDEX in the volcanic-rich YTT (Fig. 2; Nelson *et al.*, 2002).

The galena lead isotopic signatures of northern miogeoclinal and YTT deposits resemble each other; together they form a data set that is unique worldwide in that it is significantly more radiogenic than Devonian-Mississippian deposits in continental and pericratonic settings elsewhere (Fig. 6; see also Mortensen *et al.*, this volume). Figure 6 shows the overlap between lead isotopic analyses of the Finlayson district, the parautochthonous Alaska Range, and the Eagle Bay assemblage of the Kootenay terrane, all lying within the range of Devonian-Mississippian SEDEX deposits on the western North American continental margin (420-300 Ma range on the "shale
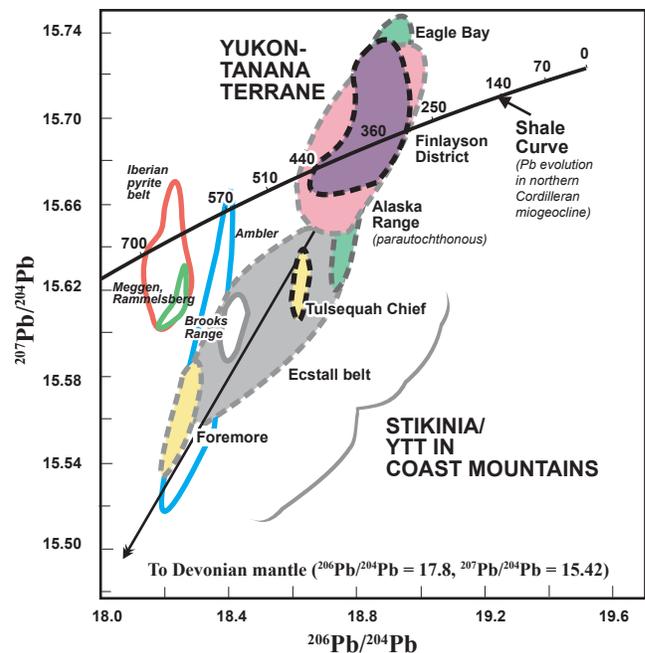


**Figure 6.** *Lead isotopic signatures of Devonian-Mississippian VMS deposits in the Finlayson Lake district of Yukon-Tanana terrane (Mortensen* et al.*, this volume) and in the Ecstall belt (Alldrick* et al.*, 2003; D. Alldrick, unpublished data, 2005), in comparison to para-autochthonous deposits in the Alaska Range (Church* et al.*, 1987) and Kootenay terrane (Mortensen* et al.*, this volume), and those of Stikinia (Tulsequah Chief: Childe, 1997; Foremore: Logan* et al.*, 2000). Also shown for contrast are Devonian-Mississippian syngenetic deposits of the northern Alaska (Ambler VMS district and Red Dog SEDEX camp in Brooks Range: Church* et al.*, 1987) and Europe (Meggan, Rammelsberg: Wedepohl* et al.*, 1978; Iberian pyrite belt: Marcoux, 1998). Shale Curve from Godwin and Sinclair (1982). Devonian mantle value from Doe and Zartman (1979).*

curve" of Godwin and Sinclair, 1982). The VMS deposits of Stikinia and the Ecstall belt fall on a mixing line between Finlayson/miogeoclinal lead at one extreme, and Devonian mantle at the other, which reflects a combination of crustal and primitive inputs. By contrast, Devonian-Mississippian deposits in continental margin and pericratonic settings in Europe and northern Alaska form a trend that intersects the "shale curve" in late Precambrian to Cambrian time; a geological contradiction most readily explained by a markedly less radiogenic character in that crustal reservoir, compared to the northern Cordillera.

Compared to that of the northern continental margin, the Devonian-Mississippian history of southwestern North America shows a far lesser degree of similarity with YTT. The Roberts Mountains allochthon in Nevada does contain Devonian stratiform barite deposits, but they lack accompanying base metals (Torres *et al.*, 2003). There are no known Devonian igneous rocks on the continental margin south of the Kootenay terrane in southern B.C.,

and the tectonics of the margin in Nevada involved passive margin sedimentation followed by a Late Devonian-Early Mississippian compressional event, the Antler orogeny, that resulted in eastward emplacement of the Roberts Mountains allochthon over slope and shelf strata (*e.g.,* Johnson and Pendergast, 1981). Subsequent shortening episodes in Middle Mississippian and Pennsylvanian time are identified in Nevada, based on thrust faults and folds, unconformities and clastic wedges (Trexler *et al.*, 2003, 2004). There is no evidence for the widespread Devonian-Mississippian crustal extension that is ubiquitous both in the YTT and the northern continental margin.

Isotopic signatures also favour a northern Cordilleran origin for YTT. Although available published data remains somewhat restricted at time of writing, detrital zircon suites from the YTT contain populations that most closely resemble those in the northern Cordillera, as opposed to more southerly parts of the continent margin (Mortensen, 1990b; Gehrels and Kapp, 1998, Gehrels *et al.*, 2002; Colpron *et al.,* this volume-b; J. Ryan, personal communication, 2004; J. Nelson and G. Gehrels, unpublished data). As shown in Figure 7, Precambrian zircons in YTT cluster between 1.8-2.1 and 2.6-2.8 Ga, most closely resembling zircon populations from auto-

chthonous Alaska and northern B.C. and least resembling Nevada, northern Mexico and the Appalachian province, where 1.0-1.6 Ga populations are important (Gehrels *et al.*, 1995; Bream and Hatcher, 2002).

In contrast with YTT, detrital zircon studies in Paleozoic pericratonic successions of Oregon, California and Nevada show influences of both northern Cordilleran and southern Cordilleran sources of siliciclastic detritus, which varied not only from region to region, but also between units within a single sequence (Gehrels *et al.*, 2000). The combination of sources is best shown in the early Paleozoic Roberts Mountains allochthon and Shoofly Complex, which provided recycled debris to Devonian and younger successions in the Golconda allochthon, northern Sierras and eastern Klamaths. Their preferred model invokes large-scale, coastwise sediment transport from the Peace River Arch area on the northern continent margin, along with more locally derived sedimentation. Sinistral transport of some tectonic slices along the margin is another possible mechanism (Wallin *et al.*, 2000), however the presence of southerly-derived units in the Roberts Mountains allochthon and Shoofly Complex argues for a generally parautochthonous origin, in proximity to the southwestern margin of North America (Gehrels *et al.*, 2000).
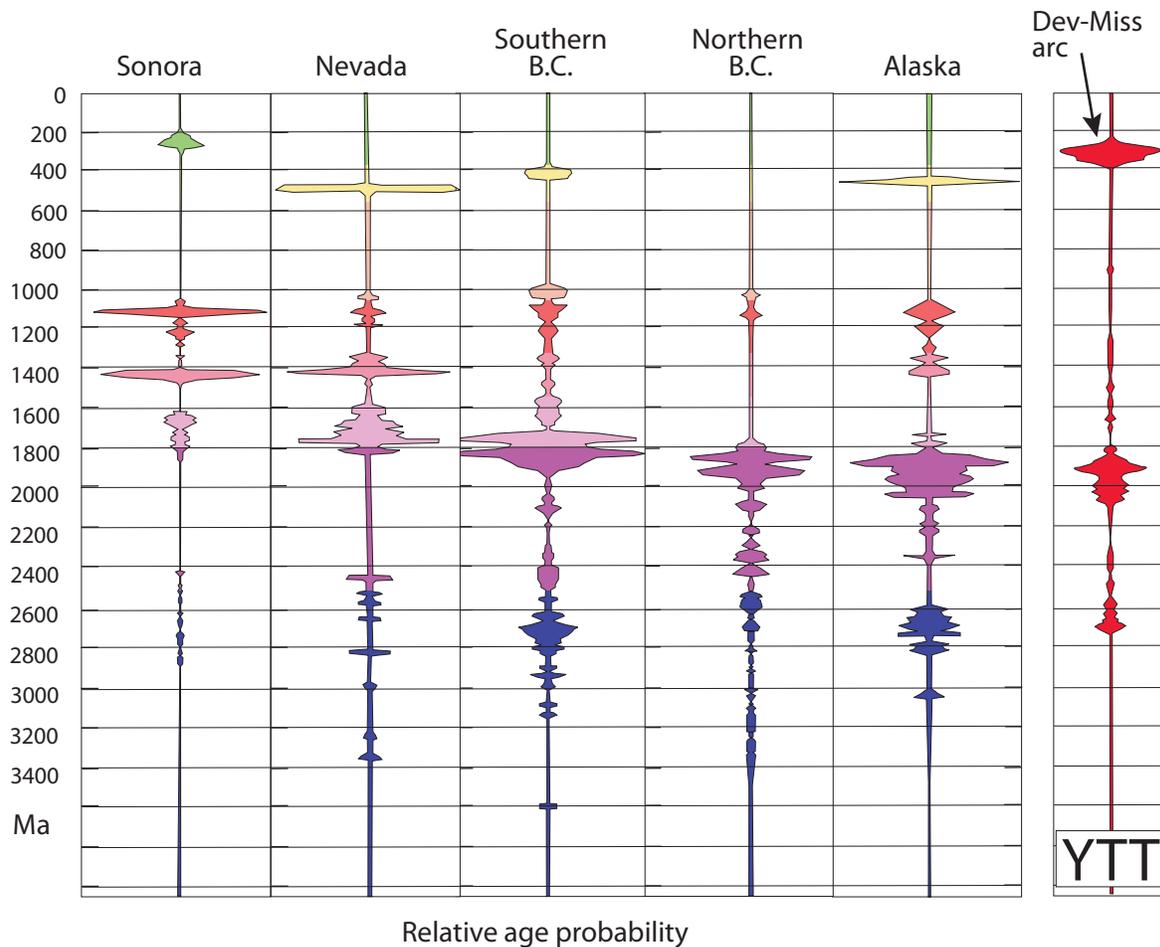


**Figure 7.** *Detrital zircon age spectra for YTT vs. North America. YTT data from Gehrels* et al. *(2002). North American reference data Gehrels* et al. *(1995). Note plots are mirrored for visual impact.*

Nd isotopic values for siliciclastic and felsic rocks in YTT show a range from near zero, to extremely negative signatures in some siliciclastic samples (εNd <-20) that are similar to values from Precambrian-Cambrian siliciclastic strata of the northern Paleozoic miogeocline (Fig. 8). These values are less specific than either detrital zircon populations, or the peculiar galena lead signature of the northern Cordilleran miogeocline, and probably have many world-wide equivalents in sedimentary rocks derived from Archean/Early Proterozoic sources. For instance, in a compilation of the neodymium isotopic signatures of basement crystalline rocks of western U.S., Bennett and DePaolo (1987) show that values of εNd <-20 are wide-spread from California north into southern B.C. Thus, these signatures are compatible with a northern Cordilleran origin, but do not require it.

In summary, YTT shares isotopic characteristics, Devonian and older stratigraphic units, and Devonian-Mississippian igneous and metallogenetic styles with the northern part of the western North American margin. None of these elements are unique to that area, but taken together, they favour an original connection. For that reason, the history of the northern miogeocline is treated as relevant to the early evolution of YTT, and the two are discussed together in the following sections.

## FRAMEWORK FOR THIS SYNTHESIS

The remainder of this paper is an examination of the tectonic and metallogenetic history of the Yukon-Tanana and its affiliated terranes beginning in the Middle Devonian. The discussion progresses through a series of time intervals, corresponding to those used in Colpron *et al.* (this volume-a) and Piercey *et al.* (this volume), which mark major magmatic/tectonic cycles within YTT. Absolute ages for faunal zones are after Okulitch (2002). Discussion of each time slice is accompanied by a summary figure that shows the data relevant to its reconstruction and interpretation. The intervals are:

| | | |
|---|---|---|
| Cycle I | 390-365 Ma | Ecstall cycle |
| Cycle II | 365-357 Ma | Finlayson cycle |
| Cycle III | 357-342 Ma | Wolverine cycle |
| Cycle IV | 342-314 Ma | Little Salmon cycle |
| Cycle V | 314-269 Ma | Klinkit cycle |
| Cycle VI | 269-253 Ma | Klondike cycle |

In the stratigraphic summary of Colpron *et al.* (this volume-a), layered rocks of the eastern YTT are divided into five assemblages, which are defined as regionally occurring units of equivalent age and broadly similar affinities (Plate 1). The Snowcap assemblage is a basement complex that underlies the units associated with the six
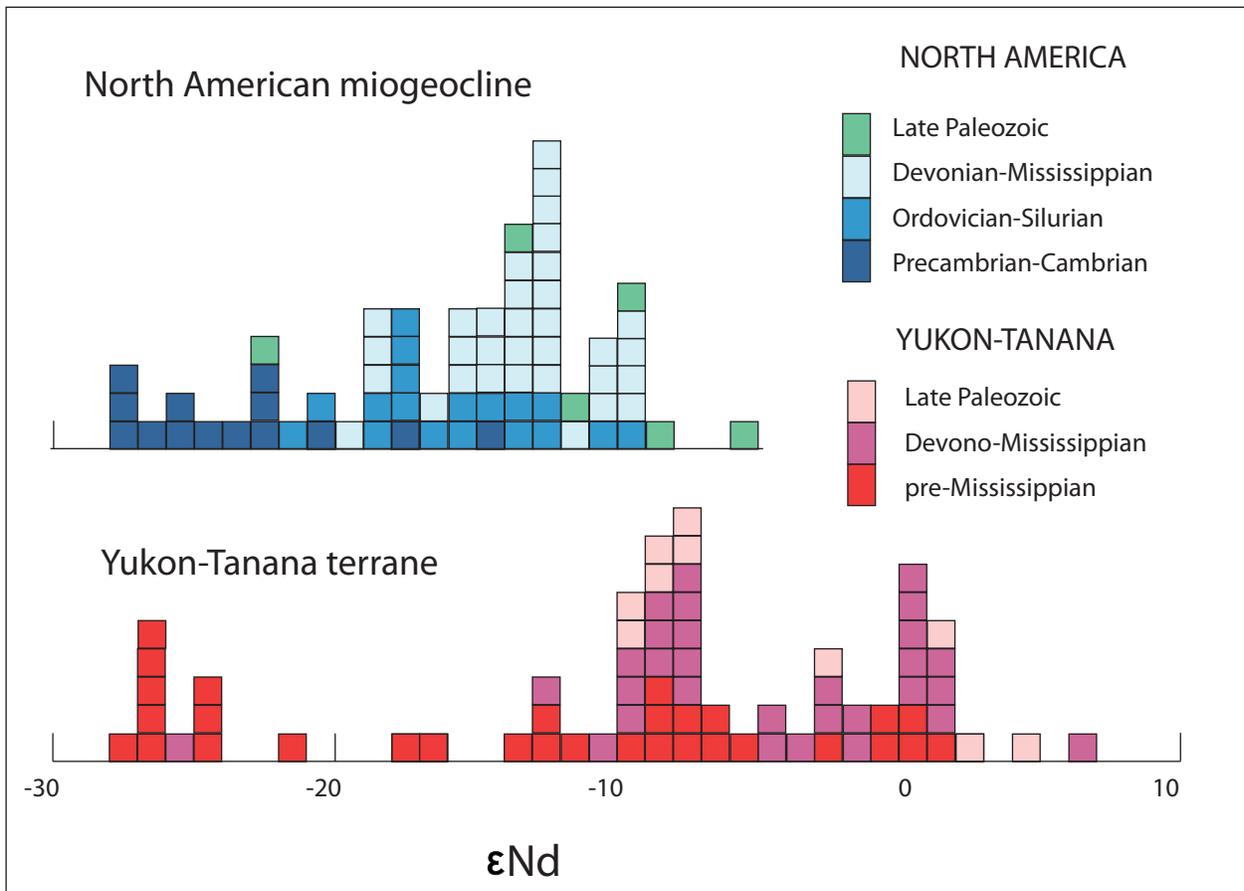


**Figure 8.** *εNd for felsic and clastic rocks in YTT vs. North America. Northern miogeoclinal reference data from Garzione* et al. *(1997). YTT data: Creaser* et al. *(1997); Fallas* et al. *(1998); Piercey* et al. *(2003); Samson* et al. *(1991); Gehrels (1998). Patchett and Gehrels (1998); Creaser and Harms (1998).*

Devonian through Permian magmatic/tectonic cycles. The Finlayson assemblage includes rocks with ages spanning the Finlayson and Wolverine cycles of arc development. The Klinkit assemblage includes rocks with ages spanning the Little Salmon and Klinkit arc cycles. The oceanic Slide Mountain assemblage spans all of the cycles except the first, as its component units reflect the evolution of a marginal ocean contemporaneous with most of the arc history of YTT. Finally, the Klondike assemblage corresponds to the Klondike cycle, the latest phase of YTT arc development.

