

Sedimentology, Stratigraphy, and Provenance of the Upper Purcell Supergroup,  
southeastern British Columbia, Canada: Implications for Syn-depositional Tectonism,  
Basin Models, and Paleogeographic Reconstructions

by

David William Gardner  
B.Sc. Dalhousie University, 2006

A Thesis Submitted in Partial Fulfillment of the  
Requirements for the Degree of

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In the School of Earth and Ocean Science

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This thesis reports eight measured sections and >400 new detrital zircon U-Pb SHRIMP-II ages from the Mesoproterozoic (~1.4 Ga) upper Purcell Supergroup of southeastern British Columbia, Canada. The goal of my study is to constrain the depositional, tectonic and paleogeographic setting of the upper Purcell Supergroup.

Stratigraphic sections across the Purcell Anticlinorium, constructed from measured sections, reveal three syn-depositional growth faults: (1) paleo-Hall Lake, (2) paleo-Larchwood Lake, and (3) paleo-Moyie. Stratigraphic sections were combined into a fence diagram, revealing a large north-northeast trending graben bound to the east by the paleo-Larchwood Lake fault and to the west by the paleo-Hall Lake fault.

Five samples were collected for detrital zircon analysis along the eastern extent of exposed Purcell strata; one sample was collected from the western limit of strata. All samples are characterized by subordinate numbers of detrital zircons that yield Paleoproterozoic and Archean ages. Detrital zircon ages from the Sheppard Formation are dominated by 1500, 1700, 1750, and 1850 Ma grains. The overlying Gateway Formation is dominated by 1400-1450, 1700, 1850, and 1900 Ma zircon grains. The overlying Phillips, Roosville (east), and Mount Nelson formations are dominated by detrital zircon ages between 1375-1450 Ma and 1650-1800 Ma. Detrital zircon ages from the Roosville Formation (west) are dominated by 1500-1625 Ma grains.

Based on the margin perpendicular orientation of the long axis of syn-depositional grabens relative to Laurentia, and on the presence of syn-depositional aged zircons through the entire sedimentary succession, we interpret the upper Purcell Supergroup to have been deposited in a transpressional pull-apart basin setting, adjacent to a convergent/translational plate margin bound to the west by terranes now located in northeastern Australia.

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# Chapter 1

## INTRODUCTION

One of the most intriguing aspects of plate tectonics is the formation of supercontinents after ocean basin closures (Silver and Behn, 2008; Murphy and Nance, 2003). Laurentia was central to Rodinia (Hoffman, 1991), a supercontinent that culminated late in the Mesoproterozoic Eon. How Earth paleogeography changed during the lead up to and formation of Rodinia at 1.1 Ga is, therefore, a primary constraint on geodynamic models of supercontinent formation (Torsvik, 2003). The story of how Laurentia came to be incorporated into the centre of Rodinia lies recorded in the ancient rocks that formed the margins of Laurentia at that time.

The Purcell Supergroup in Canada and the contiguous Belt-Supergroup in the United States, deposited as part of a rift-fill sequence between 1470 and 1350 Ma, are thought to provide a record of sedimentation along the ancient west margin of Laurentia (present coordinates). Understanding the depositional and tectonic setting for these sediments can, therefore, be used to place constraints on basin models, and on what possible source terranes lay west of Laurentia (Ross, 1999).

The world class Sullivan sedimentary exhalative (SEDEX) deposit, located in southeastern British Columbia, Canada, is hosted in turbidites of the Lower Purcell Supergroup and was the focus of past study (Höy et al, 2000). For this reason the depositional and tectonic setting for the Lower Purcell Supergroup is well understood. This, however, is not the case for the Upper Purcell Supergroup.

The goal of this thesis is to elucidate the depositional and tectonic setting of the Upper Purcell Supergroup in southeastern British Columbia, Canada. Detailed measured sections and detrital zircon geochronology presented in this thesis provide new insight into, and constrain models of Belt-Purcell basin development and paleogeographic reconstructions of western Laurentia during assembly of the Rodinian supercontinent.

## **STUDY OVERVIEW**

Findings of the study are presented in two papers (Chapters 2 and 3). Chapter 2, entitled “Sedimentology and Stratigraphy of the Upper Purcell Supergroup, southeastern British Columbia, Canada; Implications for Syn-depositional Tectonism” examines the depositional history of the Upper Purcell Supergroup. Eight measured sections spanning the Purcell anticlinorium are the basis for four stratigraphic sections constructed across the current distribution of Upper Purcell rocks. We put forward a tectonic model explaining the distribution and facies of Upper Purcell Supergroup strata and syn-depositional faults. Our stratigraphic sections allow us to identify three cryptic syn-depositional faults.

Chapter 2 forms the basis for a paper submitted for publication in a peer reviewed journal, and is authored by myself, Stephen Johnston and Suzanne Paradis. Drs. Johnston and Paradis participated in the field work, providing direction and advice through short targeted visits. In addition, Dr. Paradis aided in interpretation of the economic significance of our findings. Dr. Johnston aided in the interpretation of the sedimentary facies and the tectonic implications of our findings. David James is acknowledged for providing additional advice concerning the interpretation of the sedimentary facies.

Chapter 3, entitled “Detrital Zircon U-Pb Provenance of the Upper Purcell Supergroup, southeastern British Columbia, Canada; Implications for Belt-Purcell Basin Models and Paleogeographic Reconstructions” examines the detrital zircon U-Pb provenance of five Upper Purcell Supergroup formations and provides constraint on the timing of changes in basin architecture and source terrane character for the basin.

Chapter three is co-authored with Stephen Johnston and William Davis and is the basis for a paper to be submitted for publication to a peer-reviewed journal. Dr. Davis aided in the analyses and interpretation of detrital zircons. Dr. Johnston aided in interpretation of detrital zircon data and the tectonic implications of our findings.

## **METHODS**

Fieldwork was completed during July and August of 2006 and 2007 in the Purcell Mountains and western Rocky Mountains of southeastern British Columbia, Canada as part of the Geological Survey of Canada’s Targeted Geoscience Initiative-3 Cordilleran project. Detailed mapped and measured sections were acquired from eight locations spanning the Purcell anticlinorium. Due to significant amounts of cover, our stratigraphic sections are a combination of detailed transects and measured sections that were measured using a 1.5 m Jacob’s staff and the Geological Survey of Canada’s Ganfeld field mapping system. While mapping, samples were acquired from temporally and stratigraphically well-constrained sedimentary units within Upper Purcell Supergroup formations for detrital zircon geochronology. Detrital zircon samples were analyzed and dated on the Sensitive High Resolution Ion Microprobe II (SHRIMP II) at the Geological Survey of Canada in Ottawa, Ontario, Canada.

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## Chapter 2

### **Sedimentology and stratigraphy of the upper Purcell Supergroup, southeastern British Columbia, Canada: Implications for syn-depositional tectonism**

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#### **ABSTRACT**

This paper investigates the depositional and tectonic setting for the upper Purcell Supergroup, the upper most sediments of the Mesoproterozoic Purcell Supergroup in Canada. The sedimentary succession has subsequently been thrust into the northwest trending Purcell Anticlinorium, a major fault bend fold that developed above a Cretaceous detachment ramp. Measured sections spanning the Purcell Anticlinorium indicate upper Purcell Supergroup sediments were deposited in three broad regressive cycles. Stratigraphic sections across the Purcell anticlinorium, constructed from measured sections, reveal three syn-depositional growth faults: (1) paleo-Hall Lake, (2) paleo-Larchwood Lake, and (3) paleo-Moyie. Stratigraphic sections were combined into a fence diagram, revealing a large north-northeast trending graben bound to the east by the paleo-Larchwood Lake fault and to the west by the paleo-Hall Lake fault. The graben isolated and controlled upper Purcell Supergroup sedimentary unit thicknesses and distribution.