Note that some other assemblages referred to in this paper are based on historical nomenclature, which has resulted in substitution of the term for more standard forms of stratigraphic nomenclature such as groups, supergroups and complexes. Examples include the Lay Range, Eagle Bay, Fortymile River, Tracy Arm, Endicott Arm and Port Houghton assemblages. For further discussion of this issue see Colpron *et al.* (this volume-a).

# MIDDLE TO LATE PALEOZOIC EVOLUTION OF YUKON-TANANA TERRANE

## Pre-Cycle I - The Absence of True Cratonic Basement in the Yukon-Tanana Terrane

The oldest recognized unit in the YTT is the Snowcap complex in the Glenyon area and its correlatives (Colpron *et al.*, this volume-b), including the lower Dorsey Complex in the Wolf Lake-Jennings River area on the B.C.-Yukon border (Roots *et al.*, this volume), and the North River formation in the Finlayson district (Murphy *et al.*, this volume). Similar units in the Coast Mountains include the areally extensive Tracy Arm assemblage (Gehrels and Kapp, 1998; Gehrels, 2000), and the more restricted Whitewater (Mihalynuk *et al.*, 1994a) and Florence Range suites (Currie and Parrish, 1993; Mihalynuk, 1999). These sequences are intruded by Devonian and Mississippian plutons; the Snowcap and lower Dorsey complexes are overlain by well-dated Early Mississippian volcanic units (Colpron *et al.*, this volume-b; Roots *et al.*, this volume), which provide a minimum age. In comparison to Devonian-Mississippian arc-related successions, these 'basement' units consist predominantly of quartzites, meta-siliciclastic and calc-silicate schists, marble, and locally voluminous intercalated metabasites with N-MORB to OIB signatures (Nelson and Friedman, 2004). Although no maximum age constraints are available, the Snowcap assemblage most strongly resembles autochthonous units of late Precambrian to early Paleozoic age and the parautochthonous Lake George assemblage of east-central Alaska (Dusel-Bacon *et al.*, 2004, this volume). Despite the variations in present exposure levels throughout YTT, and although the body of robust geochronological data is now extensive, no crystalline, cratonic basement units have yet been identified within it. It thus appears to be an extensive pericratonic terrane without exposed cratonal (Archean-Early Proterozoic) basement. Cook *et al.* (2004) interpreted reflection profiles of the northern Cordillera to indicate that crystalline continental basement tapers to a zero edge around the eastern edge of the Selwyn basin, and that the westward-tapering continental

wedge that extends more than 300 km west of that point beneath the accreted terranes consists mainly of Mesoproterozoic layered strata. Cook and van der Velden (1993) attributed this architecture to crustal attenuation during deposition of the Mackenzie and Wernecke supergroups. If YTT originated near the outboard margin of this wedge, then it would have been founded, not on cratonal basement, but on fairly thin, Mesoproterozoic and younger rift-related strata. On the other hand, Evenchick *et al.* (2005) offer arguments that a wedge composed predominantly of crystalline basement is more geologically likely, as well as equally compatible with the reflection profile.

One possible scenario is that YTT originated as one or more slivers of continental margin strata deposited beyond the cratonal edge. If it did originate on thinned continental crust, then it must have detached from most of its basement during Mesozoic accretion. Another possible explanation for the lack of observed crystalline basement could be that YTT formed the upper plate of a Devonian-Mississippian 'Wernecke-style' asymmetric rift. At present we have no means to evaluate these alternative models.

## Cycle I - 390-365 Ma - (Middle-Late Devonian; Eifelian-Famennian) - Ecstall Cycle

### *Definition and Regional Data*

This cycle records the initiation of igneous activity and related syngenetic exhalative, sedimentary and volcanic-hosted mineralization on the northern continent margin and parautochthon of Alaska, and within the offshore arcs. Its commencement is defined by U-Pb ages of arc-related volcanic and intrusive rocks from the Ecstall belt of YTT in the Coast Mountains of central-western British Columbia, which range from 377-393 Ma (Fig. 2; Alldrick *et al.*, 2001). These are among the oldest known igneous ages in the terrane, except for a few Silurian dates from the Taku terrane on Revillagigedo Island in far southeastern Alaska (Saleeby, 2000).

Farther north in the Coast Mountains, the Endicott Arm assemblage, the middle unit of the YTT overlying the Tracy Arm assemblage, contains Cycle I felsic metavolcanic rocks with ages between 366 and 384 Ma (Fig. 9; Gehrels *et al.*, 1992; McClelland *et al.*, 1991). Deformed plutons that intrude the Tracy Arm assemblage have been dated at 374 and 380 Ma (Gehrels, 2001). The Boundary Ranges metamorphic suite in the western prong of YTT near the B.C.-Yukon border contains a *ca.* 366 Ma metaplutonic body (Currie, 1994). Concordant detrital zircon grains in one sample from a Permian sandstone of the Taku terrane in the Coast Mountains near Juneau, Alaska, show a range of ages from 369-387 Ma, with a mean of about 375 Ma (Gehrels, 2002). They reflect a local basement in which igneous activity peaked during Cycle I, probably the nearby Endicott Arm assemblage. A coeval volcanic sequence, including a *ca.* 380 Ma felsic tuff, occurs near the Iskut River in western Stikinia (Fig. 9). It is intruded by the *ca.* 370 Ma Forrest Kerr pluton (Brown *et al.*, 1996; Logan *et al.*, 2000).

VHMS mineralization accompanied intermediate to felsic volcanism in the Ecstall belt; the most significant prospects there are the Ecstall, Scotia and Packsack occurrences (Alldrick, 2001).

Alldrick *et al.* (2003) show that the Pb-isotopic signatures of these deposits exhibit a continuum between the radiogenic Pb signature of YTT and the more primitive signature of Stikinia (Fig. 6). Insufficient trace element igneous petrochemical data are presently available from the Ecstall belt to adequately characterize it or to compare it with later cycles.

On the North American margin, an important shift in depositional style occurred in the Frasnian, with the beginning of deposition of the Earn Group, which unconformably to paraconformably overlies fine-grained basinal strata in the Selwyn basin and Kechika trough (Fig. 2), and platformal carbonates elsewhere. It is a heterogeneous succession of chert and clastic rocks, comprising chert, argillites/porcellanite through chert-quartz sandstone to local coarse conglomerate; its origin has been attributed to rifting of the northern part of the margin with the creation of horsts and grabens (Gordey *et al.*, 1987). The oldest SEDEX deposits in the Earn Group, at Macmillan Pass on the Yukon/Northwest Territories border (Figs. 2, 9), are of Frasnian age (376-383 Ma; Irwin and Orchard, 1989). They are interpreted to be a metallogenetic expression of the regional rifting event.

On the autochthonous margin, except for parautochthonous Alaska, Cycle I meta-igneous rocks are sparse. Felsic magmatic activity began in the Selwyn basin between 373 and 381 Ma (Table DR2; Figs. 2, 9). The Marg VHMS deposit is intercalated with early Late Devonian rhyolite (J.K. Mortensen, personal communication, 2004). The age of the alkalic Ice River Complex in southeastern British Columbia (Fig. 2) has been estimated at about 368 Ma by Parrish *et al.* (1987). The oldest igneous ages in the parautochthonous Yukon-Tanana upland and Alaska Range are around 373 Ma (Dusel-Bacon *et al.,* 2004, this volume; Dashevsky *et al.,* 2003). In the Alaska Range, these include the Totatlanika Schist and Keevy Peak Formation in the Bonnifield district (Wahrhaftig, 1968) and the Jarvis belt in the Delta mineral belt (Dashevsky *et al.*, 2003), both of which contain VHMS deposits of this age. VHMS mineralization in the Delta mineral belt, and possibly also the Bonnifield district, continued into Cycle II. The Chena slate belt in the Yukon-Tanana upland is a predominantly basinal metasedimentary succession that hosts stratiform Zn-Pb-Ag SEDEX occurrences; a metarhyolite associated with one of these returned a U-Pb date of 372 ± 5 Ma (Dusel-Bacon *et al.*, 2004). The Lake George assemblage, which occupies a structurally low position in the upland, is host to a number of large, peraluminous augen gneiss bodies with U-Pb ages between 373 and 347 Ma. This age spread is even reflected in individual bodies, which typically display broad ranges of U-Pb ages (Dusel-Bacon *et al.*, this volume).

On the North American margin, there is evidence for a pre-Mississippian compressional event in the Kootenay terrane and Purcell arch in southern British Columbia (Klepacki and Wheeler, 1985; Root, 2001). Within YTT, the only clear evidence for Devonian ductile deformation is in the Dorsey Complex (formerly Rapid River tectonite) in the Sylvester allochthon, where a *ca.* 362 Ma pluton is late synkinematic to isoclinal folding and shearing (Gabrielse *et al.*, 1993). It is not known whether this deformation was extensional or

compressional in nature. Devonian ductile deformation could have been more widespread along the outer margin of the terrane, in regions strongly affected by later tectonic events that have thoroughly obscured the evidence for it.
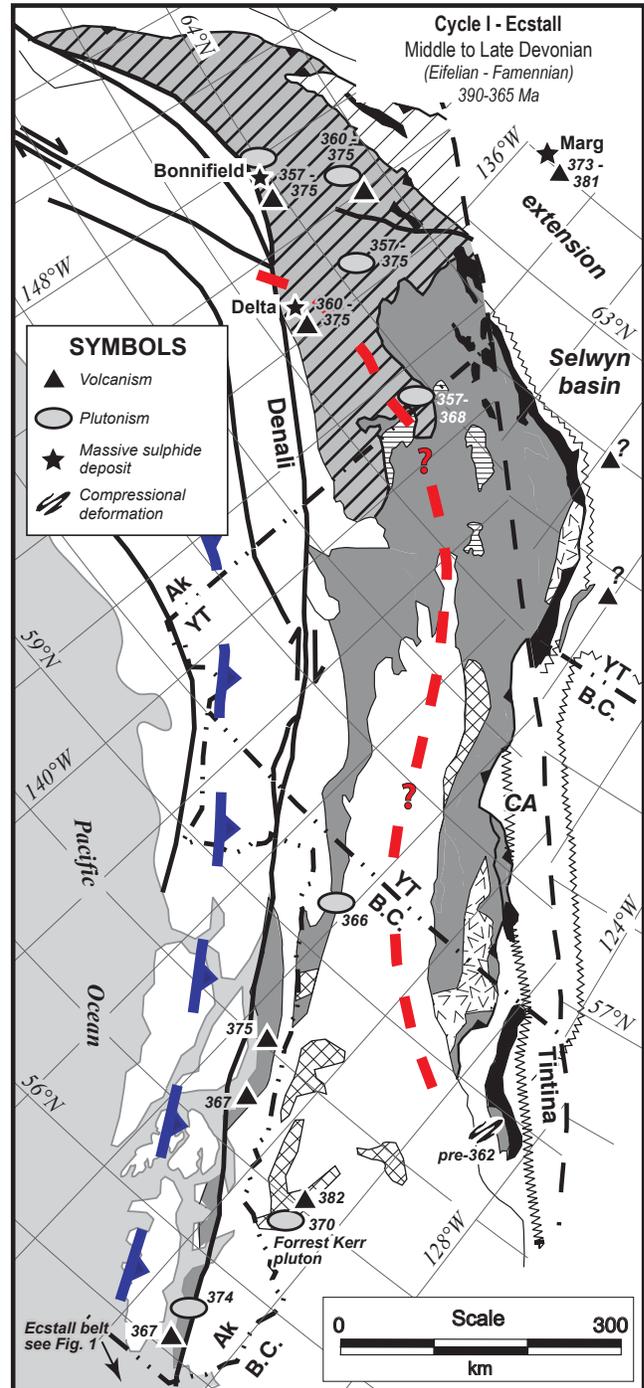


**Figure 9.** *Cycle I (Ecstall cycle) igneous patterns and metallogeny. Blue toothed line shows interpreted, approximate location and facing direction of subduction zone; red line is interpreted, approximate arc/back-arc boundary.*

## Interpretation and Synthesis

Cycle I in YTT and its then-contiguous regions is part of a much broader onset of subduction and arc development on mixed continental and primitive crust along the entire western North American margin (Rubin *et al.*, 1990). Within YTT and related terranes, arc activity commenced in an area including the Ecstall belt, the Tracy Arm and Endicott Arm assemblages, and adjacent Stikinia (Figs. 2, 9). Deformation in the Dorsey Complex may have resulted from transient compression and/or extension associated with the beginning of subduction. By the beginning of Late Devonian time, outward arc migration was generating extension in the continental back-arc region, as shown by tectonics, sedimentation and SEDEX mineralization in the Selwyn basin; and by mixed felsic and mafic igneous suites in its extension southwest of the Tintina fault in the Yukon-Tanana upland and Alaska Range.

## Cycle II - 365-357 Ma - Late Devonian-Earliest Mississippian (Famennian-Early Tournaisian ) - Finlayson Cycle

### Definition and Regional Data

Cycle II is characterized by the blossoming of widespread, voluminous igneous activity and accompanying VHMS mineralization throughout YTT, as attested to by the steeply ascending frequency curves in Figure 4 and the broadly distributed igneous units on Figure 10, as opposed to much more limited Cycle I data on Figure 9. Its temporal limits are defined by the age range of the Grass Lakes group in the Finlayson Lake belt, which hosts three notable VHMS deposits of this age: Kudz Ze Kayah, GP4F and Fyre Lake (Murphy *et al.*, this volume). Prominent siliciclastic, pre-Upper Devonian basement strata and common Precambrian inheritance in igneous zircons attest to a pericratonic setting. The Grass Lakes plutonic suite in the Finlayson Lake belt comprises a number of large, foliated granitic bodies that physically resemble the parautochthonous Fiftymile batholith in western Yukon (Plate 1; Fig. 10). Petrochemically, most of the mafic meta-igneous rocks are of continent-margin arc to back-arc affinity, including MORB and BABB (back-arc basin) metabasalts in the Fire Lake formation (Piercey *et al.*, 2004, this volume). Anomalous OIB and A-type components in the Finlayson Lake area are closely associated with mineralization (Piercey *et al.*, 2002, this volume). This is attributed to local intra-arc and back-arc extension, which simultaneously created pathways for the influx of enriched lithospheric mantle, and gave rise to hydrothermal systems along seafloor rift zones (Piercey *et al.,* 2001, 2002, 2004, this volume). Although not yet robustly documented, a transition from back-arc to arc facies occurs in the southern part of the Big Campbell thrust sheet below the Money Creek thrust; and the Waters Creek formation in the hanging wall of the Money Creek thrust is thought to represent an arc-proximal igneous environment (Murphy *et al.*, this volume).

Minor rhyolitic metatuffs within the mostly black phyllitic Nasina assemblage in western Yukon are dated as 358-360 Ma by U-Pb methods on zircon (Brietsprecher *et al.*, 2002; Dusel-Bacon *et al.*, this volume). This unit may represent a back-arc facies that contains an insignificant igneous component, compared to the Finlayson Lake belt.

Within Stikinia, a diverse suite of Mississippian arc volcanic and lesser sedimentary rocks is partly of Cycle II age. Recent dis-
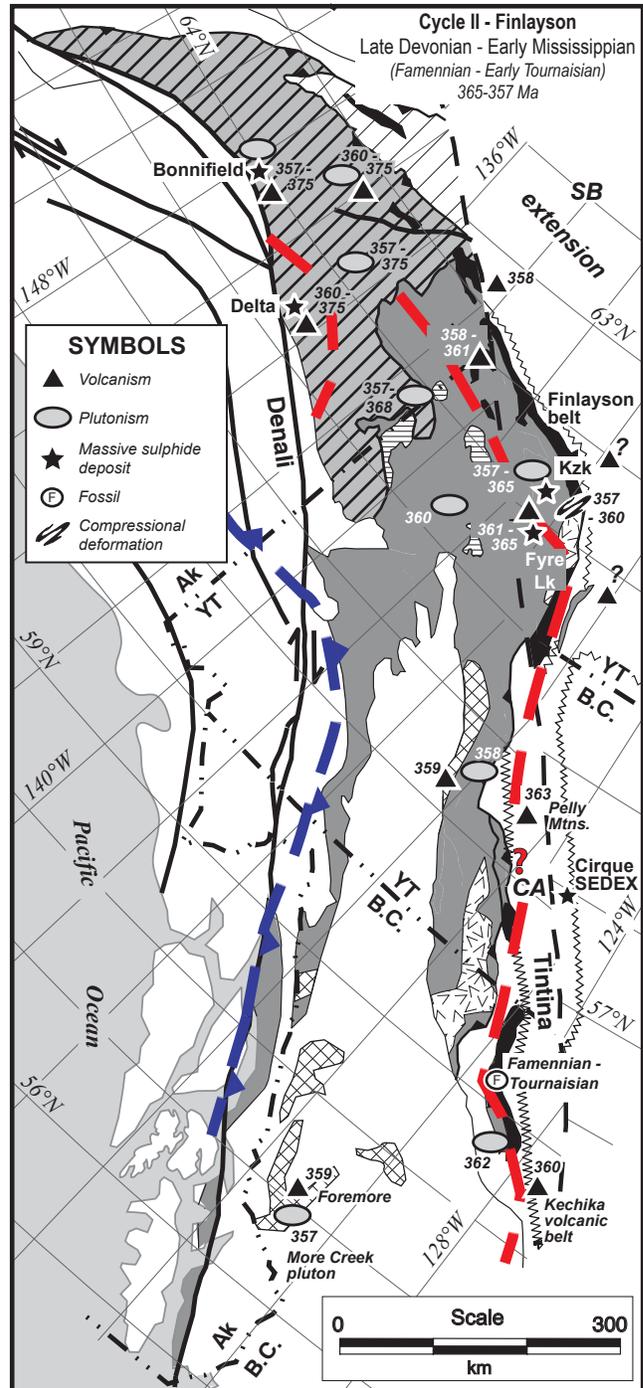


**Figure 10.** *Cycle II (Finlayson cycle) igneous patterns and metallogeny. Blue toothed line shows interpreted, approximate location and facing direction of subduction zone; red lines are interpreted, approximate arc/back-arc boundaries in YTT and in parautochthonous Alaska*

coveries of in-situ, precious-metal-enriched massive sulphides at the Foremore VHMS deposit have renewed interest in the syngenetic potential of the Stikine assemblage (Logan, 2004). A rhyolite body that forms the footwall to mineralization at the SG zone has a preliminary U-Pb age of *ca.* 359 Ma (J.M. Logan, personal communication, 2004). The mineralized sequence is intruded by the slightly younger, *ca.* 357 Ma More Creek pluton (Logan *et al.*, 2000). It probably lies unconformably on Devonian (Cycle I) rocks. Trace element abundances of mafic and felsic rocks show a general calc-alkalic affinity (Logan, 2004). The relatively primitive character of arc magmatism in this region is shown by the unradiogenic galena lead signature at Foremore (Fig. 6) and lack of interbedded quartzose siliciclastic strata (Logan *et al.*, 2000), and low initial $^{87}Sr/^{86}Sr$ values of 0.7039-0.7043 and lack of Precambrian zircon inheritance in the Forrest Kerr and More Creek plutons (Logan, 2004). In contrast to YTT proper and even to the transitional Ecstall belt, this part of the magmatic belt developed at some distance from continental influences. It represents an arc-front environment, perhaps analogous to the intra-oceanic Kermadec arc, which rapidly loses evidence of continental input along its trend northwards from pericratonic New Zealand (Gamble *et al.*, 1996).

Unit ages in the Coast Mountains are not as well constrained as elsewhere in YTT; however, there is evidence for Cycle II magmatism there as well. The most concordant Devonian-Mississippian detrital grains in a sample from the late Paleozoic Port Houghton assemblage near Juneau, Alaska, are in the range 354-359 Ma (Gehrels and Kapp, 1998); and Paleozoic grains in a Triassic sandstone from the adjacent Taku terrane form a prominent cluster around 356 Ma, indicating a local igneous event near the end of Cycle II (Gehrels, 2002). These grains were presumably derived from the underlying Endicott Arm assemblage, from which the few available metavolcanic and metaplutonic ages are in the same range (Gehrels and Kapp, 1998). On this basis, we infer that significant igneous activity took place in the YTT in the Coast Mountains during the Finlayson cycle (Cycle II).

On the North American margin, syngenetic exhalative mineralization, both volcanic- and sedimentary hosted, peaked during Cycle II (Figs. 4, 10). Famennian SEDEX deposits, such as Cirque, occur in a rifted continental margin setting in the Kechika trough (Paradis *et al.*, 1998). U-Pb igneous ages show a peak at 362-357 Ma, after which they rapidly decline in frequency (Fig. 4). Parautochthonous, Late Devonian to earliest Mississippian volcanic suites and accompanying VHMS deposits are well-developed in the Alaska Range (Dusel-Bacon *et al.,* 2004, this volume), including the Bonnifield (Mystic Creek member, Totatlanika Schist and Keevy Peak Formation; Gilbert and Bundtzen, 1979; Newberry *et al.*, 1997) and Delta mineral belts (Drum unit, Jarvis belt; Dashevsky *et al.,* 2003) and Kantishna Hills (Bundtzen, 1981); and in the Eagle Bay assemblage of the Kootenay terrane in southern B.C. (Paradis *et al.*, this volume). Minor occurrences of volcanic-hosted mineralization have also been identified in the Yukon-Tanana Upland (Dusel-Bacon *et al.*, this volume). With the exception of one VHMS prospect in the Drum unit, the uncertainties on the U-Pb zircon dates for all of the other metavolcanic host rocks in Alaska result in ages (~375-

~357 Ma) that span the 365 Ma boundary between Cycles I and II; therefore it is not possible to differentiate separate episodes.

More restricted alkalic volcanism with associated VHMS deposits occurred in the Pelly Mountains and the Kechika volcanic belt, both in the Cassiar terrane west of the Tintina fault (Hunt, 1997; Nelson *et al.*, 2002; Fig. 1). Felsic tuffs, dated at *ca.* 363 Ma by U-Pb method on zircons, are interbedded with latest Devonian basinal strata of the Exshaw Formation in the southern Rocky Mountains (Richards *et al.*, 2002).

Parautochthonous igneous rocks with true arc geochemical signatures are only found in the Delta mineral belt in the Alaska Range and the Eagle Bay assemblage of southern B.C. (Dashevsky *et al.,* 2003; Paradis *et al.,* this volume). In the Bonnifield district and Yukon-Tanana Upland, peralkaline rhyolites show A-type, intraplate signatures, and are associated with alkalic mafic rocks, consistent with remelting of extended continental crust rather than slab-derived, subduction-related magmas (Dusel-Bacon *et al.*, 2003, this volume). Many U-Pb ages of 'augen orthogneiss' (foliated granite) bodies span the Cycle I-Cycle II boundary, indicating that felsic plutonism continued as well (Dusel-Bacon *et al.*, this volume).

In the Slide Mountain terrane, the oldest age of a basalt-bearing, basinal sequence is late Fammenian, based on a single conodont collection from a unit (IIMvs) that otherwise is productive of numerous Early Mississippian faunas (Nelson and Bradford, 1993, p. 13). In this unit, basalt of MORB affinity and fine grained, aquagene, basaltic tuff are interbedded with black argillite, chert and continentally-derived chert-quartz sandstone.

## *Interpretation and Synthesis*

During Cycle II, volcanism and plutonism increased dramatically throughout YTT, accompanied by lesser igneous activity and rifting of the more distal back-arc throughout a broad region of the North American margin (Figs. 1, 10). Igneous suites of this age both in YTT and on the North American margin are typically bimodal, with non-arc mafic components and felsic components of largely crustal derivation. Rocks of arc affinity in the hanging wall of the Money Creek thrust fault in the Finlayson Lake belt, in Stikinia, and in the parautochthonous Delta mineral belt and Eagle Bay assemblage present a fragmentary record of the Late Devonian-earliest Mississippian arc-axial region. The Finlayson Lake belt in the footwall of the Money Creek thrust, along with most autochthonous felsic and alkalic igneous suites, display distal, back-arc magmatic activity. The Earn Group, which ranges from Late Devonian (Frasnian) into Early Mississippian age, represents rift-related sedimentation. Together, YTT, the parautochthonous terrane in Alaska, and the margin of North America reconstruct as a very broad, west-facing continent-margin arc and back-arc region, all of which was undergoing crustal extension. As such, it provided a fertile environment for seafloor rift-related hydrothermal activity (VHMS and SEDEX), as is shown by the extensive suite of syngenetic sulphide deposits, both in the North American margin and in YTT (Fig. 1).

As the oldest known oceanic basalt-bearing strata in the Slide Mountain terrane range as old as late Famennian, there was probably not yet an intervening marginal ocean of any significant width be-

tween the YTT and North American margin. Instead, extension was distributed throughout a wide zone along the continent margin. In the Yukon-Tanana upland, the parautochthonous belt including Late Devonian igneous rocks is about 200 km wide, comparable to the Selwyn basin, which restores along strike to the southeast (Fig. 3). These present widths include not only the effects of Devonian-Mississippian tectonism, but Jura-Cretaceous shortening and Cretaceous extension in the upland as well. However, they indicate that the zone of Late Devonian continental back-arc extension was of the order of hundreds of kilometres wide. In this region, non-arc mafic igneous suites show enriched mantle sources, which Piercey *et al.* (this volume) attribute to remobilization and melting of a sub-continental, plume-enriched lithosphere. At the same time, the up-welling and ponding of MORB-type asthenosphere gave rise both to the extensive felsic crustal melts and to widespread thermal softening, which led to crustal thinning, attenuation, and ultimately the separation of YTT from the margin.

Between YTT in the Coast Mountains and Stikinia, there is a profound decrease in continental character from west to east. This is expressed as the long-known southwestern "prong" of the 0.706 $^{87}Sr/^{86}Sr$ line (Armstrong, 1988), by the radiogenic Pb isotopic signatures of galenas in Ecstall belt VHMS deposits compared to the primitive signature of the Foremore deposit (Alldrick *et al.*, 2003; Logan *et al.*, 2000), and by the contrast between Devonian and older siliciclastic-bearing sections in the Ecstall belt and Coast Mountains compared to the absence of such material in the Stikine assemblage. Precambrian detrital zircons and xenocrystic cores are also restricted to the Coast Mountains and westernmost Stikinia. This eastward diminution of continental influence on Late Devonian arc sequences can be interpreted as defining an eastward-facing Stikine arc, opposite to that suggested for central and southeastern YTT; in present coordinates related to subduction away from, rather than toward, the margin of North America.

## Cycle III- 357-342 Ma - (Early Mississippian; Tournaisian) - Wolverine Cycle

### Definition and Regional Data

The beginning of Cycle III is placed at the short interval of deformation and erosion that separated the end of Grass Lakes volcanism (*ca.* 357 Ma) in the Finlayson Lake belt from deposition of the overlying Wolverine Lake group (*ca.* 357-342 Ma; Murphy *et al.*, this volume). It represents a break in deposition and possibly a change in arc configuration, but not a lessening of intense igneous activity (Fig. 4). The 357-342 Ma Wolverine Lake group (Fig. 11) comprises mainly felsic volcanic tuffs, flows and sills intercalated with black carbonaceous phyllite (Murphy *et al.*, this volume). It hosts the precious metal-rich Wolverine VHMS deposit (Plate 1). As at Kudz Ze Kayah, rhyolites associated with the Wolverine deposit are of A-type, rifted back-arc affinity (Piercey *et al.*, 2001, 2003, this volume). The Early Permian Money Creek thrust juxtaposes the Wolverine and the underlying Grass Lakes back-arc sequence with a hanging wall that contains Cycle II, probably arc-related volcanic strata of the Waters Creek formation, intruded by 358-343 Ma hornblende-bearing

plutons of the Simpson Range suite (Murphy, 2004; Murphy *et al.*, this volume). Therefore it juxtaposes co-spatial Cycle II and III arc and back-arc tectonic facies.
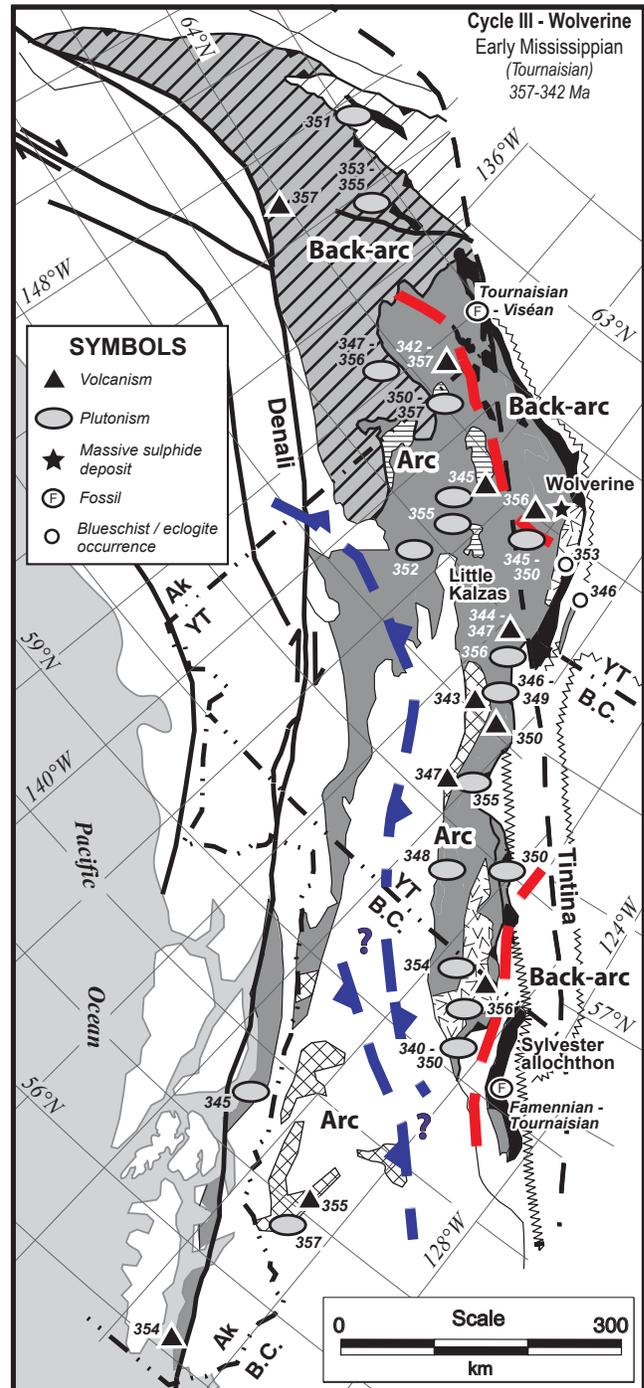


**Figure 11.** *Cycle III (Wolverine cycle) igneous patterns and metallogeny; and locations of high P/T metamorphic assemblages. Blue toothed lines show interpreted, approximate locations and facing directions of subduction zones; red line is interpreted, approximate arc/back-arc boundary.*

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In Glenlyon area, late in this cycle (346-344 Ma), the intermediate to basaltic Little Kalzas formation was deposited above a prominent unconformity, accompanied by intrusion of the 349-343 Ma Little Kalzas plutonic suite (Colpron *et al.*, this volume-b). Petrochemical signatures from the Little Kalzas suite include both arc and E-MORB, and are interpreted to reflect arc rifting (Colpron *et al.*, this volume-b). To the southeast in Teslin map area, a suite of tonalite to quartz diorite plutons range in age from 351 to 341 Ma; their moderately negative εNd signatures reflect crustal contamination of subduction zone magmas (Stevens *et al.*, 1996). In southeasternmost YTT, Cycle III arc activity is evidenced by *ca.* 355 Ma felsic tuff in the upper Dorsey Complex (Roots and Heaman, 2001) and 356-350 Ma gabbro to tonalite plutons (Nelson and Friedman, 2004, Mihalynuk *et al.*, this volume).