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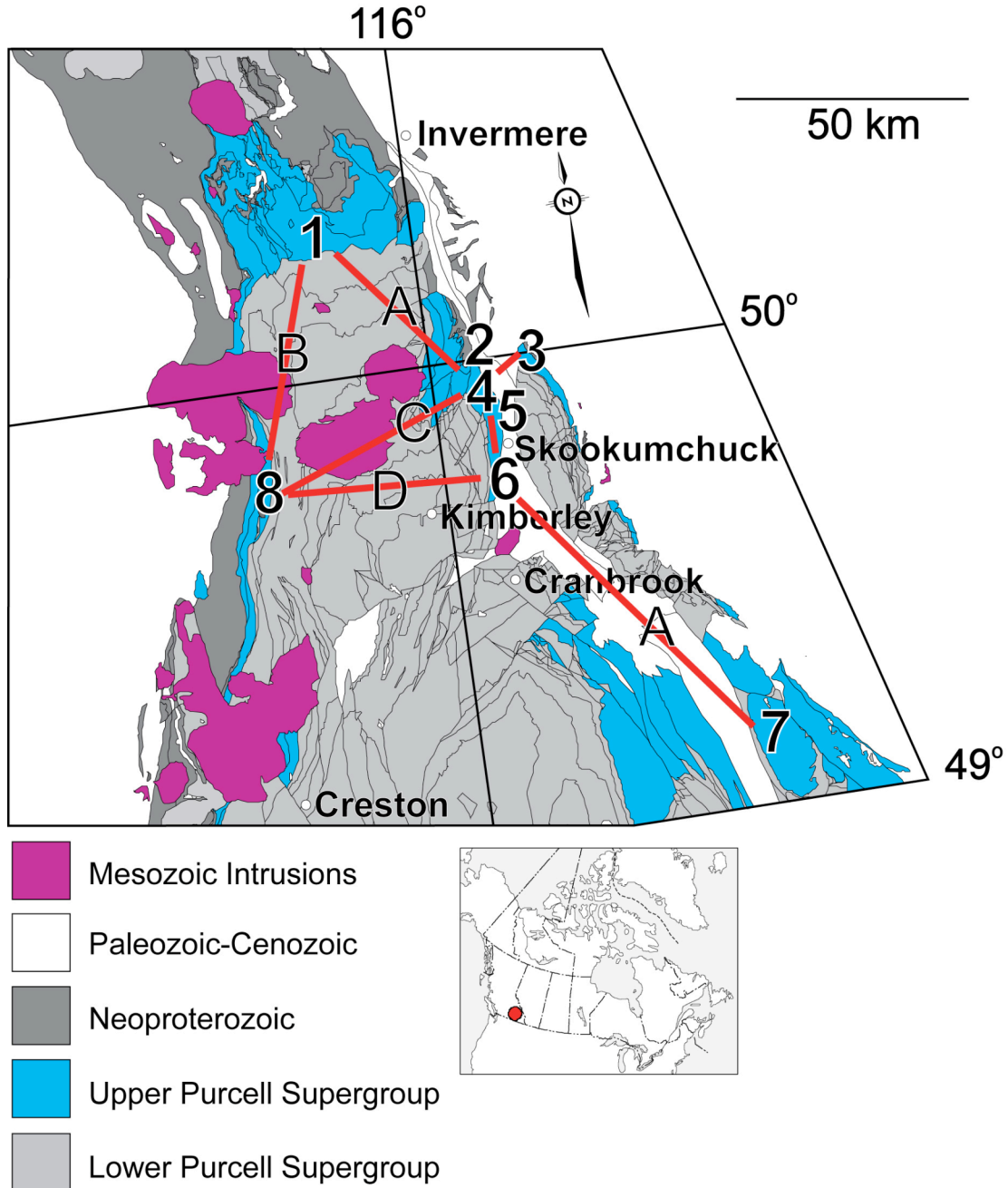
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The orientation of the graben provides a first order constraint on the orientation of the stress responsible for basin formation. Assuming that sigma one was aligned parallel with the long axis of the graben, and that the north-south orientation of the margins of the Purcell anticlinorium approximately reflect the original margins of the basin, implies that the upper Purcell Supergroup was deposited within a pull-apart that developed in response to dextral shear, perhaps analogous to the modern day southern Caspian Sea.

**KEYWORDS** Belt-Purcell Supergroup; Mesoproterozoic; Sedimentary basins; Stratigraphy; Southern British Columbia.

## **INTRODUCTION**

The Purcell Supergroup in Canada and the contiguous Belt Supergroup in the United States were deposited as part of a rift-fill sequence between 1470-1350 Ma (Evans et al., 2000). The sedimentary succession is now exposed in the northwest trending Purcell Anticlinorium, a major fault bend fold developed above a ramp in a late Cretaceous thrust fault (Price, 1964) (Fig. 2.1). The Sullivan deposit, a world-class sedimentary exhalative (SEDEX) deposit, is hosted in turbidites of the lower Purcell Supergroup (Lydon, 2000). Because of its economic significance, the lower Purcell Supergroup has been extensively studied and its stratigraphy and depositional setting are well understood (Höy, 1982; Höy et al., 2000). This is not the case for the upper Purcell Supergroup. No SEDEX mineral deposits have been found within the upper Purcell Supergroup and, as a result, this siliciclastic and carbonate sequence has received less attention. Ross and Villeneuve (2003), based on detrital zircon studies, determined that the lower to upper Purcell Supergroup boundary was coincident with a change in



**Figure 2.1.** Regional map of the Purcell Supergroup in southeastern British Columbia, Canada illustrating the current distribution of the upper Purcell Supergroup around the Purcell Anticlinorium, and the locations of mapped and measured sections 1 through 8 (NAD 83, NTS 82 G, F, J, and K), and the locations of stratigraphic sections (A, B, C, and D). The location of the study area is indicated in the inset map at lower right. Measured sections: (1) Coppercrown Creek, (2) Canal Flats, (3) Northern Hughes Range, (4) Larchwood Lake North, (5) Larchwood Lake South, (6) Echoes Lakes, (7) Galton Range, and (8) Grey Creek Pass.

provenance. They attributed this change to syn-depositional tectonism, modification of Purcell basin architecture, and a change in the nature of the source terrane. Höy (1992) conducted regional mapping of the upper Purcell Supergroup. Based on apparent changes in the thickness of units within the upper Purcell Supergroup, Höy suggested that basin evolution involved significant syn-depositional extensional block faulting. These indications of ongoing syn-depositional tectonism within the Purcell basin imply significant SEDEX potential for the upper Purcell Supergroup; however none have been found to date.

This study aims to: (1) test and refine sedimentary unit correlations within the upper Purcell Supergroup; (2) use changes in unit lithology, thickness and facies, to constrain the location and nature of syn-depositional faults within the Purcell basin; and (3) utilize the orientation and nature of syn-depositional structures and the distribution and character of stratigraphic units to help ascertain the tectonic setting and evolution of the basin. In this way we hope to determine the geographic regions and stratigraphic units with the highest potential for upper Purcell Supergroup SEDEX mineralization. We first review the geological setting of the upper Purcell Supergroup in southeastern British Columbia, Canada. New data, consisting of eight measured sections from around the anticlinorium, are presented. These measured sections are the basis for four stratigraphic sections constructed across the current distribution of upper Purcell rocks. Finally, we put forward a tectonic model explaining the distribution and facies of upper Purcell Supergroup strata and syn-depositional faults. Our stratigraphic sections allow us to identify three cryptic syn-depositional faults not able to be recognized in the field.