In the Dawson area, the Cycle III igneous suite comprises foliated 351-348 Ma augen granites, including the Moose Creek, West Dawson, Reindeer Creek, Selwyn and Mt. Burnham bodies that intrude the Nasina assemblage (J.K. Mortensen, unpublished data, *in* Breitsprecher *et al.*, 2002; Dusel-Bacon *et al.*, this volume; J. Ryan, unpublished data). The granites, lithologically comparable to the Grass Lakes suite and orthogneisses the Lake George assemblage, represent a continuation of Cycle II felsic intrusive activity.

The Fortymile River assemblage in eastern Alaska and western Yukon contains an extensive suite of sill-like metaplutonic bodies, with a compositional range including trondjemite, tonalite, granodiorite and granite, that intruded older metamorphosed siliciclastic strata and amphibolites (Werdon *et al.*, 2001; Szumigala *et al.*, 2002). Reported U-Pb zircon ages from these bodies range from *ca.* 355 to *ca.* 341 Ma in eastern Alaska, with the exception of one *ca.* 360 Ma U-Pb date from a rare occurrence of augen orthogneiss within the generally intermediate composition plutonic suite (Szumigala *et al.*, 2002; Dusel-Bacon *et al.*, this volume, and references therein); and *ca.* 346 Ma in western Yukon (J. Ryan, unpublished data). They are equivalent in age, and similar in degree of compositional heterogeneity, to the Simpson Range plutonic suite in the Finlayson Lake belt. Metamorphosed arc basalt, basaltic andesite and andesite occur within the assemblage (Dusel-Bacon and Cooper, 1999; Szumigala *et al.*, 2002; Dusel-Bacon *et al.*, this volume). Felsic rocks in both the Fortymile River and Nasina assemblages resemble crustal melts (Dusel-Bacon *et al.*, this volume; Piercey *et al.*, this volume). In the northern Dawson sheet, mafic schist in the Nasina assemblage has arc petrochemistry identical to that of mafic rocks in the Fortymile River assemblage (Dusel-Bacon *et al.*, this volume). In addition, field observations in the vicinity of the Fortymile River, near the Alaska-Yukon border, show a gradational contact between the Fortymile River and the Nasina assemblages, indicating an original proximity of the two assemblages in an arc setting adjacent to a back-arc basin (Dusel-Bacon *et al.*, this volume).

In other areas, however, the Fortymile River assemblage has been interpreted as a klippe that rests above the Nasina assemblage (Hansen and Dusel-Bacon, 1992; Dusel-Bacon and Cooper, 1999). Foster (1992) and Szumigala *et al.* (2002) depicted its base in the southeastern corner of the Eagle A-1 quadrangle as a thrust fault. Immediately below it are slivers of serpentinite and gabbro, which

in turn overlie Nasina assemblage and Permian Klondike Schist. This fault is analogous to the Money Creek thrust fault. It juxtaposes two very distinct geotectonic elements. In its hanging wall, the Fortymile River assemblage is a Cycle II arc, correlative with the Little Kalzas and Simpson Range suites, which is developed on older pericratonic basement, correlative with the Snowcap complex. In its footwall is a Cycle II-III back-arc basin, similar to the Grass Lakes and Wolverine Lake groups in the Finlayson Lake belt.

Early Mississippian retrogressed eclogites with coincident *ca.* 353 Ma U-Pb peak metamorphic ages and $^{40}Ar/^{39}Ar$ plateau ages occur within the Klatsa metamorphic complex in the southeastern Finlayson Lake belt (Devine *et al.*, this volume). They interpret the coeval U-Pb and Ar-Ar dates to signify very rapid exhumation of the complex. Correlative, apparently less-retrogressed eclogite occurs in the Stewart Lake klippe in southern Yukon near Watson Lake (Fig. 11). Mafic protoliths show arc-like as well as N-MORB petrochemistry (Creaser *et al.*, 1999; Devine *et al.*, this volume); they are interlayered with serpentinite, leucogabbro and metasiliciclastic rocks with Precambrian detrital signatures, all enclosed in a phyllitic mélange matrix. The Simpson Range eclogites, although they are exposed near the eastern margin of YTT, occur within the hanging wall of the Cleaver Lake thrust, the highest panel in the Finlayson Lake belt. The Cleaver Lake thrust sheet lies structurally above Cycle III arc strata of the Money Creek thrust sheet (Devine *et al.*, 2004, this volume). It is interpreted to represent a most westerly Early Mississippian fore-arc tectonic facies, that was juxtaposed with coeval, west-facing arc and back-arc facies by nearly layer-parallel, east-vergent Permian thrust faults (Devine *et al.*, 2004, this volume; Murphy, 2004; Murphy *et al.*, this volume). Subsequent open folding of the thrust stack resulted in a complex outcrop pattern of different structural levels throughout the Finlayson Lake belt, including the exposure of the most westerly, outboard Cleaver Lake thrust sheet near the eastern margin of YTT (Devine *et al.*, this volume, Figures 1, 15). The Stewart Lake locality is in an area of poor exposure that has not been mapped in detail. Eastward projection of gently-dipping imbricate structures from the Simpson Range suggests that the Stewart Lake klippe also may lie in the hanging wall of the Cleaver Lake fault (Devine *et al.*, this volume, figure 15).

Voluminous Carboniferous volcanic suites in the Stikine assemblage span the time range of Cycles III through IV (Gunning *et al.*, this volume). One dacite tuff has been dated as *ca.* 355 Ma (U-Pb zircon; Logan *et al.,* 2000) and a volcanic sequence that unconformably overlies the Forrest Kerr pluton has returned a *ca.* 344 Ma U-Pb age (M. Gunning, unpublished data). Elsewhere, ages are less well-constrained. These volcanic suites are characterized by variable volcanic facies and chemistry. Bimodal basalt and dacite/rhyolite typify some sections, and calc-alkaline and E-MORB signatures are intermixed; this suggests a transtensional arc setting, with volcanic products accumulating in fault-controlled basins (Gunning *et al.*, this volume). A few igneous ages in the Coast Mountains fall within the Wolverine cycle, including *ca.* 354 Ma and *ca.* 345 Ma ages from metavolcanic rocks of the Endicott Arm assemblage (Gehrels, 2001; McClelland *et al.*, 1991).

In contrast with the continued vigourous igneous activity in the YTT and related terranes, on the North American margin igneous activity dwindled to insignificance during Early Mississippian time (Fig. 4). There are very few U-Pb ages of less than 357 Ma, and only one less than 347 Ma (the 339 Ma Trident Mtn. syenite; see Table DR2). Earn Group deposition on the Cassiar terrane ended in mid-Tournaisian time (Nelson and Bradford, 1993), and in the late Tournaisian in Selwyn basin (Irwin and Orchard, 1989). SEDEX activity waned after the Late Devonian, and only syngenetic barite and very minor sulphide mineralization occurs in the upper, Mississippian-age part of the Earn Group (Irwin and Orchard, 1989; Paradis *et al.*, 1998; Fig. 11).

The Slide Mountain terrane in the Sylvester allochthon contains basalts with MORB chemistry, interbedded with thick sequences of Earn-like clastic sedimentary strata; dark grey argillites, chert-quartz grits and sandstones (Nelson and Bradford, 1993). Precise conodont ages from thin calcareous interbeds in this unit are predominantly Early Mississippian (late Tournaisian). Identical, coeval clastic strata, but without the accompanying basalts, occur in a structurally lower position. They contain sparse baritic and sulphide exhalite occurrences (Nelson and Bradford, 1993). These Slide Mountain assemblages, and those of the lithologically similar and coeval Fortin Creek and Mt. Aho groups in the Finlayson Lake (Murphy *et al.*, this volume) and Faro (Pigage, 2004) districts, intervene structurally between the parautochthonous Cassiar terrane, and overlying Yukon-Tanana assemblages (Nelson and Friedman, 2004). Tectonic reconstruction prior to northeast-vergent thrusting would place the Slide Mountain basin between North American margin and the YTT. In the related Seventymile terrane of Alaska, Early to mid-Mississippian (Osagean to likely Meramecian) radiolarians (Foster *et al.*, 1994; Dusel-Bacon and Harris, 2003) were recovered from chert overlain by greenstone from the Mount Sorenson peridotite body.

## Interpretation and Synthesis

Continuing from Cycle II, the Wolverine cycle is characterized by widespread magmatic arc development in YTT (Fig. 11). Arc-related magmatism from the Fortymile River assemblage south into the Finlayson Lake belt (hanging wall of Money Creek thrust), Glenlyon and Wolf Lake-Jennings River areas, with coeval back-arc activity in the Dawson area and Finlayson Lake belt (footwall of Money Creek thrust), constitute a well-developed, west-facing arc/back-arc pair paleogeographically similar to Cycle II. The eclogites in the hanging wall of the Cleaver Lake thrust reconstruct farthest west, indicating the relative position of the subduction zone and westerly arc polarity.

During Cycle III, magmatic activity on autochthonous North America dwindled away, and ceased altogether at about 340 Ma (Fig. 4). Instead, in the intervening Slide Mountain terrane, MORB volcanism was accompanied by Earn-style clastic sedimentation. Cycle III, then, marks the main phase of rifting of the continental arc and back-arc of YTT away from the North American margin by opening of the Slide Mountain ocean, as originally proposed by Tempelman-Kluit (1979).

At present, a series of allochthons of Slide Mountain assemblage rocks act as structural markers that demarcate the boundary between the part of the continent margin that rifted away and the part that was left behind. These include the Slide Mountain assemblage in the Sylvester allochthon and along the Tummel fault (Colpron *et al.*, 2005, this volume-b), the Fortin Creek group and the pre-Triassic rocks in the Big Campbell window in the Finlayson Lake area, the pre-Triassic rocks in the Clinton Creek window near Dawson, and the Mt. Sorensen and Nail allochthons in Alaska (Dusel-Bacon *et al.*, 2004, this volume). Pericratonic rocks that lie structurally below and/or inboard (east) of these marginal ocean remnants are probably parautochthonous and not part of the rifted fragment that became YTT. This includes both the Kootenay terrane east of the Fennell Formation in southern B.C., and the western and southern Yukon-Tanana Upland in Alaska. It is also significant that the igneous suites in the western and southern upland, as well as in the Alaska Range, are predominantly no younger than Cycle II. The Early Mississippian demise of magmatism in the western upland and Alaska Range fits with the North American margin pattern, not with YTT, where igneous activity continued to be vigourous and widespread into Late Mississippian and later time. Moreover, in this broad region, arc-related geochemical signatures are only seen in the Delta mineral belt (Dashevsky *et al.*, 2003). The remainder has the aspect of an extending continental province (Dusel-Bacon *et al.*, 2004, this volume). For these reasons, then, this former part of YTT is reinterpreted here as a part of the continent margin arc and back-arc that remained behind when the Slide Mountain ocean opened between it and the active arc front.

VHMS deposits like Wolverine are local expressions of the Early Mississippian Cycle III continent-scale arc rifting event. Wolverine's geographic position next to the eastern margin of YTT, and the strong back-arc signature of its host strata, suggests that it developed at the very trailing edge of the newly-intraoceanic continental fragment, just as that fragment detached itself from the continent margin. It is significant that the unit immediately overlying the felsic Wolverine stratigraphy is a basalt of MORB affinity (Murphy *et al.*, this volume).

The complex volcanic facies and mixed calc-alkalic and non-arc signatures in Stikinia are compatible with an arc-rift setting similar to that manifested in YTT, with the notable difference that in central Stikinia there is no isotopic evidence for underlying continental crust.

## Cycle IV - 342-314 Ma – (Late Mississippian; Viséan-Serpukhovian) - Little Salmon Cycle

### Definition and Regional Data

Like the previous Wolverine Cycle, the commencement of Cycle IV is defined by a prominent unconformity. Its type locality is in the Glenlyon area, where the base of the *ca.* 340 Ma Little Salmon formation overlies, and the undeformed 340 Ma Tatlmain batholith intrudes, Early Mississippian and older, previously deformed units (Fig. 12; Colpron *et al.*, this volume-b). The timing of the intervening deformational event is well constrained, in that southwest-vergent

folds were developed in the slightly older (349-343 Ma) Little Kalzas formation prior to emplacement of the Tatlmain batholith. The Little Salmon formation is predominantly an arc-derived volcaniclastic to epiclastic succession, which also includes basalt flows of OIB affinity, fossiliferous limestone, rare dacite porphyry and a manganiferous exhalite unit (Colpron *et al.*, this volume-b).

Importantly, dated igneous rocks younger than *ca.* 342 Ma are very rare north of the Glenlyon area (Fig. 12). There are only two known exceptions. U-Pb zircon crystallization ages for felsic metatuff from the Fortymile River assemblage in eastern Alaska could be as young as 336 Ma, allowing for analytical uncertainties (Dusel-Bacon *et al.*, this volume), and a similar age U-Pb zircon age of approximately 340-335 Ma was reported for a deformed pluton intruding the Fortymile River assemblage in eastern Alaska (J.K. Mortensen, personal communication, cited *in* Werdon *et al.*, 2002). These ages represent the northernmost occurrence of Cycle IV igneous activity.

Late Mississippian igneous rocks within the Ram Creek and Big Salmon complexes in the Wolf Lake-Jennings River area are more southerly correlatives of the Little Salmon formation and Tatlmain batholith (Roots *et al.*, this volume; Nelson and Friedman, 2004; Mihalynuk *et al.*, this volume). They include felsic tuffs and high-level intrusions dated at *ca.* 340 to *ca.* 322 Ma. In the Ram Creek Complex, these are associated with greenschist-facies inter-mediate to mafic volcaniclastic and flow rocks. The Ram Creek volcanic rocks show typical arc signatures (Nelson and Friedman, 2004).