## **BACKGROUND**

The Purcell Supergroup is commonly split into four informal groups: the Basal, the lower, the Middle Carbonate, and the upper Purcell. Similarly, the contiguous Belt Supergroup in the United States is split into four informal groups: the lower, the Ravalli, the Middle Carbonate, and the Missoula (Tables 2.1 and 2.2). The upper Purcell Supergroup, the focus of our study, consists of, in ascending order, the Nicol Creek, Sheppard, Gateway, Phillips, Roosville, and Mount Nelson formations. The broadly correlative Missoula Group (Gardner and Johnston, 2007; McMechan, 1981) consists of, in ascending order, the Purcell Lava, Sheppard, Mount Shields, Bonner, McNamera, Garnet Range and Pilcher formations. Strong correlations can be made between basalt flows of the Nicol Creek Formation and the Purcell Lava, and between distinct micaceous sandstones of the Phillips and Bonner formations. While these marker units constrain correlation of intervening units, remaining correlations are less certain.

The Nicol Creek Formation is comprised of amygdaloidal and phenocrystic basalt flows, shallow marine volcanoclastic to siliciclastic sediment, and minor tuff (McMechan et al., 1980). Zircon from a rhyolitic tuff within the contiguous Purcell Lava in the USA has a U-Pb age of 1443 +/- 7 Ma (Evans et al., 2000). The Sheppard Formation is comprised of fine-grained sandstone and dolomitic limestone, and unconformably overlies the Nicol Creek Formation (Höy, 1992). Sedimentary facies of the Sheppard Formation grade from siliciclastic sediments at the formation base, to stromatolitic and oolitic, dolomitic limestones at the top (Höy, 1992). A series of massive stromatolitic and oolitic,

**Table 1** The stratigraphic nomenclature of the Upper Purcell Supergroup in Canada and the corresponding stratigraphy of the Missoula Group in the United States employed in past studies and our revised nomenclature developed in this study (Höy, 1992; McGill and Sommers, 1967; Pope, 1991; Reesor, 1996).

<b>Prior To This Study</b>					<b>This Study</b>	
<b>Upper Purcell Supergroup (Canada)</b>					<b>Upper Purcell Supergroup Revised</b>	
(7) Grey Creek Pass, western Purcell Mountains (Reesor, 1996)	(1) Coppercrown Ck., B.C., northern Purcell Mountains (Pope, 1991)	(3&6) North Skookumchuck, B.C. (Hoy, 1992)	(5) South Skookumchuck, B.C. (Hoy, 1992)	Missoula Group (USA)  Lewis and Clark Range, Montana (McGill and Sommers, 1967)	Northwestern Purcell Mountains (this study)	(3&6) Southeastern Purcell Mountains (Hoy, 1992; used in this study)
Mount Nelson Fm.	Mount Nelson Fm.	Mount Nelson Fm.		Pilcher Fm.  Garnet Range Fm.	Mount Nelson Fm.	
La France Ck. Gp.	Dutch Ck. Fm.	Dutch Ck. Fm.	Roosville Fm.	McNamara	Coppercrown Ck. Mb. (new) Roosville Fm.	Roosville Fm.
			Phillips Fm. Gateway Fm.	Bonner Fm. Mount Shields Fm.	Dutch Ck. Group	Phillips Fm. Gateway Fm.
Coppery Ck. Gp.	Gateway Fm.	Sheppard Fm. Nicol Ck. Fm.	Sheppard Fm. Nicol Ck. Fm.	Sheppard Fm. Purcell Lava	Sheppard Fm.	Sheppard Fm. Nicol Ck. Fm.

**Table 2** Revised formation nomenclature of the Upper Purcell Supergroup in Canada developed in this study, the formation nomenclature of the contiguous Missoula Group in the USA, and the generalized sedimentary facies of each formation.

Northwestern Purcell Supergroup, Canada		Southeastern Purcell Supergroup, Canada		Belt Supergroup, USA		Description		Depositional Environment	
Dutch Creek Group	Mount Nelson Fm			Pitchee Fm		Thick, well bedded units of white ortho-quartzite, buff weathered dolomite, purple dolomite, and argillite	Shallow Marine		
	Coppercrown Ck Member (new)	Roosville Fm		McNamara Fm		Dark grey to green argillite and siltstone with fine- to medium-grained dolomitic sandstone	Tidal Flat to Lagoonal		
	Roosville Fm			Bonner Fm		Thin to massively bedded pink-purple micaceous sandstone and siltstone	Foreshore Fluvial		
Sheppard Fm		Phillips Fm		Mount Shields Fm		Light to dark, green-grey succession of siltstone and sandstone, with rare buff dolomite beds	Lagoonal		
		Gateway Fm							
		Sheppard Fm		Sheppard Fm		Calcareous light green-grey to buff, fine- to medium-grained sandstone and siltstone interspersed with stromatolitic and oolitic dolomatized limestone beds and massive medium-grained non-calcareous sandstone beds	Intertidal		
		Nicol Creek		Purcell Lava		Grey-green, amygdaloidal and phenocrystic basalt flows interspersed with occasional fine siliceous sandstone beds	Subaerial – Shallow Marine		

dolomitized limestone beds mark the formation top (Höy, 1992). The Gateway Formation overlies the Sheppard Formation. It is comprised of fine-grained, light grey-green siltstone and sandstone with minor dolomitic limestone. The base of the Gateway Formation is marked by the first occurrence of salt casts, mud cracks, and rip-up clast beds within siliceous fine-grained sediments that overlie the massive dolomitized limestone beds that mark the top of the Sheppard Formation (Höy, 1992; McMechan, 1981). Sedimentary facies of the Gateway Formation fine upwards from predominantly fine-grained sandstone at the formation base to fine-grained siltstone and argillite at the formation top (Höy, 1992). The north tapering Phillips Formation is comprised of purple, micaceous sandstone and siltstone (Höy, 1992). The Libby Tuff, an ash layer at the top of the contiguous Bonner Formation in the USA has a U-Pb age of 1401 +/- 6 Ma (Evans et al., 2000). The Phillips Formation pinches out at Larchwood Lake, northwest of Skookumchuck, British Columbia (Carter and Hoy, 1987; Gardner and Johnston, 2007; Höy, 1992). The Roosville Formation overlies sandstone of the Phillips Formation and predominantly comprises dark grey-black, fine-grained, siltstone and argillite with occasional massive stromatolitic, dolomitic sandstone beds (Höy, 1992). Pinch out of the north tapering Phillips Formation at Larchwood Lake makes the distinction between the Gateway and Roosville Formations difficult (Gardner and Johnston, 2007). In this study I mark the base of the Roosville Formation by the first occurrence of massive stromatolite beds within finely laminated, dark grey-black argillite and siltstone. In the northwestern Purcell Mountains the top of the Roosville Formation coarsens from predominately dark argillite to a purple-green, dolomitic, medium- to coarse-grained, arkose sandstone unit, referred to here informally as the Coppercrown Creek Member (new in this study). The