Marbles are present, one containing poorly preserved late(?) Paleozoic colonial and solitary corals (Mihalynuk *et al.*, 2000, this volume, fig. 4D). Three concordant U-Pb ages of felsic units associated with the Big Salmon Complex are between *ca.* 340 and *ca.* 336 Ma (Mihalynuk *et al.*, this volume). The Big Salmon Complex is host to several VHMS prospects, the Mor, Cabin and Caribou, associated with undated felsic bodies; and contains a prominent, regionally continuous manganiferous exhalite unit that can be traced along strike through recumbent folds for tens of kilometres (Mihalynuk *et al.*, 2000), this volume). It is intruded by the Mount Hazel pluton, which gives conflicting U-Pb zircon ages of *ca.* 362 and *ca.* 337 Ma, and is probably cut by a *ca.* 340 Ma dacite porphyry (see Mihalynuk *et al.*, this volume). Thus the exhalite unit may be equivalent in age to those in the Little Salmon formation, or it may be older.

In the central structural panel in the Wolf Lake-Jennings River area, the Upper Mississippian to Lower Pennsylvanian (Viséan to Bashkirian) Screw Creek Limestone overlies the siliciclastic, basinal Swift River Group above a prominent unconformity, marked in part by a cobble to boulder conglomerate (Nelson and Friedman, 2004; Roots *et al.*, this volume). This sub-Viséan unconformity and overlying basal conglomerate compare with the base of the Little Salmon formation, but here it marked the beginning of carbonate deposition, not renewed arc volcanism. Similarly, in the Finlayson Lake district, the Upper Mississippian Whitefish limestone unconformably overlies Wolverine cycle Tuchitua volcanic rocks in the hanging wall of the Money Creek thrust (Murphy *et al.*, this volume). This onset of

limestone deposition marks the beginning of a hiatus in volcanism in the area, which perhaps then evolved into a back-arc region.

An unconformity is recognized above the manganiferous chert unit in the Big Salmon Complex (Mihalynuk *et al.*, this volume). Conglomerates above it contain clasts that texturally resemble the *ca.* 340 Ma quartz-feldspar dacite porphyry and the unconformity
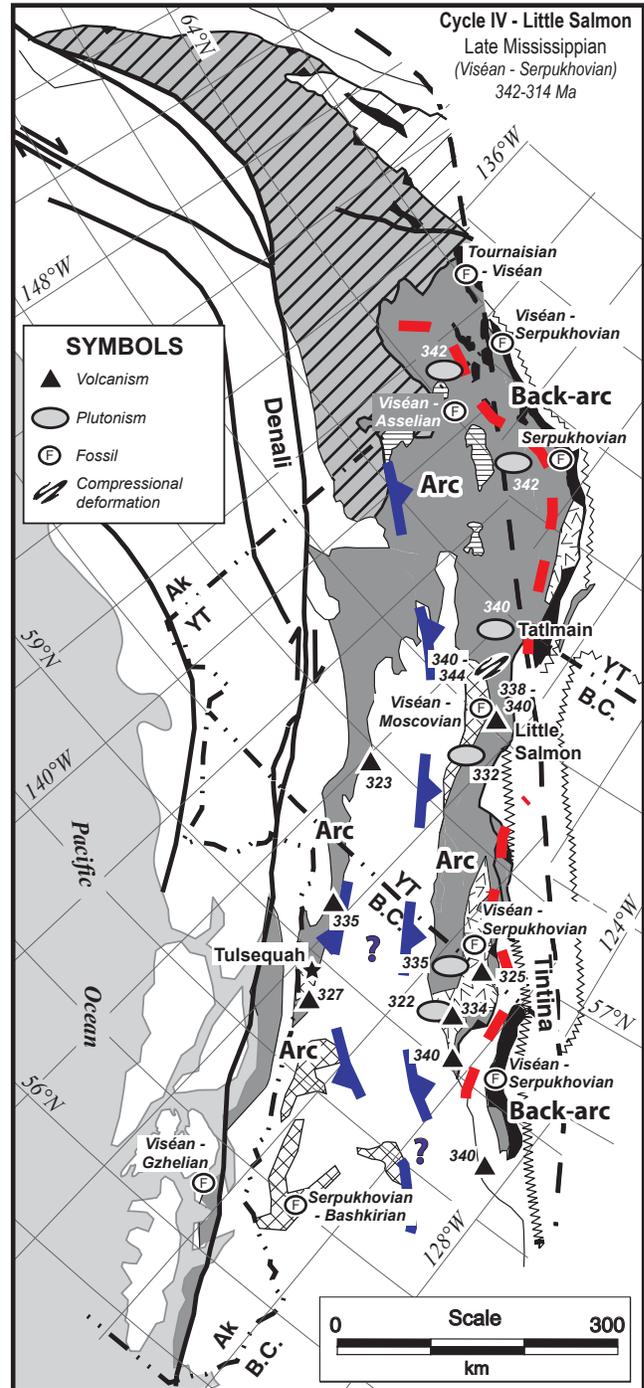


**Figure 12.** *Cycle IV (Little Salmon cycle) igneous patterns and metallogeny. Blue toothed lines show interpreted, approximate locations and facing directions of subduction zones; red line is interpreted, approximate arc/back-arc boundary.*

may be associated with a phase of deformation that predates a *ca.* 331 Ma dike.

In far northern Stikinia, the Tulsequah Chief VHMS deposit is hosted by the Mt. Stapler suite, which is gradational into the Boundary Ranges and Whitewater suites of western YTT (Mihalynuk *et al.*, 1994a). Footwall rhyolite has been dated at *ca.* 327 Ma by U-Pb methods on zircon, with strong Precambrian inheritance in some samples (Childe, 1997). Tulsequah Chief is the youngest of the significant volcanogenic deposits associated with YTT.

Elsewhere in the Stikine assemblage, Cycle IV is characterised by thick volcanic-sedimentary successions, including thin limestones that range in age from Viséan through Kasimovian (Late Mississippian-Late Pennsylvanian). One of the sequences has yielded a *ca.* 319 Ma U-Pb zircon date (Gunning *et al.*, this volume). Similar volcanic sequences above and below the limestone show that deposition and volcanism were essentially continuous from Mississippian into Pennsylvanian time, *i.e.*, extending from Cycle IV to Cycle V with no apparent break. In a few locales, Upper Mississippian strata lie unconformably on the Early Mississippian More Creek pluton and on deformed Devono-Mississippian volcanic units (Logan *et al.*, 2000). The poorly-known Takhini assemblage north of Whitehorse contains a $322.9 \pm 1.2$ Ma deformed felsic volcanic rock (U-Pb zircon; Hart, 1997). There is also an imprecise U-Pb zircon date of *ca.* 335 Ma from an intrusion within the Tracy Arm assemblage of southeastern Alaska (Gehrels *et al.*, 1991b).

In stratigraphic successions in the Slide Mountain terrane in the Sylvester allochthon, only two Late Mississippian-Early Pennsylvanian and no specifically Late Mississippian faunas were recovered from intravolcanic sedimentary rocks, in contrast to the eleven specifically Tournaisian and eighteen Late Pennsylvanian-Early Permian and Permian collections (Nelson and Bradford, 1993, Table 2). This may represent a mid-Carboniferous lull in ridge activity and in ocean spreading, or alternatively lack of preservation of oceanic crust of this age.

*Interpretation and Synthesis*

The deformational event that separates the Little Salmon from the Wolverine cycle and the subsequent arc reconfiguration marks a major transition within YTT. Widespread igneous activity in YTT came to a close then, and never resumed to the same degree. The U-Pb cumulative probability curve (Fig. 4) shows a slight subsidiary peak at about 328 Ma, and decreases to essentially nil by 315 Ma (Middle Pennsylvanian), taken as the end of the Little Salmon cycle. Cycle IV arc development concentrated in two bifurcating belts: in southeastern YTT where it adjoins Quesnellia, and from the southwestern Whitehorse trough into northern Stikinia (Fig. 12). The extensive bimodal suites in continental back-arc regions of earlier cycles are not in evidence in Cycle IV; igneous activity was restricted to a fairly narrow arc axis, and to the now-intervening marginal ocean between YTT and the continent.

During Cycle IV the YTT continental fragment had become part of an intraoceanic arc system, separated from North America by an expanding marginal ocean basin of significant width — the Slide Mountain ocean. The end of widespread Cycle III arc activity

in YTT coincided with a dramatic decrease in MORB volcanism, and perhaps strong rifting, within the Slide Mountain ocean. The renewed Cycle IV arc was much more limited in extent. Intra-arc extension continued to give rise to hydrothermal activity, expressed in the Late Mississippian VHMS deposit at Tulsequah Chief and the manganiferous-siliceous layers in the Little Salmon formation, and possibly in the Big Salmon Complex.

## Cycle V- 314-269 Ma (Pennsylvanian-Early Permian) - Klinkit Cycle

*Definition and Regional Data*

Pennsylvanian-Early Permian sequences in YTT are of two strongly contrasting volcanic/sedimentary styles, arc and back-arc (Fig. 13). Their respective distribution is like that of Cycle IV, *i.e.*, arc to the west, back-arc to the east. Isotopically primitive, predominantly andesitic and basaltic arc sequences represent a departure from earlier assemblages that contain significant amounts of continental crust-derived material. The Klinkit Group in southeastern YTT (Simard *et al.*, 2003; Roots *et al.,* this volume) comprises the Middle Mississippian to Lower Pennsylvanian (Viséan to Bashkirian) Screw Creek Limestone, overlain by younger Pennsylvanian to Permian arc-related volcanic strata, limestones and siliciclastic units. The volcanic rocks, although still showing minor crustal inheritance, are relatively more primitive and mantle-influenced compared to earlier arc products, to the continentally-derived units that underlie them, and to the quartz-rich clastic rocks that in places interfinger with them (Simard *et al.*, 2003). The Klinkit Group and underlying Swift River Group closely resemble the Lay Range assemblage of central Quesnellia (Simard *et al.*, 2003; Nelson and Friedman, 2004), one of the type sections for late Paleozoic Quesnellia (Monger *et al.*, 1991). In both successions, Lower Pennsylvanian carbonate lies depositionally on a siliciclastic sedimentary section and is overlain by a thick, predominantly andesitic Pennsylvanian-Permian volcanic sequence (Ferri, 1997). Figure 5 shows that, prior to dextral Cretaceous-Tertiary motion on regional faults, Lay Range exposures were essentially contiguous with southeastern YTT, and that towards the south, older Yukon-Tanana units are progressively buried beneath the younger, late Paleozoic assemblage.

Deposition of Fortymile sedimentary protoliths apparently continued into this cycle, as conodonts of Late Mississippian to Early Permian (late Meramecian to early Sakmarian) have been identified in marble layers from the east-central Alaska (Dusel-Bacon and Harris, 2003). Poorly preserved conodonts of late Paleozoic, possibly Mississippian age (Foster, 1992; Dusel-Bacon and Harris, 2003) suggest a similar age for the Chicken Metamorphic Complex, a thick section of greenschist facies metavolcanic, metaplutonic and lesser metasedimentary rocks that is considered to be of arc affinity (Werdon *et al.*, 2001; Dusel-Bacon *et al.*, this volume). Protoliths range from basalt to andesite to rhyolite, and commonly show tuffaceous textures. A metadiorite dike from the complex gave hornblende $^{40}Ar/^{39}Ar$ ages of 305-288 Ma (Werdon *et al.*, 2001). Thus, the Chicken Metamorphic Complex and the Fortymile River assemblage contain the farthest northwesterly occurrences of late Paleozoic arc
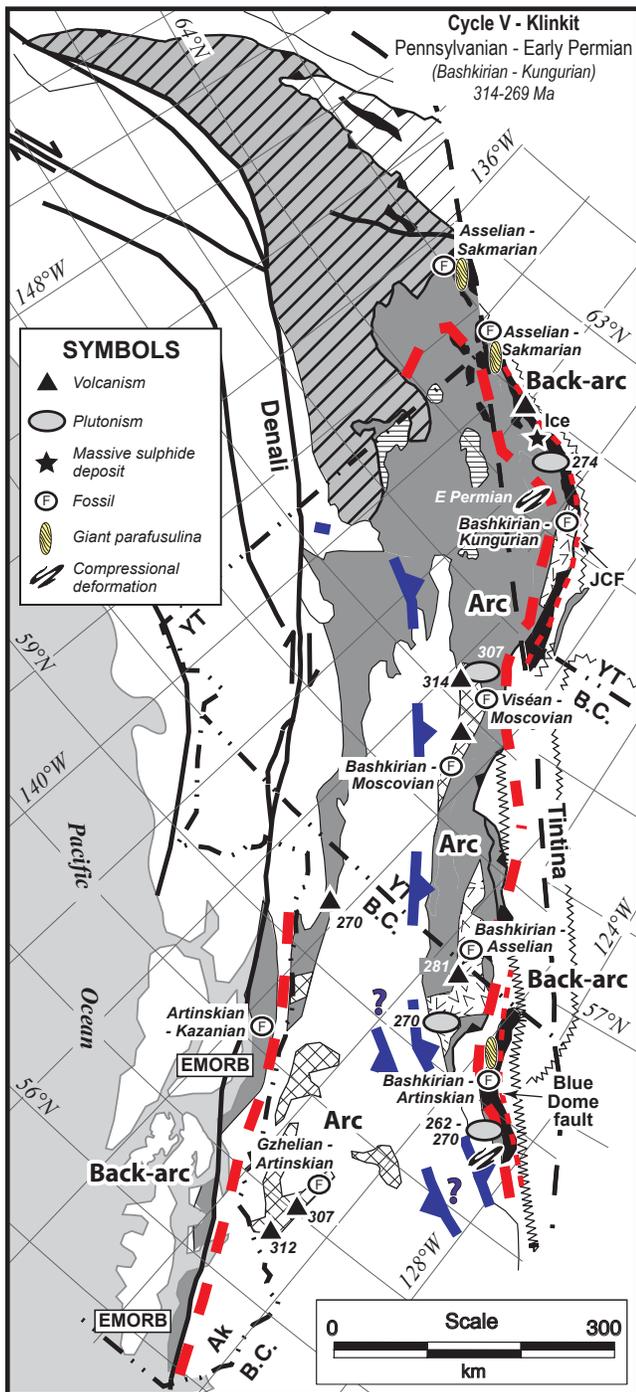
suites in the YTT. Both the Chicken Metamorphic Complex and the Fortymile River assemblage form wall rocks to the Late Triassic Taylor Mountain Batholith and related smaller intrusions, but locally



**Figure 13.** *Cycle V (Klinkit cycle) igneous patterns and tectonics. Blue toothed lines are interpreted, approximate location and facing directions of subduction zones; dashed red line is interpreted, approximate arc/back-arc boundary. Dotted red line is trajectory of Jules Creek (JCF) and Blue Dome faults.*

all three units are separated by a steep faults (Foster, 1992; Werdon *et al.*, 2001).

Late Paleozoic arc strata of the Klinkit assemblage also occur within the Sylvester allochthon, partly in depositional contact with YTT rocks (for local stratigraphic names see Nelson, 1993; Nelson and Friedman, 2004). A Middle Permian (Wordian) limestone within this assemblage contains a giant parafusulina species that is distinctive of the McCloud faunal belt (Ross, 1969; Nelson, 1993). Similar Wordian giant parafusulina, as well as brachiopods, are reported from a fault sliver of calcareous siltstone associated with serpentine assigned to Seventymile terrane just south of the Tintina fault in eastern Alaska (Stevens, 1995; Dusel-Bacon and Harris, 2003). This is an unusual association, as most exposures of the Seventymile terrane, such as the Nail (Salcha River) and Mount Sorenson klippe, contain basalt-chert-fine-grained sedimentary rocks-ultramafic associations correlative with the oceanic Slide Mountain terrane. At another unusual Seventymile exposure in eastern Alaska, the Wolf Mountain klippe, some greenstones have MORB signatures but others have arc petrochemical signatures (Dusel-Bacon and Cooper, 1999; Dusel-Bacon *et al.*, this volume). The arc greenstones are associated with Triassic (late Carnian and early Norian) sedimentary rocks, which at one locality appear to be in depositional contact with the greenstone, indicating either a later, Triassic cycle of arc magmatism (Dusel-Bacon and Harris, 2003), or possibly a sub-Triassic unconformity.