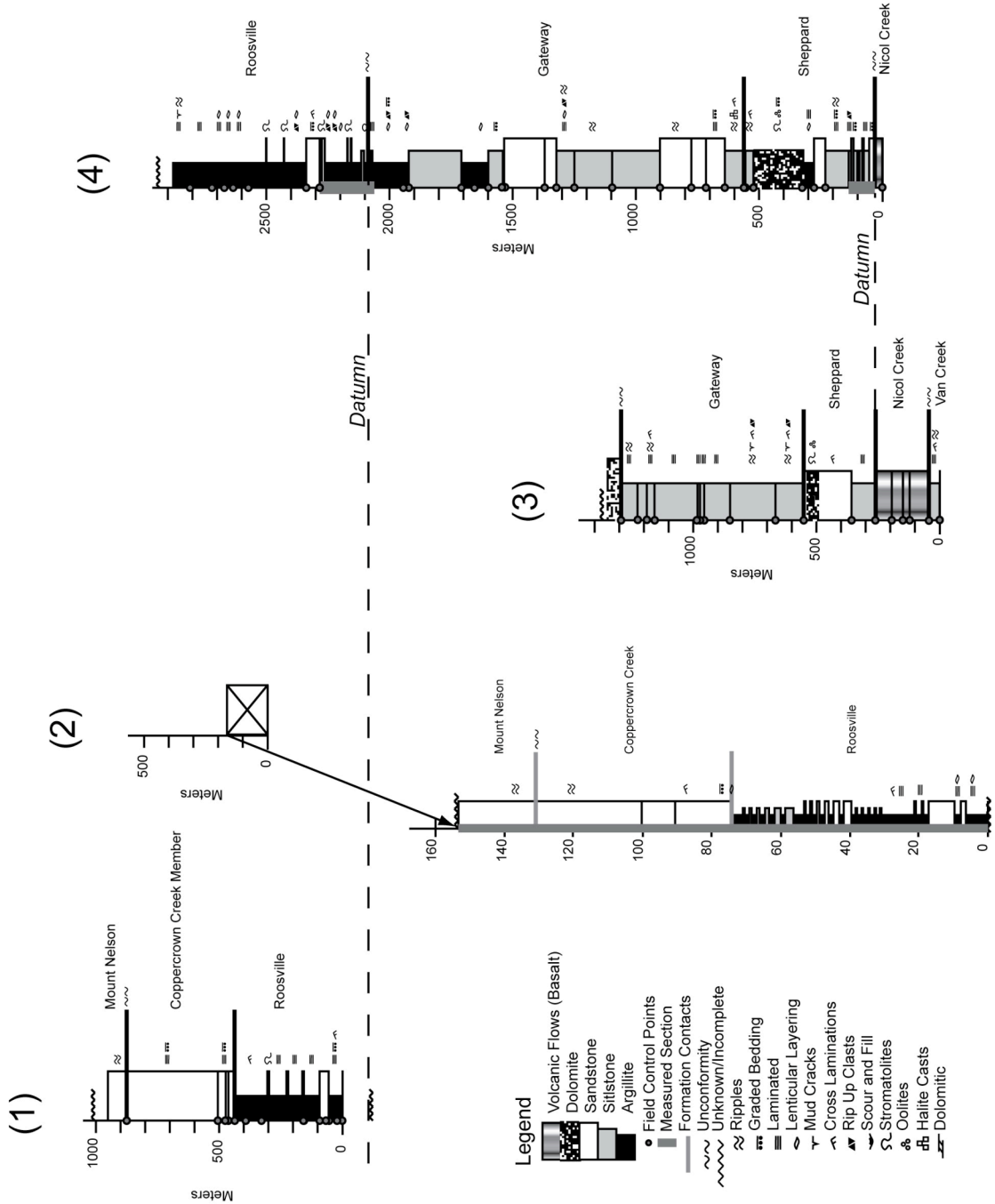
Mount Nelson Formation, whose base is marked by a white, well sorted, quartz arenite sandstone, overlies the Coppercrown Creek Member. The Mount Nelson Formation consists of shallow marine sandstone, calcareous argillite, and dolomite. Root (Root, 1987) suggested that a hiatus in deposition explains the dramatic change in lithology between the top of the Roosville Formation and the base of the Mount Nelson Formation.

## **MEASURED SECTIONS**

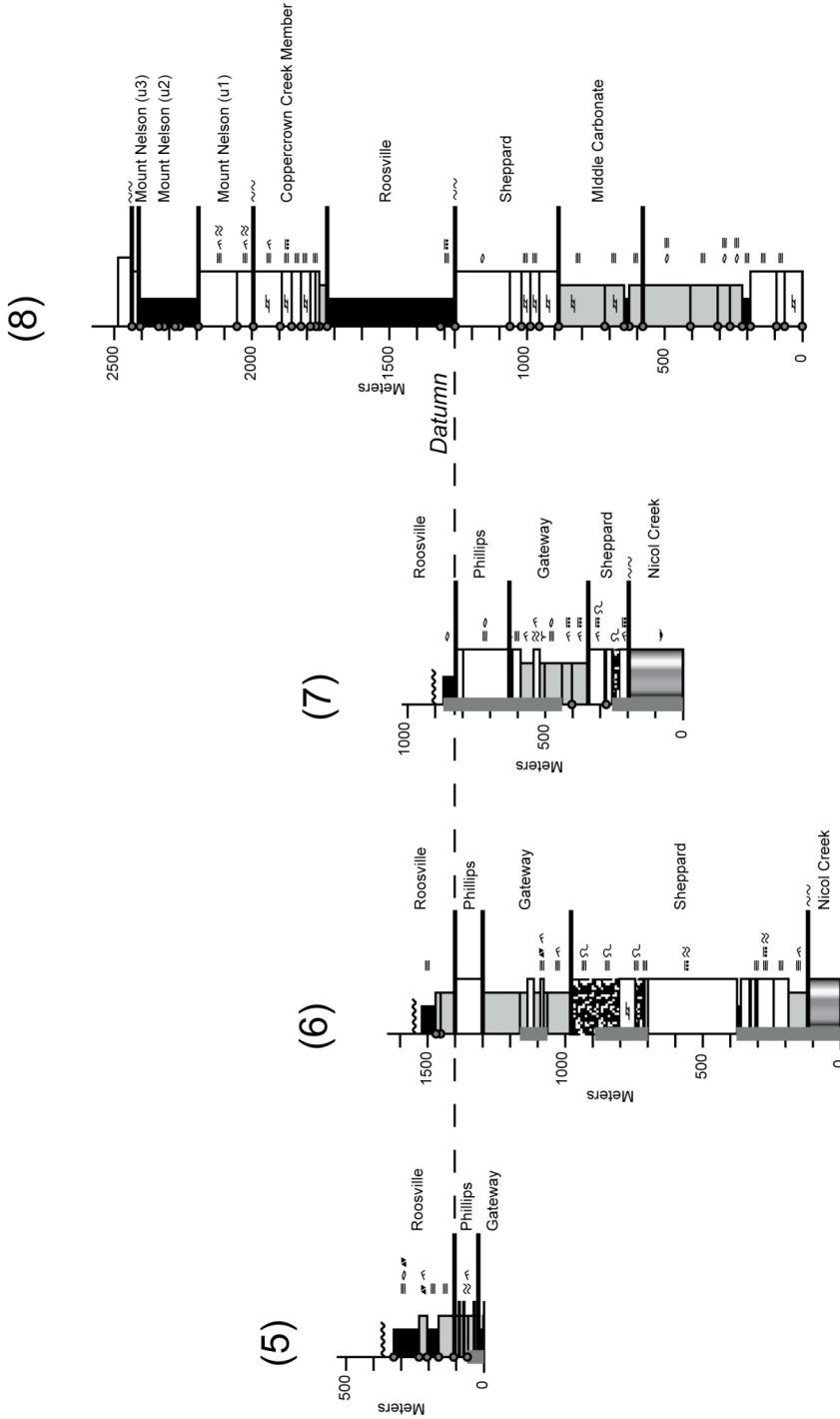
Detailed stratigraphic sections were described and measured in eight locations spanning the Purcell Anticlinorium: (1) Coppercrown Creek, (2) Canal Flats, (3) the Northern Hughes Range, (4) Larchwood Lake North, (5) Larchwood Lake South, (6) Echoes Lake, (7) the Galton Range, and (8) Grey Creek Pass (Fig. 2.1; data in Fig. 2.2). Here we provide detailed descriptions of the individual measured sections, followed by our interpretation of the depositional settings that gave rise to these sedimentary successions.