In the Tulsequah Chief section, Mississippian felsic tuffs that host the deposit are overlain by undated pyroxene-phyric volcanogenic strata, and in turn by Middle Pennsylvanian limestone and highly variable Pennsylvanian-Permian volcanic and sedimentary units (Mihalynuk *et al.*, 1994a). Elsewhere in northwestern Stikinia, volcanic activity continued from Mississippian into Late Pennsylvanian time, when it abruptly ceased (Gunning *et al.*, this volume). Early Permian limestones, with insignificant volcanic interlayers, characterise all Stikine assemblage exposures. In those farthest west (Logan, 2004), basalts immediately below the Permian limestone have non-arc, OIB to E-MORB signatures, due to intra-arc or back-arc rifting. In eastern Stikinia, a U-Pb zircon date on felsic tuff in the lower bimodal volcanic unit of the Asitka Group is *ca.* 308 Ma (Late Pennsylvanian), and an overlying sedimentary unit contains Early Permian limestones and varicoloured cherts (Diakow and Rogers, 1998). Here, too, volcanism seems to have terminated by Early Permian time. This contrasts strongly with active Early Permian arc activity recorded in the Klinkit Group, Lay Range assemblage and units of Harper Ranch (Quesnellian) affinity in the Sylvester allochthon.

In the northwestern Coast Mountains, strata of the former Taku terrane have been linked depositionally to YTT on the basis of shared detrital zircon populations (Gehrels, 2002). Within this sequence, Permian basalts exhibit only non-arc, E-MORB to within-plate multi-element signatures. Primitive mantle-normalized multi-element plots of representative analyses are shown on Figure 14, to conform to data presentation in other papers in this volume (see also Rubin and Saleeby, 1991). In the northeastern Coast Mountains, the Wann River gneiss, a *ca.* 270 Ma metavolcanic package, is structur-

ally imbricated with the Florence Range and Boundary Ranges metamorphic suites (Currie and Parrish, 1993). No petrochemical data is available from this unit.

During the Pennsylvanian-Early Permian, the Finlayson Lake belt evolved from a stable, amagmatic back-arc basin into which arc-derived sediments were shed, to an active foreland region in front of Early Permian thrust faults; and finally to an Early Permian transtensional back-arc basin (Murphy *et al.*, this volume). The Upper



**Figure 14.** *Geochemistry of the Permian Taku basalts. Unpublished data from Harold Stowell (shown on figures in Stowell* et al.*, 2000). (A) OIB signatures; (B) E-MORB signatures; (C) contaminated or mixed samples. Primitive mantle values of Sun and McDonough (1989).*

Pennsylvanian Whitefish limestone was succeeded by green and pink tuffaceous chert and limestone of the Pennsylvanian White Lake formation and lithic arenite and conglomerate of the Pennsylvanian King Arctic formation. These units are unconformably overlain by an unnamed bioclastic Pennsylvanian to Lower Permian limestone (Devine *et al.*, this volume). In the Early Permian, easterly directed displacement on the Cleaver Lake thrust placed Devonian and Mississippian forearc and arc front facies rocks over coeval arc-axis rocks; and the latter were subsequently thrust over back-arc facies rocks along the Money Creek thrust (Murphy *et al.*, this volume). Flysch-like dark clastic rocks and argillite of the Money Creek formation were deposited just before, and are also inferred to have been deposited during and after thrusting.

Following thrusting, Permian MOR basalts of the Campbell Range formation accumulated in the eastern Finlayson Lake belt. The Campbell Range formation represents back-arc volcanism of the Slide Mountain ocean basin that impinged on the eastern margin of YTT (Murphy *et al.*, this volume; Piercey *et al.,* this volume; Plint and Gordon, 1997). South of the Jules Creek fault (JCF on Fig. 13), the current boundary between YTT and Slide Mountain terrane, the basalts rest in depositional contact above older YTT units of the Big Campbell and Money Creek thrust sheets. North of the Jules Creek fault, the basalts overlie the Fortin Creek group of Slide Mountain terrane. Mafic-ultramafic bodies, inferred to be feeders to the basalts, crosscut rocks of both YTT and Slide Mountain terrane; both basalts and feeders occur only in a narrow corridor straddling the Jules Creek fault. Leucogabbro from two of these bodies has been dated at *ca.* 274 Ma (U-Pb zircon; Mortensen, 1992; Murphy *et al.*, this volume). The Jules Creek fault offsets Artinskian limestone and therefore is in part post-Early Permian (Murphy *et al.*, this volume). However, the gently-dipping basal contact of the Campbell Range basalts projects across the fault trace. The minimal vertical throw across the Jules Creek fault on one hand, and its spatial association with the Campbell Range basalts on the other, suggest that it may have been a major transcurrent fault that localized mafic intrusion and volcanism, perhaps a leaky transform fault that developed along the western margin of the Slide Mountain ocean basin (Murphy *et al.*, this volume). Early development of the Jules Creek fault is dated as late in Cycle V by the *ca.* 274 Ma Campbell Range feeder gabbros.

The Ice prospect in the northern Campbell Range belt (Plate 1) is a Cyprus-type, copper-rich, VHMS deposit (Hunt, 1997), hosted by pillow basalts and red cherts of the Campbell Range formation (Murphy *et al.*, this volume).

Throughout the Slide Mountain terrane, a strong pulse of Late Pennsylvanian to mid-Permian MORB magmatism, and presumably back-arc rifting, is evidenced by abundant conodont ages in interlava sedimentary rocks (Nelson and Bradford, 1993; Ferri, 1997; Schiarizza and Preto, 1987). In Alaska, cherts interlayered with greenstones at the Nail klippe have conodonts and radiolarians that indicate a middle Early Permian age; greenstones have N-MORB and OIB trace-element signatures (Dusel-Bacon *et al.*, this volume). In strong contrast to the coarse clastic-rich Early Mississippian sequences, most Slide Mountain basalts of this age are interbedded with cherts and argillites. Many of these cherts are brightly coloured
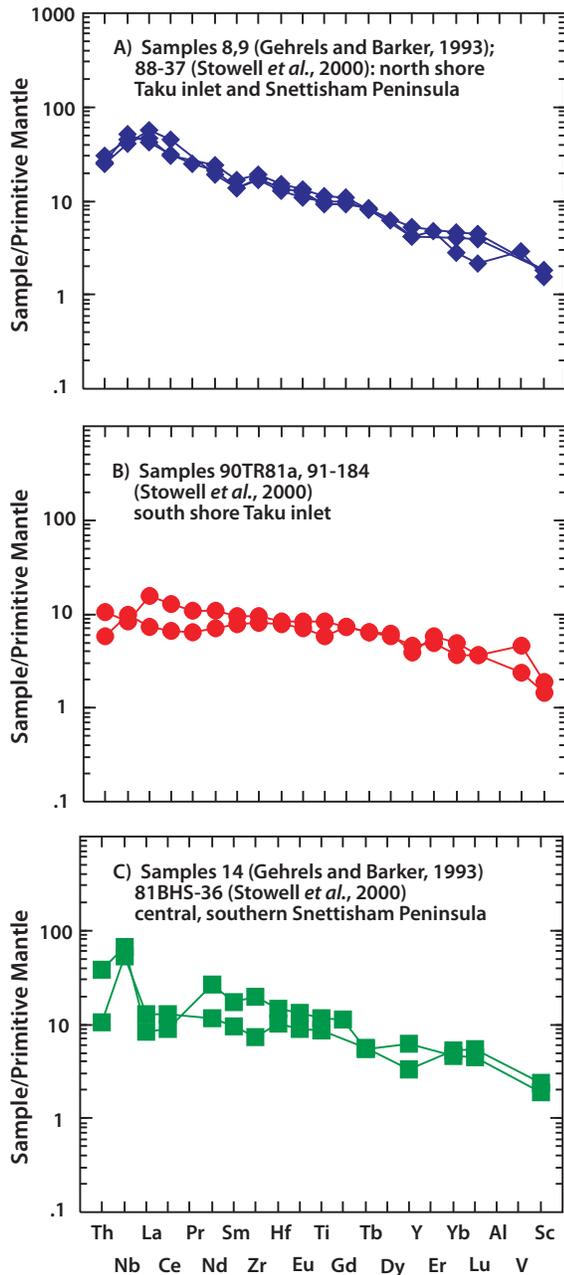
in red, pink, maroon and green, unlike the greys, blacks and dull greens of Early Mississippian sedimentary rocks. The large ultramafic-gabbro panel in the Sylvester allochthon has returned an Early Permian U-Pb zircon age of *ca.* 269 Ma (Gabrielse *et al.*, 1993).

The Blue Dome fault (Fig. 13) is a steep structure with a strike length over 80 km, that runs nearly the length of the Sylvester allochthon; it contains lenses of serpentinite and also extensive sedimentary breccias and ophicalcites, one of which yielded Kungurian to Middle Permian conodonts (M. Orchard *in* Nelson and Bradford, 1993; revised age assignment in Orchard, this volume). Like the Jules Creek fault, it is probably a fossil transform fault with motion in Permian time.

### Interpretation and Synthesis

Pennsylvanian-Early Permian arc volcanic and related sequences are widespread on the southern fringes of YTT, merging into Quesnellia and Stikinia. The Chicken Metamorphic Complex and the youngest magmatic products of the Fortymile River assemblage are the only known correlatives in northern YTT. This may be due to a greater degree of later uplift and erosion in the north. Unlike earlier episodes, the Pennsylvanian-Early Permian volcanic products were overwhelmingly mafic to andesitic, with very few cogenetic plutons: thus, erosional removal of surface deposits would remove them from the geologic record.

Geographic relationships between the arc-related Klinkit Group and Finlayson Lake belt back-arc suggest that, like its antecedents, the Pennsylvanian-Permian arc of eastern YTT and northern Quesnellia faced towards the west. Farther east, rifting and ocean crust generation in the Slide Mountain basin intensified, increasing the separation between YTT/Quesnellia/Stikinia and North America. The Jules Creek fault, with its associated mafic and ultramafic intrusions and oceanic basalts, shows the penetration of a back-arc transform fault/rift zone into the crustal block that supported the corresponding arc. The Blue Dome fault, similar in age and style, is probably related to it (Fig. 13).

Petrochemical evidence shows the dominance of non-arc, enriched basalts on the southwestern margin of YTT near Juneau, Alaska (Fig.14). This area may possibly represent a back-arc region to the mature calc-alkaline arc of the Stikine assemblage, described by Gunning *et al.* (this volume).

The strongly bimodal, continentally-influenced character of earlier arc cycles is far less pronounced in Cycle V in YTT. In general, andesites and basalts predominate, and typical intra-oceanic calc-alkaline to tholeiitic character prevails. Perhaps at this stage the lithosphere under YTT had become so attenuated that the underlying asthenosphere became the chief source of magmas (Simard *et al.*, 2003; Piercey *et al.*, this volume).

The Permian McCloud faunas are a distinctive group of marine invertebrate species — primarily corals and fusulinids — that characterize Cordilleran arc terranes from the Sonora province of northern Mexico, through the northern Sierras and eastern Klamaths to Quesnellia and Stikinia (Miller, 1987). They differ significantly from endemic North American forms. Belasky *et al.* (2002) used statistical tests of faunal similarity to show that in Early to mid-Permian time, Stikinia and Quesnellia probably lay north of the Eastern Klamath terrane, and that all three probably lay 2000-3000 km west of North America. Stevens (1995) notes that the only autochthonous occurrence of species related to the giant parafusulina of the McCloud belt is in west Texas, suggesting a more southerly Permian location for all of the McCloud terranes. Thus the combined YTT/Quesnellia/Stikinia must have migrated seaward and southward by thousands of kilometres by mid-Permian time, with a very wide back-arc ocean developed between them and the continent. Evidence for strong Late Pennsylvanian-Early Permian spreading and paucity of siliciclastic sedimentation in the Slide Mountain terrane are consistent with a broad ocean between YTT and the continent at this time.

## Cycle VI - 269-253 Ma (Middle to Late Permian) - Klondike Cycle

### Definition and Regional Data

Mid-Permian tectonics of the YTT and related terranes diverged markedly from earlier trends (Fig. 15). All earlier arc and back-arc magmatism of the Klinkit cycle ceased by the end of the Early Permian. Cycle VI igneous activity was restricted to two areas. In the Dawson/Stewart River area, the comagmatic Klondike Schist and Sulphur Creek orthogneiss are 263 to 253 Ma, with two apparent age peaks at 260 and 255 Ma (Fig. 4). Similar aged felsic metaplutonic and metaporphyry bodies locally intrude the Fortymile River and Nasina assemblages that span the Alaska/Yukon border (Dusel-Bacon *et al.*, this volume). They are generally of very felsic composition, have calc-alkaline character, and isotopic signatures indicative of interaction with continental crust (Piercey *et al.*, this volume; Ruks, 2004).

In the northern part of the Campbell Range belt, near the Ice property, felsic rocks overlying the pillow basalts have been dated at 260-259 Ma by U-Pb methods on zircon (Murphy *et al.*, this volume). They presumably correlate with Klondike felsic volcanic rocks in the Dawson area. Interestingly, here they overlie Early Permian back-arc rocks.

A somewhat older suite of 270-258 Ma gabbro, diorite, tonalite and granite bodies intrudes both the Dorsey Complex and late Paleozoic arc strata that fringe the southeastern YTT, including the Ram stock west of the Cassiar batholith (Liverton *et al.*, 2005; Roots *et al.*, this volume) and the Nizi and Meek plutons in the Sylvester allochthon (Nelson and Friedman, 2004). One of them, a tonalite dated by U-Pb methods on zircon at *ca.* 269 Ma, seals a thrust fault that imbricates Mississippian and Pennsylvanian carbonate strata (Harms, 1985). Others, with slightly younger U-Pb zircon ages, are truncated by the top-to-the-northeast thrust fault that places the Dorsey Complex on top of the late Paleozoic arc assemblage (Nelson and Friedman, 2004). These apparently conflicting temporal relationships suggest that the plutonic suite was intruded synchronously with mid-Permian thrusting.

A belt of mid-Permian blueschist and eclogite can be traced intermittently along the eastern margin of YTT from Faro south to Last Peak and the St. Cyr klippe (Faro HP belt, Fig. 15). $^{40}Ar/^{39}Ar$

mica ages of high P/T facies rocks range from 273 to 239 Ma, with a pronounced peak at about 260 Ma (Fig. 4; Erdmer *et al.,* 1998, Fallas *et al.,* 1998; see Table DR3 for supporting data [see footnote 1]). The Last Peak locality is dated at *ca.* 269 Ma by U-Pb zircon

methods (Creaser *et al.*, 1997b; Erdmer *et al.,* 1998); and Fallas *et al.* (1998) report a *ca.* 266 Ma zircon age from an eclogite in the St. Cyr klippe. The protolith is basalt of MORB to within-plate affinity, which could have been derived from the structurally subjacent Slide Mountain terrane (Creaser *et al.,* 1999), or from mafic rocks within the Snowcap assemblage. Mid-Permian to Triassic synorogenic conglomerates and sandstones occur along the eastern margin of the YTT (Fig.15). In the Finlayson Lake belt, the Triassic conglomerates contain a variety of clast types, including blueschist and eclogite (Mortensen *et al.*, 1999; Murphy, 2004; Murphy *et al.*, this volume).

The oldest K-Ar metamorphic cooling age in the eclogite-bearing Chatanika assemblage near Fairbanks is 240 ± 18 Ma by K-Ar methods on amphibole (Swainbank and Forbes, 1975), which matches the set of Late Permian ages farther south. All other ages in this unit are Jurassic to Cretaceous, and probably reset. In Figure 15, after restoration of motion on the Tintina fault, it forms a reasonable along-strike projection of the high-pressure metamorphic belt along the inner side of the terrane.

The youngest MORB volcanic rocks in the Slide Mountain terrane are dated by radiolaria in interbedded red chert as Early-Middle Permian boundary (T.A. Harms *in* Nelson and Bradford, 1993). The mid-Permian marks the onset of a prolonged Permo-Triassic hiatus in deposition throughout YTT, Slide Mountain terrane, Stikinia and Quesnellia; except for the Klondike arc, which persisted until the end of the Permian (*ca.* 253 Ma). Significant Permo-Triassic deformation affected late Paleozoic rocks throughout Quesnellia, and is shown in sub-Triassic unconformities (Read and Okulitch, 1977). A sub-Triassic unconformity is also interpreted in the Wolf Lake-Jennings River area in southeastern YTT (Roots *et al.*, this volume).

*Interpretation and Synthesis*

The eastern margin of YTT in Middle to Late Permian time, with its short-lived Klondike arc, exposure of high P/T metamorphic slivers and synorogenic clastic rocks, was manifestly a short-lived consuming plate boundary (Fig. 15). Demise of the older, west-facing Klinkit cycle arc sequences in mid-Permian time was followed by a reversal to east-facing polarity and consumption and closure of the Slide Mountain ocean. Easterly-directed mid-Permian thrust faults within the arc basement were partly synthetic to the west-dipping subduction zone, and could also have resulted from early stages of collision.

In detail, the northeastern margin of the Klondike arc and its associated belt of high P/T metamorphic occurrences is segmented (Fig. 15). There is a broad arc-magmatic zone in the western Yukon, paired with a blueschist belt, the Faro belt, in the northern Finlayson district. A separate west-northwest-striking trend of eclogite occurrences extends from Last Peak into the St. Cyr klippe in southeastern YTT; south of it are the Ram stock and Late Permian plutons in the Sylvester allochthon. On Figure 15 we speculate that a transform segment, equivalent to the Jules Creek fault, accounts for the offset between these two regions. The Blue Dome fault is a separate trans-
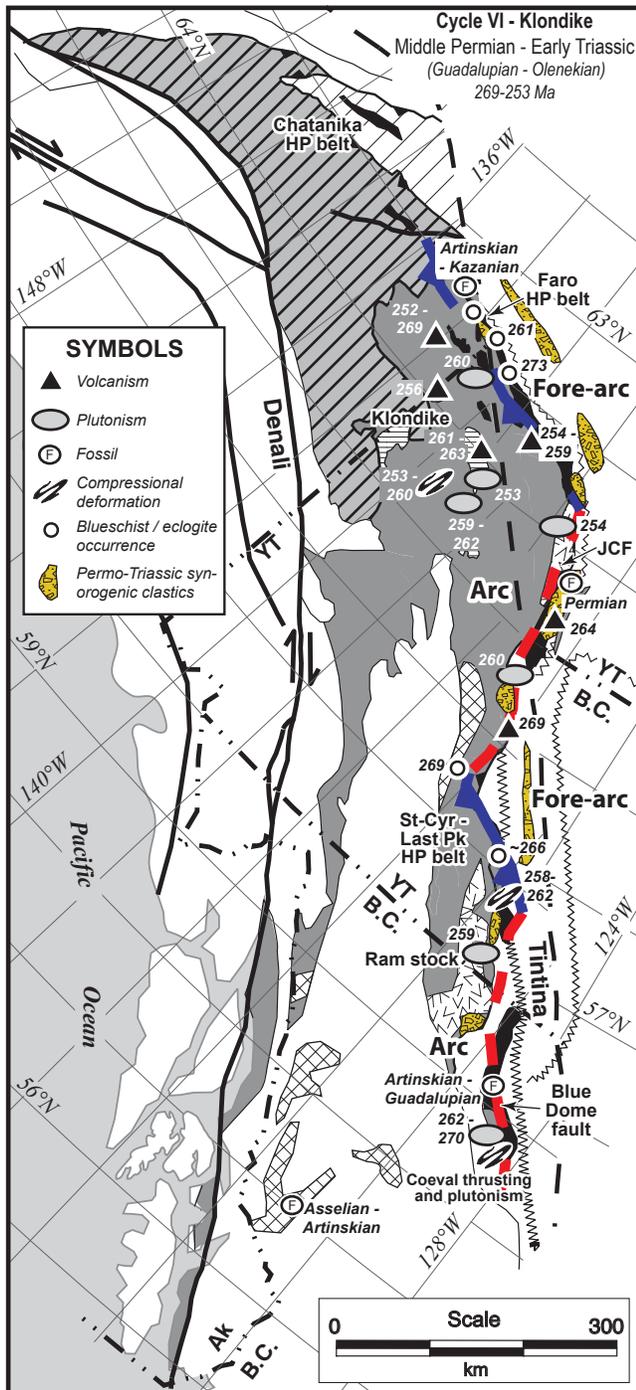


**Figure 15.** *Cycle VI (Klondike cycle) igneous patterns; and location of high P/T metamorphic assemblages. Blue toothed line is interpreted, approximate location and facing of subduction zone; red line is inferred extension of Jules Creek as transform possibly linked to Blue Dome fault in Sylvester allochthon.*

form that intersects the eastern end of the more southerly subduction segment. Implied motion on the transform segments is dextral.

The present northerly convex shape of YTT — the "clothes pin" described earlier — could be partly a relict of an arcuate geometry towards the subducting plate, like the New Hebrides arc towards Australia as described and modelled by Schellart *et al.* (2002). Their model shows a short arc segment "pinned" at one end and ending at a transform at the other. The arc segment advances asymmetrically towards the sinking slab; its outline becomes more convex with time in the direction of propagation. Figure 16 shows a possible configuration of the Klondike arc, bordered on its southeastern side by the Jules Creek and Blue Dome faults.

By the end of this cycle, the intervening Slide Mountain ocean was consumed, and both YTT and Quesnellia were colliding with promontories or outliers of the North American margin. Direct evidence for this initial collision with the outermost margins of the continent is now buried beneath Jurassic allochthons. Indirect evidence is shown by the demise of both arc and back-arc igneous activity, regional unconformities, and the Middle to Upper Triassic sedimentary overlap on YTT, Quesnellia and Slide Mountain terrane, as well as North America (Read and Okulitch, 1977; Klepacki and Wheeler, 1985; Nelson, 1993; Unterschutz *et al.*, 2002).

Triassic sedimentary sequences on all three terranes are similar to each other and to autochthonous sedimentary units. Dark grey siltstones and calcareous siltstones are accompanied by lesser quartz sandstones and limestones. Graded bedding and cross laminations are typical, and large white micas occur on bedding planes. Coarse polymictic conglomerates occur locally along the eastern edge of
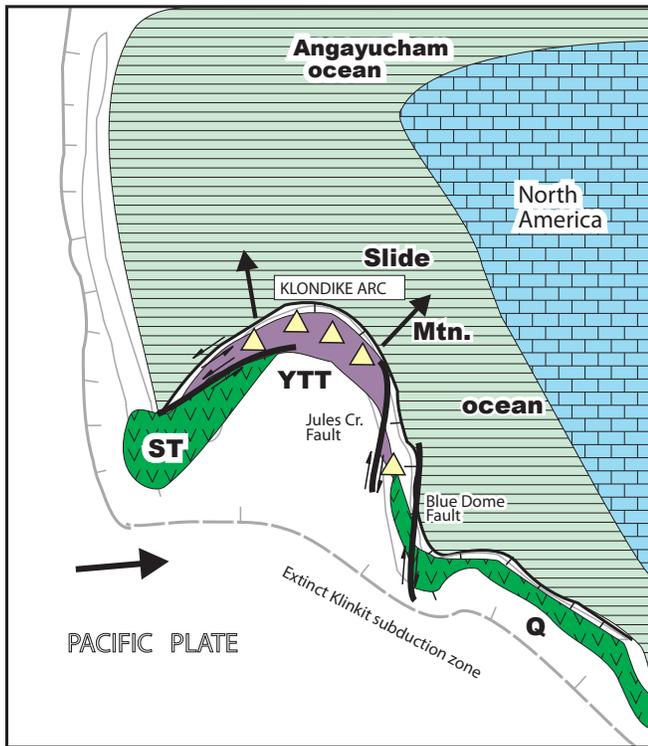
YTT. In southern British Columbia, Unterschutz *et al.* (2002) show a continuum from evolved to more primitive Nd isotopic signatures within Triassic sedimentary rocks exposed within the Kootenay terrane and southern Quesnellia, and suggest that they form an overlap between the two. However, Triassic sedimentary sequences very close in appearance to these occur along the length of the North American Cordillera: unless overlap is demonstrated in continuous outcrop, they constitute a somewhat imprecise pin. Dusel-Bacon and Harris (2003) showed the wide distribution of Late Triassic conodonts in the allochthonous terranes and the North American continental margin of east-central Alaska and the Canadian Cordillera and proposed that the fauna were an indication that all the areas shared approximately similar warm, normal marine conditions, but did not represent an overlap assemblage, in the sense of draping across contacts of arc fragments and the ancient Pacific margin. Orchard (this volume) has identified a "Tethyan" conodont species from an allochthonous site, located in the northeastern YTT in the hanging wall of the Inconnu thrust. This species, *Paragondollela? hallstattensis*, has never been observed within the autochthonous northern miogeocline, nor in YTT elsewhere or Stikinia or Quesnellia. Its paleogeographic significance is unclear, but it and other indicators may require a more southerly position (Orchard, this volume).

The Klondike cycle represents a dramatic break from long-lived tectonic patterns. After 150 m.y. of easterly subduction and back-arc extension, a brief episode of westerly subduction eliminated the marginal ocean and accreted the arcs to the westernmost edge of the continent margin. This event was part of the Sonoman orogeny, which produced arc-continent collisions along the entire west coast of North America (Wyld, 1991; Dickinson, 2000). Subsequent transport of YTT and its affiliated terranes to their final points of accretion during Jurassic and Cretaceous time was in the form of translation and shortening within the North American plate (Hansen, 1990; Hansen and Dusel-Bacon, 1998).

## SUMMARY

The YTT, as reconfigured in this volume, is a large, allochthonous pericratonic province in the northern Canadian Cordillera. Within it, Devonian-Mississippian arc and back-arc assemblages were constructed on an older substrate that included abundant continentally-derived sedimentary rocks: not craton *sensu stricto*, but a metasedimentary/mafic meta-igneous complex analogous to Late Precambrian/early Paleozoic units of the autochthonous and parautochthonous continental margin. Frontal Mississippian arc assemblages in the YTT include the Fortymile River assemblage on the Yukon-Alaska border, rocks above the Money Creek and Cleaver Lake thrusts in the Finlayson belt, and the southeastern YTT east of the Teslin fault. Fore-arc rocks of this age are preserved solely in two far-travelled klippen in eastern YTT. Late Devonian to Early Mississippian YTT back-arc assemblages occur near Dawson and in the footwall of the Money Creek thrust, in both cases east, or inboard, of the arc assemblages. This configuration suggests that the Devonian-Mississippian arc faced west.



**Figure 16.** *Cartoon development of the Klondike arc and flanking Jules Creek and Blue Dome transcurrent faults.*

In some respects, the geological evolution of YTT differs markedly from that of the autochthonous continent margin, principally in its intense Devonian-Mississippian arc magmatism, and depositional ties with the younger arc terranes of Quesnellia and Stikinia. In YTT and in the younger onlapping arc terranes, volcanic successions and plutonic suites of Late Mississippian through Early Jurassic age have no autochthonous equivalents. Furthermore, a belt of Permian high-pressure metamorphic slivers, a late Paleozoic marginal ocean terrane, the Slide Mountain terrane, and a Jurassic terrane-bounding thrust fault intervene between it and the miogeocline.

The YTT, however, also shows a strong affinity for the northern continental margin, including the parautochthonous assemblages of east-central Alaska. Precambrian detrital zircon populations and εNd values match those of the northern miogeocline, indicating similar basement sources. Pb isotopic ratios from Devonian VHMS occurrences are in accord with the signatures of SEDEX deposits in the Selwyn basin and Kechika trough. Episodic syngenetic sulphide deposition was a feature of both the YTT and the outer miogeocline in Middle Devonian through Early Mississippian time, along with major volcanism in the YTT and minor volcanism within most of the continent margin.

Others, beginning with Dirk Tempelman-Kluit (1979), have viewed the YTT as a rifted fragment of the North American margin, which was re-accreted during Mesozoic contraction (*e.g.*, Hansen, 1990; Dusel-Bacon *et al.*, 1995; Hansen and Dusel-Bacon, 1998). Here, we refine and build on this argument. The Devonian-Mississippian history of the northern Cordilleran margin of North America depicts a broad extending back-arc region (Selwyn basin and parautochthonous assemblages of east-central Alaska), from which the corresponding frontal arc is largely missing; whereas that of the YTT in isolation depicts a continental arc with little preserved of its corresponding back-arc region. The observed differences between the YTT and the northern miogeocline can be accounted for by the late Paleozoic to early Mesozoic history of a rifted continental fragment that evolved independantly within the active eastern Pacific margin, outboard of the coeval Slide Mountain marginal ocean basin, with the building of superposed arcs from Late Devonian through Early Jurassic time, prior to final re-accretion following the closure of the intervening ocean (Nelson, 2003). YTT and its affiliated terranes, Slide Mountain, Quesnellia and Stikinia record the evolving plate tectonic evolution of that attenuated subducting margin. This composite terrane embraces the west-facing arc/marginal ocean complex that insulated the passive western margin of North America from Panthalassa throughout the late Paleozoic and early Mesozoic (Fig. 17).

The history of the YTT is part of the history of the western North American margin as a whole. The YTT proper, plus YTT as pericratonic basement to Quesnellia, extends as far south as the U.S. border (Roback and Walker, 1995; Erdmer *et al.*, 2002). Farther south, the eastern Klamath and Northern Sierra terranes are also allochthonous Devonian-Mississippian pericratonic arc terranes (Rubin *et al.*, 1990; Dickinson, 2000). Restoration of post-accretionary dextral faults brings YTT/Quesnellia closer to the Klamaths and

Sierras. Taken together, they constitute a belt that extends roughly the length of the North American margin. While detrital zircon populations in YTT suggest that it was once contiguous with the northern continent, those in the more southerly terranes favour a southerly origin near their present positions (Gehrels *et al.*, 2000). It may be that these terranes were all created as entities during a Devonian-Mississippian back-arc rifting event or set of events that affected much of the margin (Fig. 17A).