### **Coppercrown Creek (1)**

An approximately 950 m thick section was measured through the Roosville Formation, including the Coppercrown Creek Member, and Mount Nelson Formation at Coppercrown Creek, west of Invermere, British Columbia (Fig. 2.2 a). The Roosville Formation is >875 m thick and is composed of dark grey to green, finely bedded argillite with minor buff to grey, dolomitic, algal laminitic to massive, thick sandstone beds. The uppermost 438 m of the Roosville Formation forms the Coppercrown Creek Member. The member coarsens upward from argillite to purple-grey, medium to coarsely grained,



**Figure 2.2.** (a): Detailed mapped and measured sections from (1) Coppercrown Creek (base of section UTM 5575176N, 545345E), (2) west of Canal Flats (base of section UTM 5542009N, 584425E), (3) the Northern Hughes Range (base of section UTM 5538648N, 597094E), (4) north of Larchwood Lake (Larchwood Lake North); (base of section UTM 5533455N, 582590E). All section locations correspond to locations indicated on Figure 1 and are referred to numerically in following figures. The legend shown here applies to all following measured section plots and diagrams.



**Figure 2.2.** (b): (5) south of Larchwood Lake (Larchwood Lake South) (base of section UTM 5533196N, 586228E), Detailed mapped and measured sections from (6) Echoes Lakes (base of section UTM 5524540N, 586261E), (7) the Galton Range (base of section UTM 5442291N, 640660E), and (8) at Grey Creek Pass (base of section UTM 5495869N, 527643E). All section locations correspond to locations indicated on Figure 1 and are referred to numerically in following figures.

dolomitic sandstone. The overlying Mount Nelson Formation is >75 m thick and is composed of a white, well-sorted quartz arenite sandstone/quartzite.

### **Canal Flats (2)**

An approximately 150 m thick section was measured through the Roosville Formation, including the Coppercrown Creek Member, and Mount Nelson Formation west of Canal Flats, British Columbia (Fig. 2.2 a). Approximately 130 m of section was measured through the top of the Roosville Formation. It is composed of dark grey to green, finely bedded argillite with minor buff to grey, dolomitic, algal laminitic to massive, thick sandstone beds. The uppermost approximately 55 m of the Roosville Formation forms the Coppercrown Creek Member. The member coarsens upward from argillite to purple-grey, medium to coarsely grained, dolomitic sandstone. The overlying Mount Nelson Formation is >30 m thick and is composed of a white, well-sorted quartz arenite sandstone/quartzite.

### **Northern Hughes Range (3)**

A 1443 m thick section measured in the Northern Hughes Range extended from the top of the underlying Middle Carbonate through the Nicol Creek, Sheppard, and Gateway formations (Fig. 2.2 a). The Nicol Creek Formation is 216 m thick and is dominantly composed of green-mauve to grey, amygdaloidal basalt flows with minor green-mauve volcanoclastic sediments. The Sheppard Formation overlies the Nicol Creek Formation and is 293 m thick. It coarsens from green-grey siltstone and fine sandstone at the base of the formation to white quartz arenite, buff-green dolomitic sandstone, and buff oolitic and stromatolitic limestone/dolostone at the formation top. The Gateway Formation overlies carbonates of the Sheppard Formation, its base is marked by mud

cracks, rip-up clast beds, ripples and cross bedding. It is 741 m thick, and is composed of green-grey, finely bedded siltstone. The top of the Gateway Formation is an unconformity, above which are siliciclastic strata of the Neoproterozoic Windermere Supergroup.

#### **Larchwood Lake North (4)**

Approximately 2810 m of section was measured north of Larchwood Lake through the Nicol Creek, Sheppard, Gateway, and Roosville formations (Fig. 2.2 a). Thirty meters of grey-green, amygdaloidal basalt form the top of the Nicol Creek Formation. The Sheppard Formation is 531 m thick and is dominated by green-buff to grey fine-grained siltstone and sandstone. Massive stromatolitic and algal laminated, sandy limestone/dolomite beds mark the top of the formation and are interbedded with siltstone clasts similar to those forming the lower part of the formation. The Gateway Formation is 1593 m thick and is composed of grey-green siltstone to very fine sandstone and minor dolostone. Salt casts, ripple marks, and cross bedding mark the base of the Gateway Formation. The Roosville Formation is a minimum of 656 m thick and is incomplete north of Larchwood Lake. It predominantly comprises dark grey to black argillite and siltstone with occasional massive, stromatolitic, sandy dolomite beds. The absence of the Phillips Formation north of Larchwood Lake makes differentiation of the Gateway and Roosville formations difficult. We mark the base of the Roosville Formation by the first occurrences of massive stromatolitic, sandy dolomite beds within dark grey-black argillite.

#### **3.5. Larchwood Lake South (5)**

Three hundred and twenty seven meters of section was measured south of Larchwood Lake through the Gateway, Phillips and Roosville formations (Fig. 2.2 b). Twenty meters of section was measured through the top of the Gateway Formation. It is composed of light to dark green, finely laminated to bedded argillite and siltstone. The Phillips Formation is approximately 144 m thick and is composed of micaceous, interbedded green to purple sandstone and siltstone, and massive pink sandstone. The contact between the Gateway and overlying Phillips Formation is gradational over approximately 50 m. The Roosville Formation is composed of dark-grey to black argillite interbedded with minor buff dolomitic sandstone beds. The contact between the Phillips Formation and the overlying Roosville Formation is gradational over approximately 10 m.

#### **Echoes Lakes (6)**

A 1471 m section was measured near Echoes Lakes, southwest of Skookumchuck, BC through the Nicol Creek, Sheppard, Gateway, Phillips, and Roosville formations (Fig. 2.2 b). Sixty-nine meters of grey-green, amygdaloidal basalt flows forms the top of the Nicol Creek Formation. The overlying Sheppard Formation is 909 m thick and is composed of light to medium green siltstone and sandstone with minor dolomite and argillite at the base of the formation. Sedimentary facies coarsen to buff-green, medium grained sandstone and stromatolitic/algal, dolomatized limestone at the top of the Sheppard Formation. The overlying Gateway Formation is approximately 286 m thick and is composed of green to purple very fine-grained siltstone and sandstone. The top and bottom of the Gateway Formation are covered and the total thickness is therefore an estimate. Mud cracks, rip-up clast beds, and ripples are common near the base of the

Gateway Formation. The Phillips Formation does not crop out in the Echoes Lakes section. The Roosville Formation is at least 100 m thick; only the base of the formation is exposed. It is composed of dark grey to black, well-laminated, calcareous argillite and siltstone.

### **Galton Range (7)**

Approximately 870 m section was measured in the southern Galton Range near Red Canyon Creek and Phillips Creek through the Nicol Creek, Sheppard, Gateway, Phillips, and Roosville formations (Fig. 2.2 b). Two hundred and twelve meters of green-mauve, phenocrystic to amygdaloidal basalt flows was measured through the top of the Nicol Creek Formation. The overlying Sheppard Formation is approximately 132 m thick and is composed of green grey siltstone, white quartz arenite, buff dolomitic algal/stromatolite beds and dolomitic sandstone. The top of the Sheppard Formation is marked by a series of massive, stromatolitic and oolitic, dolomitized limestone beds. The Gateway Formation is approximately 498 m thick and consists of light to medium green siltstone and very fine sandstone. The base of the Gateway Formation is not exposed; however, the fine-grained siliceous nature of the rocks, and presence of mud cracks, rip up clast beds, and ripples are characteristic of the Gateway Formation. The Phillips Formation is 195 m thick and is composed of purple-mauve to green, micaceous, bedded sandstone and siltstone. The contact between the top of the Gateway Formation and the base of the Phillips Formation is gradational and is marked by an increase in mica and change to purple colour over approximately 10 m. Approximately 45 m of section was measured through the base of the Roosville Formation. It is composed of dark grey to black, finely bedded to lenticular argillite and siltstone, with minor dolomitic, medium

grained sandstone. The contact between the Phillips and Roosville formations is gradational over approximately 10 m.

### **Grey Creek Pass (8)**

A 1550 m thick section was measured at Grey Creek Pass through the Sheppard, Roosville, Coppercrown Creek Member, and Mount Nelson formations (Fig. 2.2 b). The Sheppard Formation is 376 m thick and is composed of light to medium grey-green, fine-grained sandstone and minor dolostone. Both Gateway and Phillips formations are absent; therefore the Roosville Formation directly overlies the Sheppard Formation. The Roosville Formation is 733 m thick and coarsens from dark grey to black, calcareous, laminated argillite and siltstone at its base to dolomitic sandstone of the Coppercrown Creek Member at its top. The Coppercrown Creek Member is 268 m thick and coarsens from argillite to green-grey, medium grained, slightly dolomitic sandstone. The Mount Nelson Formation is in total 441 m thick and can be split, in ascending order, into units one to three. Unit 1 is 199 m thick and is composed of white, well sorted, quartz arenite sandstone/quartzite. Unit 2 is 217 m thick and is composed of dark grey to black, laminated argillite and siltstone. Unit 3 is 25 m thick, and consists of buff, massively bedded dolostone, and is unconformably overlain by sediments of the Neoproterozoic Windermere Supergroup.

### **DEPOSITIONAL SETTINGS**

Based on the distribution of correlative sedimentary successions, our measured sections can be split broadly into two geographically separate packages: (1) a southeastern package that includes the measured sections in the Hughes Range, at

Larchwood Lake North and South, at Echoes Lakes, and in the Galton Range; and (2) a northwestern package that includes the measured sections at Coppercrown Creek, west of Canal Flats, and at Grey Creek Pass (Fig. 2.2).

### **Southeastern Depositional Setting**

The amygdaloidal character of the Nicol Creek basalt flows, together with the lack of pillow basalts, implies a sub-aerial eruptive environment. Sandstone beds with well developed ripple marks between basalt layers implies periodic inundation. Fine-grained clastic sediments with ripple marks and cross bedding, and stromatolitic and oolitic limestone beds of the overlying Sheppard Formation are characteristic of an intertidal shallow-marine depositional environment. Intertidal shallow-marine dolomitic limestone at the top of the Sheppard Formation pass upward into fine-grained siliciclastic siltstone and sandstone of the Gateway Formation. Halite casts, mud cracks, rip-up clast beds, ripple marks, and cross bedding in fine grained siliciclastic sediments of the Gateway Formation are characteristic of a lagoonal depositional environment with intermittent subaerial exposure. The relatively coarse grain size, oxidized nature (purple colour), and presence of ripple marks and cross-bedding within the overlying Phillips Formation sandstones suggests a foreshore-fluvial depositional environment. We interpret the fine-grained, finely bedded, dark argillite of the Roosville Formation as recording a lagoonal tidal-flat depositional environment, and the arkosic, rippled and cross-bedded Coppercrown Creek Member sandstones as recording a fluvial environment. The well sorted mature sandstone of the Mount Nelson Formation are characteristic of a shallow marine depositional environment (Pope, 1991).

Transition from sub-aerial amygdaloidal basalt flows of the Nicol Creek Formation to deposition of intertidal sediment and carbonates of the Sheppard Formation suggests a transgressive, basin-ward shift in depositional environment and a rise in relative sea level. Hence we interpret the Nicol Creek—Sheppard Formation boundary as an unconformity that corresponds with a flooding surface. Sedimentary facies in the Sheppard, Gateway and Phillips formations record a single continuous shallowing upwards sequence from the intertidal Sheppard Formation, through the lagoonal Gateway Formation, to the fluvial oxidized sandstone of the Phillips Formation. We interpret this up-section shallowing of sedimentary facies as a record of a single major regression. The base of the Roosville Formation, along which fluvial Phillips Formation sandstones are overlain by deeper water lagoonal argillites, is interpreted as an unconformable flooding surface. The Roosville Formation records a second regressive sequence, culminating in deposition of fluvial Coppercrown Creek Member sandstones. The mature shallow marine sandstone of the overlying Mount Nelson Formation requires a relative rise in sea level and suggests that the base of the Mount Nelson Formation is an unconformable flooding surface that marks the base of a third regressive sequence.

### **Northwestern Depositional Setting**

The northwestern Sheppard Formation is more siliceous, and lacks the massive stromatolitic limestone beds that mark the top of the formation to the east. The fine-grained sandstone and minor dolostone of the Sheppard Formation at Grey Creek Pass records deposition in a shallow marine-intertidal depositional environment. These shallow marine sedimentary rocks are abruptly overlain by finely laminated, calcareous, black argillite of the Roosville Formation; the Gateway and Phillips formations are both

missing. The abrupt transition from Sheppard Formation sandstone to argillite of the Roosville Formation, together with the absence of the Sheppard Formation stromatolite beds, and the Gateway and Phillips formations, indicates that the base of the Roosville Formation is an unconformity.

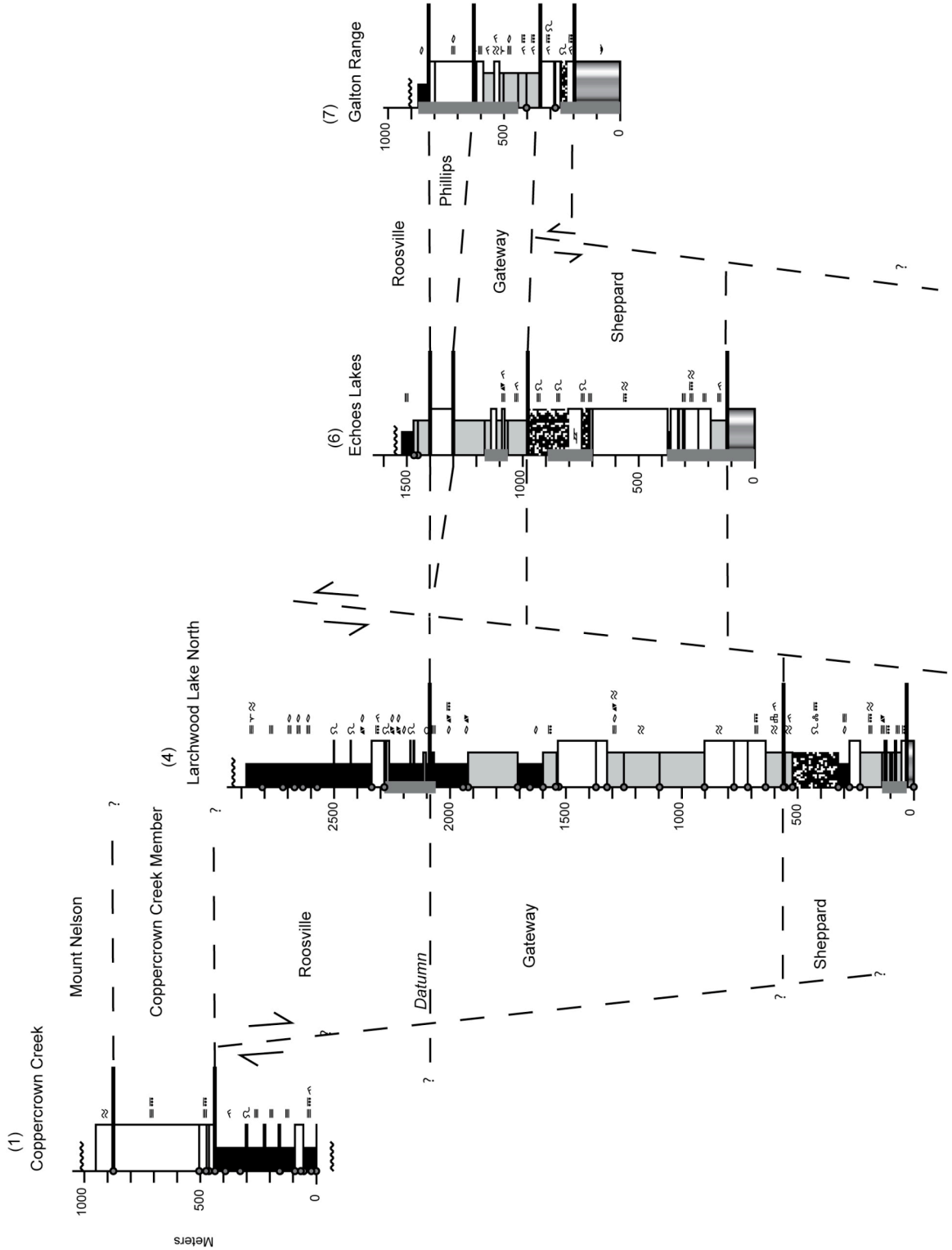
Sedimentary facies of the Roosville Formation shallow upwards from lagoonal tidal flat black argillites at the formation base to arkosic fluvial sandstone of the Coppercrown Creek Member at the formation top, recording a regressive depositional sequence. Sedimentary facies of the Mount Nelson Formation are characteristic of a shallow marine depositional environment (Pope, 1991). Transition from immature fluvial sandstones of the Coppercrown Creek Member to the mature marine sandstones of the Mount Nelson Formation indicates that the base of the Mount Nelson Formation is an unconformable flooding surface, marking the base of another regressive sequence.