Margin-long subduction began in the mid-Devonian, as evidenced by magmatism the length of the Cordillera (Rubin *et al.*, 1990). After an initial compressional event, retreat of the down-going slab first caused extension, arc rifting and widespread syngenetic sulphide exhalation in rift basins, and then eventual detachment of a broad continent-margin arc complex from the continent and development of a marginal ocean or oceans behind it; the Slide Mountain ocean in the north, the Havallah basin in the south (Figs. 17A, B). The Kootenay terrane, Alaska Range, western Yukon-Tanana Upland and Selwyn basin represent mainly back-arc portions of the system that remained behind. In general, the tectonic style manifested in the YTT throughout Devonian-Mississippian time was dominantly extensional in character from the onset of arc development, punctuated by the brief compressional episodes that mark cycle boundaries II-III (*ca.* 357 Ma) and III-IV (*ca.* 342 Ma). A local collision between the southern frontal arc and the miogeocline resulted in the Antler orogeny within an overall extensional scenario (Dickinson, 2000). Subsequent to rifting, throughout the late Paleozoic, the highly extended North American margin was festooned with volcanic islands and intervening seas, with scattered emergent continental fragments: geologically comparable to the modern Indonesian region (Hamilton, 1979). Figure 17C depicts a possible configuration of the frontal arcs in Permian time, assuming the widest estimate for the back-arc ocean (Belasky *et al.*, 2002). Figure 17D shows the Permo-Triassic closure of the Slide Mountain ocean and original accretion of YTT and associated terranes at a more southerly latitude, as suggested by Early Jurassic ammonite distributions (Smith *et al.*, 2001).

Arc polarity in Quesnellia and eastern YTT was consistently west-facing, from Late Devonian through Early Permian time. In contrast, east-facing arc polarity is inferred for Stikinia in the Devonian and Pennsylvanian-Permian. These two opposing arcs were connected via the YTT to the north, which forms partial basement to both of them. Farther south, the Cache Creek ophiolitic terrane, with its profoundly exotic Late Permian Tethyan faunas, its oceanic plateaux and subduction-related assemblages, intervenes between the two long-lived arc terranes. Mihalynuk *et al.* (1994b) have shown that this peculiar present configuration could have resulted from a net counterclockwise rotation of Stikinia during the early Mesozoic with respect to Quesnellia and the continent margin. This event postdated closure of the Slide Mountain ocean in the Late Permian.

The story of the YTT and its affiliated terranes depicts a first-order cycle in the plate tectonic regime of the North American margin. In the Devonian, some 200-300 m.y. after initial continental rifting, subduction commenced and slab retreat led to the formation of a
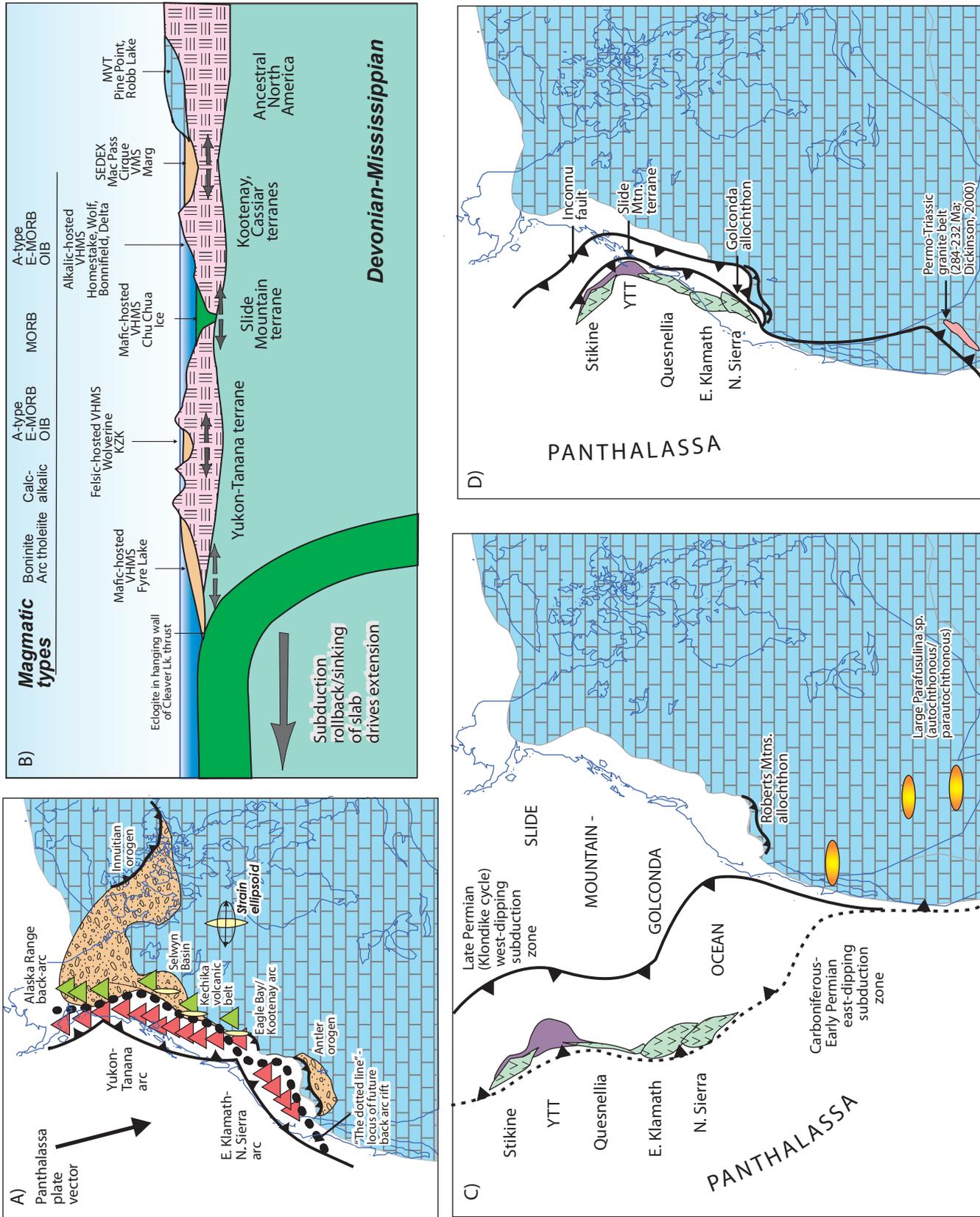
**Figure 17.** *Caption on facing page.*

complex, attenuated, southwest-Pacific style margin that persisted until the mid-Permian. Subsequent events reflect the reverse: advance of the continent towards its frontal arc. Permo-Triassic back-arc basin closure, the Sonoma orogeny (Miller *et al.*, 1984; Wyld, 1991; Ferri, 1997), was followed first by minor oceanward stepping of the Quesnel arc axis in the Triassic (Triassic volcanic rocks lie mainly west of YTT and Lay Range/Harper Ranch; see Wheeler and McFeeley, 1991); and then by eastward stepping of the Quesnel arc axis in the Jurassic, as shown by the well-developed Early Jurassic plutonic suite within YTT. This was followed shortly by final collapse and accretion of the combined Intermontane terranes in mid-Jurassic to Cretaceous time (Monger *et al.*, 1982; Hansen and Dusel-Bacon, 1998).

The cause of the fundamental mid-Permian shift from retreating to advancing subduction is not known. It predates Jurassic opening of the Atlantic Ocean by some 80 million years, and thus cannot be related to that obvious pulse of North American westward motion. Perhaps all of Pangea began to move west relative to its fringing arcs in Permian time, and the Atlantic nucleated as the Old World subcontinents were left behind. The other major unanswered question implied in this history is why, given the late Paleozoic wanderings of YTT, it eventually re-accreted to a location very near that of its most likely origin. There are two possible explanations. First, there is disagreement as to the maximum width of the Slide Mountain ocean, with estimates ranging from several thousands of kilometres (Belasky *et al.*, 2002; see Fig. 17B) to much less (Thompson *et al.*, this volume). Closure of a narrower back-arc ocean could favour "accordion tectonics" and re-accretion near sites of rifting. However, faunal evidence places the YTT along with its associated terranes considerably south in Permian (Stevens, 1995), Triassic (Orchard, this volume; Stanley and Senowbari-Daryan, 1999) and Early Jurassic (Smith *et al.*, 2001) time. Perhaps a more satisfactory explanation lies in the likely convoluted geometry of the post-rift margin. If detachment of YTT created a reentrant in the continent margin, then adjacent to its site of origin, a promontory would remain behind. The trajectory of YTT in late Paleozoic time seems to have been towards the south. During subsequent Mesozoic dextral transpression, northward motion of the far-travelled crustal fragment would eventually bring it to rest against the backstop of its once-adjacent ground.

## FUTURE RESEARCH

The Ancient Pacific Margin NATMAP project has increased our understanding of the anatomy and history of the Paleozoic YTT on many fronts. It has shown the multicyclic nature of arc development and VHMS formation in it, defined stratigraphic successions and arc *vs.* back-arc regions, and shown its role as basement to northern Quesnellia. Many of these advances have come about through systematic, detailed, regional mapping projects combined with isotopic, geochemical and other related studies. The project areas outlined on Figure 1 are like finely pixelated windows into this complex terrane. Elsewhere the resolution is far less. In particular, most of the western region of YTT between Stewart River and the B.C. Coast Mountains remains poorly known, and should be the focus of subsequent pioneering projects.

The precise location and nature of the YTT boundary in eastern Alaska and western Yukon needs further attention, in order to solve the thrust-*vs.*-detachment controversy and to refine which elements do and do not distinguish YTT from the parautochthonous assemblages of the Yukon-Tanana Upland. Similarly, the nature of its border in the Coast Mountains against Stikinia is only locally well-documented, given its major paleogeographic significance, and warrants further detailed examination.

The Snowcap assemblage stands out as the least-understood unit in the YTT. It proxies for basement; but with which element of the North American margin does it correlate: the Windermere Supergroup, the Lardeau Group, or even older stratified units? Systematic detrital zircon studies could shed light on this issue.

Within YTT, the nature and extents of Paleozoic metamorphic and deformational events need further clarification. In some parts of the terrane, notably the Big Salmon Complex and Stewart River area, complex overgrowths on zircons mean that conventional TIMS dating is too blunt an instrument to resolve multistage growth histories (Mihalynuk *et al.*, this volume; J. Ryan, personal communication, 2004), and future studies involving SHRIMP instrumentation are necessary.

The recognition of a Mississippian subduction complex located within a single thrust sheet in the Finlayson belt raises the question of continuity. Where is the rest of this sheet and what does it comprise? Presumably it roots west of the coeval arc facies in the Glenlyon area, but where and with what strike extent; and what lies still farther outboard?

The kinematics, magnitude, sense and sequence of motion on the Jules Creek and Blue Dome faults need to be established with greater certainty, in order to incorporate them effectively into Permian to Triassic tectonic models. Does the Blue Dome fault extend southward into southeastern YTT? Do pre-accretionary transcurrent faults play a role in the juxtaposition of the central structural belt with its neighbours in the Wolf Lake-Jennings River area (Roots *et al.*, this volume)? Other faults in YTT are inadequately understood as well. The Teslin fault is apparent in the Glenlyon area, but not farther north in the Stewart River area. Does all of its motion bleed

**Figure 17.** *(facing page) Paleogeographic reconstructions for YTT and related terranes. (A) Devonian-Early Mississippian reconstruction (*ca. 356 Ma): Sinistral-convergent margin with extension in overriding plate. Preferred position of Eastern Klamath and Sierran arcs from Gehrels* et al. *(2000). (B) Cartoon cross-section of tectonics and metallogeny of the northern Cordilleran margin in Late Devonian - Early Mississippian, Cycle II-III time. Concept after Hutchison (1980). (C) Mid-Permian reconstruction (*ca. 270 Ma, end of Cycle V, beginning of Cycle VI), with paleogeographic position of combined YTT-Stikinia-Quesnellia and Eastern Klamaths after Belasky* et al. *(2002). Autochthonous and parautochthonous localities of giant Parafusulina (West Texas, Sonora) are noted in Stevens (1994) and references therein. (D) Permo-Triassic reconstruction, showing initial accretion at a lower latitude. Sinistral fault and Permo-Triassic subduction zone in northern Mexico from Dickinson (2000).*

off into splays, or is it still cryptically present? How important were transcurrent faults *vs.* depth of erosion in shaping the elongate geometry of the southwestern YTT prong in the Coast Mountains?

The cause of Early Permian shortening in the Finlayson belt and Sylvester allochthon remains speculative. It heralded the mid-Permian subduction reversal, but its cause is not known. Was Stikinia the local collider, or was it related to margin-long changes in plate kinematics; if so, what were they?

The relationship of the Triassic clastic rocks to YTT, other terranes and to North America remains unclear. How firm a pin do they constitute? Are they a "hard" tie, a direct overlap in the sense of Unterschutz *et al.* (2002)? Or only more general indicators of a widespread depositional regime? At present, the single 'Tethyan' conodont (Orchard *et al.*, this volume) is an unexplained anomaly. Additional detailed isotopic and fossil provenance studies are called for.

This project has focused on the early protolith history of YTT and the parautochthonous continental margin of east-central Alaska, with much less emphasis on Mesozoic tectonics between the demise of the Klondike arc and final accretion. The enormous differences in metamorphic grades and levels of exhumation observed within the terrane and the parautochthonous continental margin assemblages are the result of Mesozoic as well as Paleozoic events. Pressure-temperature data and Early Jurassic $^{40}Ar/^{39}Ar$ cooling ages from amphibolite facies rocks in the Fortymile River assemblage and near the Teslin fault have been interpreted as the result of Jurassic accretion (Hansen, 1990; Dusel-Bacon *et al.*, 1995; Hansen and Dusel-Bacon, 1998). Similar studies could be expanded into other parts of the terrane, supplemented by other thermochronometric indicators. For instance, J. Ryan and M. Villeneuve (personal communication, 2004) have found Permian titanite overgrowths in the Fortymile River assemblage that could indicate peak metamorphism, followed by exhumation and final cooling in the Jurassic. In either case, what caused the metamorphism, and then the rapid exhumation? Were they linked, or related to Permo-Triassic subduction/collision on one hand, Jurassic amalgamation on the other?

More globally, what is the relationship of the YTT to the Mesozoic Whitehorse trough, in terms of stratigraphic and structural relationships? And what light does the Lithoprobe SNORCLE crustal reflection profile shed on collisional geometries and processes?

Here, we have divided the former Yukon-Tanana terrane (*cf.* Mortensen, 1992a) into two distinct entities, a parautochthonous continent margin terrane in the Alaska Range and Yukon-Tanana Upland, and an allochthonous, pericratonic Yukon-centred terrane that is expanded to include correlatives in the Coast Mountains and north-central B.C. Because the Yukon-Tanana terrane has long been considered allochthonous to North America, ever since it was first described and named by Coney *et al.* (1980), we have retained that name in its original meaning, while substantially modifying its spatial extents. This poses a nomenclatural problem, in that the name derives from the schists of the Yukon-Tanana Upland (Mertie, 1937; Foster *et al.*, 1973), which we now consider for the most part parautochthonous and no longer part of the terrane. Dusel-Bacon *et al.* (this volume), to avoid confusion, have chosen not to apply any specific name to the newly-defined parautochthonous terrane in Alaska. Since the Yukon-Tanana terrane as we now define it now includes little of its original type area, it may be appropriate to change its name. We leave that for a future time, when and if consensus is achieved on the model that we have presented.

## CONCLUSIONS

The YTT is composite more in a stratigraphic than in a tectonic sense. Most of its internal complexity derives from the repeated superposition of continent-margin magmatic arc suites, each one a set of related but variable facies. During the Devonian to Early Mississippian, the same rifted arc and back-arc tectonic setting that led to its separation from the continent also created a highly fertile environment for the formation of numerous syngenetic massive sulphide deposits that constitute the hallmark of its metallogeny. Its history from then until Cretaceous time can be summed up as an odyssey: detachment, departure, adventure and eventual return. Like Homer's hero, those long intervening years changed it to such a degree that only subtleties such as detrital zircons and early shared igneous suites still hint at its native origin. There it rests now, home again at last, leaning up against the neat ledger of passive margin history; rumpled, wild-featured, full of sea-faring tales. Listen.

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