## **REGIONAL STRATIGRAPHIC SECTIONS**

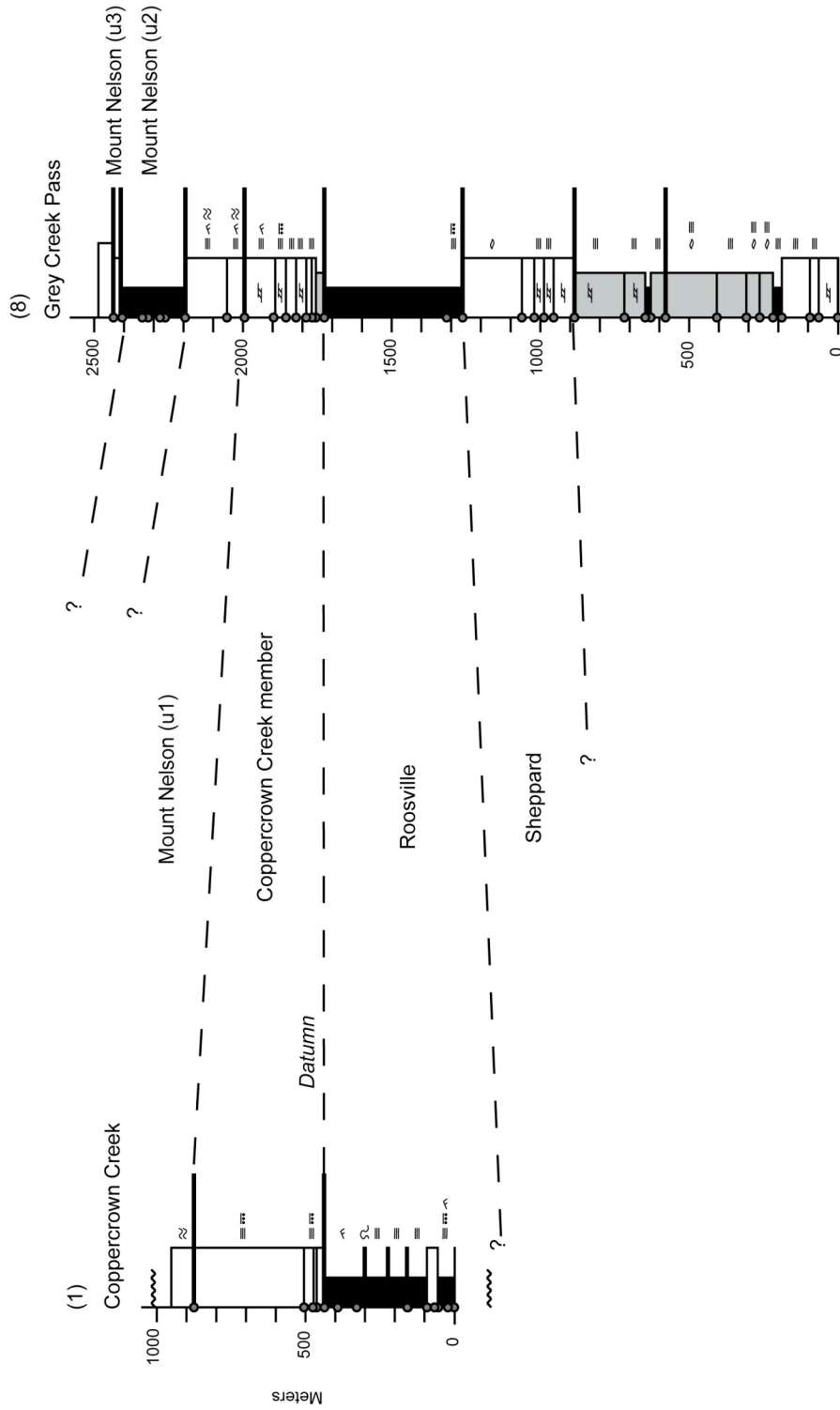
Four regional stratigraphic sections, A, B, C, and D were constructed from our measured sections (Locations on Fig. 2.1; Sections Figs. 2.3, 2.4, 2.5, and 2.6).

### **Section A**

Stratigraphic section A runs north-south along the east side of the anticlinorium and utilizes, from north to south, the Coppercrown Creek, Larchwood Lake North, Echoes Lakes, and the Galton Range measured sections (Fig. 2.3). Three major variations in unit thickness are evident: (1) northward thickening of the Sheppard Formation between the Galton range and Echoes Lakes from approximately 150 m to 900 m; (2) southward thickening of the Roosville Formation between Coppercrown Creek and



**Figure 2.3** Stratigraphic Section A: correlation of the Upper Purcell Supergroup from north to south (measured sections 1, 4, 6, and 7) along the eastern limb of the Purcell Anticlinorium (not to horizontal scale).



**Figure 2.4** Stratigraphic Section B: correlation of the Upper Purcell Supergroup from north to south (measured sections 1 and 8) along the western limb of the Purcell Anticlinorium (not to horizontal scale).

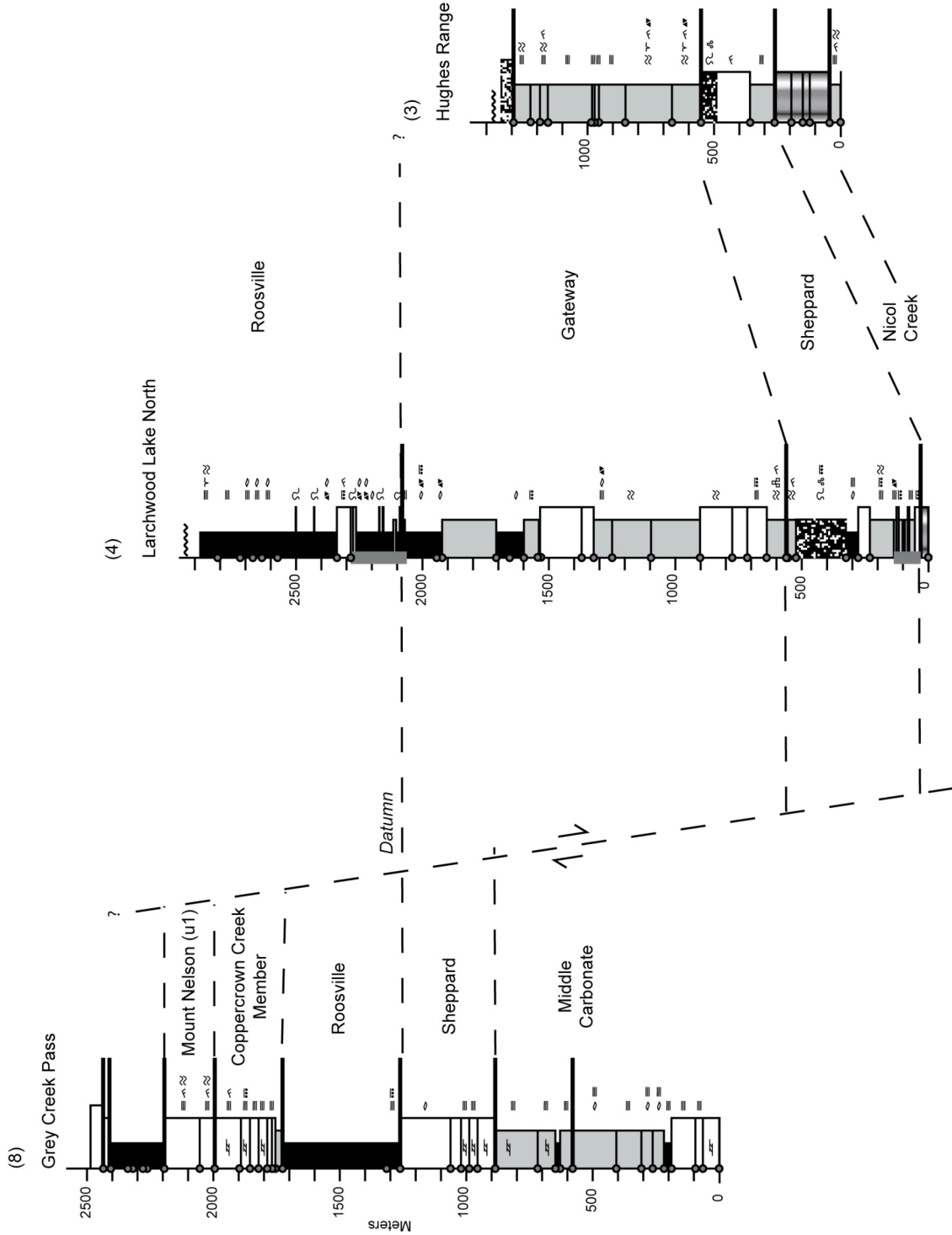
Larchwood Lake North from approximately 600 m to at least 900 m; and (3) northward thickening of the Gateway Formation from approximately 300 m to approximately 1500 m between Echoes Lakes and Larchwood Lake North. Post-depositional erosion has removed the upper portion of the Roosville formation. The north-tapering Phillips Formation sandstone pinches out between Echoes Lakes and Larchwood Lake North.

### **Section B**

Stratigraphic section B extends from sections measured at Grey Creek Pass to Coppercrown Creek along the western limb of the anticlinorium (Fig. 2.4). No significant variations in formational thickness or lithology are evident in section B. The Roosville Formation and its upper member, the Coppercrown Creek Member can be correlated confidently north from Grey Creek Pass to Coppercrown Creek. Similarly the basal sandstone of the overlying Mount Nelson Formation can be correlated north from Grey Creek Pass to Coppercrown Creek.

### **Section C**

Stratigraphic section C stretches east across the anticlinorium from Grey Creek Pass to Larchwood Lake North and the Hughes Range (Fig. 2.5). Between Larchwood Lake North and the Hughes Range little change is observed in formation thickness and lithology. Between Grey Creek Pass and Larchwood Lake North two variations in formational thickness and lithology are evident: (1) At Larchwood Lake the Gateway Formation is approximately 1500 m thick and separates the Sheppard and Roosville formations, while at Grey Creek Pass there is no Gateway Formation separating the Sheppard and Roosville formations; and (2) The Roosville Formation is at least twice as thick at Larchwood Lake North than at Grey Creek Pass.



**Figure 2.5** Stratigraphic Section C: correlation of the Upper Purcell Supergroup from west to east (measured sections 8, 4, and 3) across the Purcell Anticlinorium (not to horizontal scale).

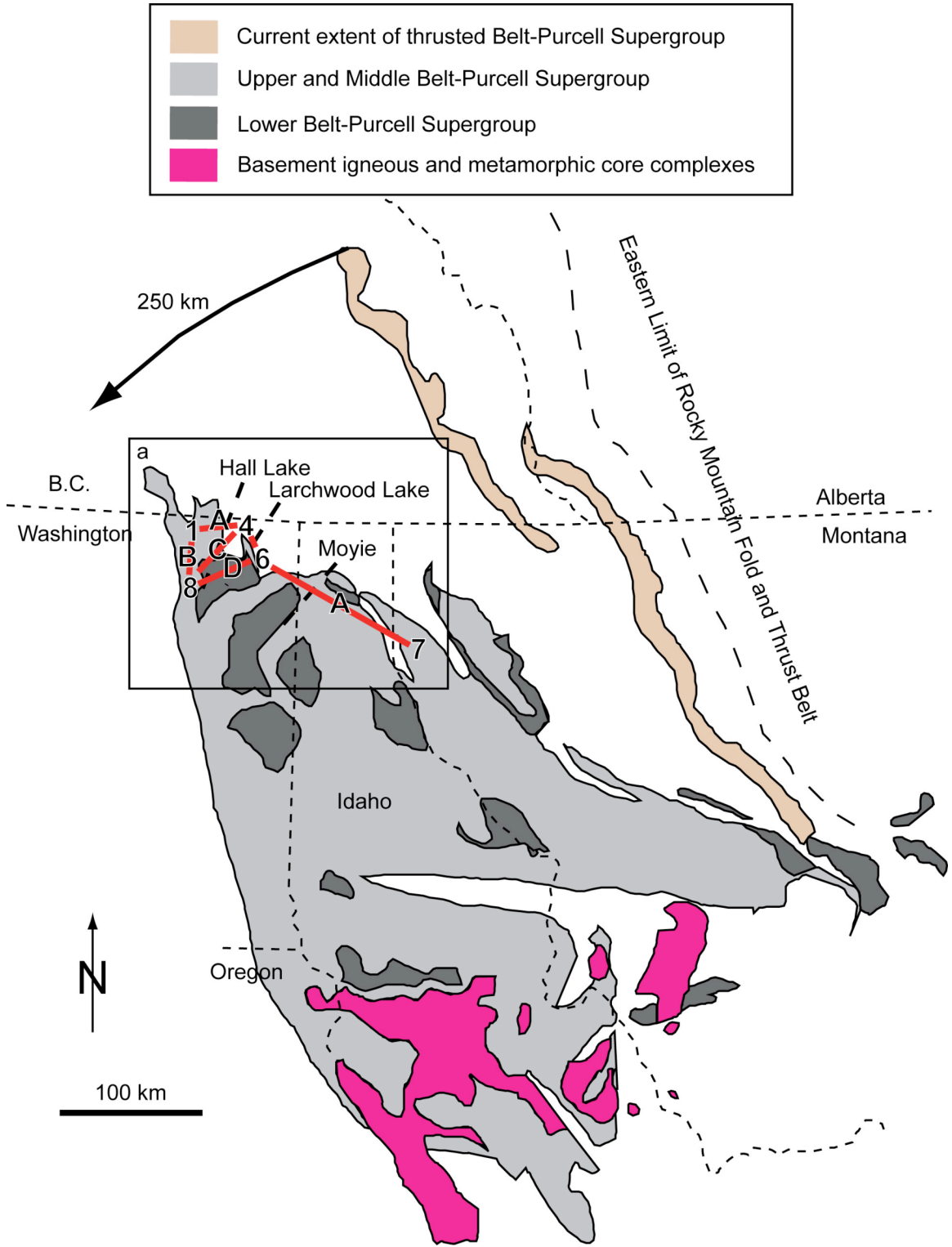


## **Section D**

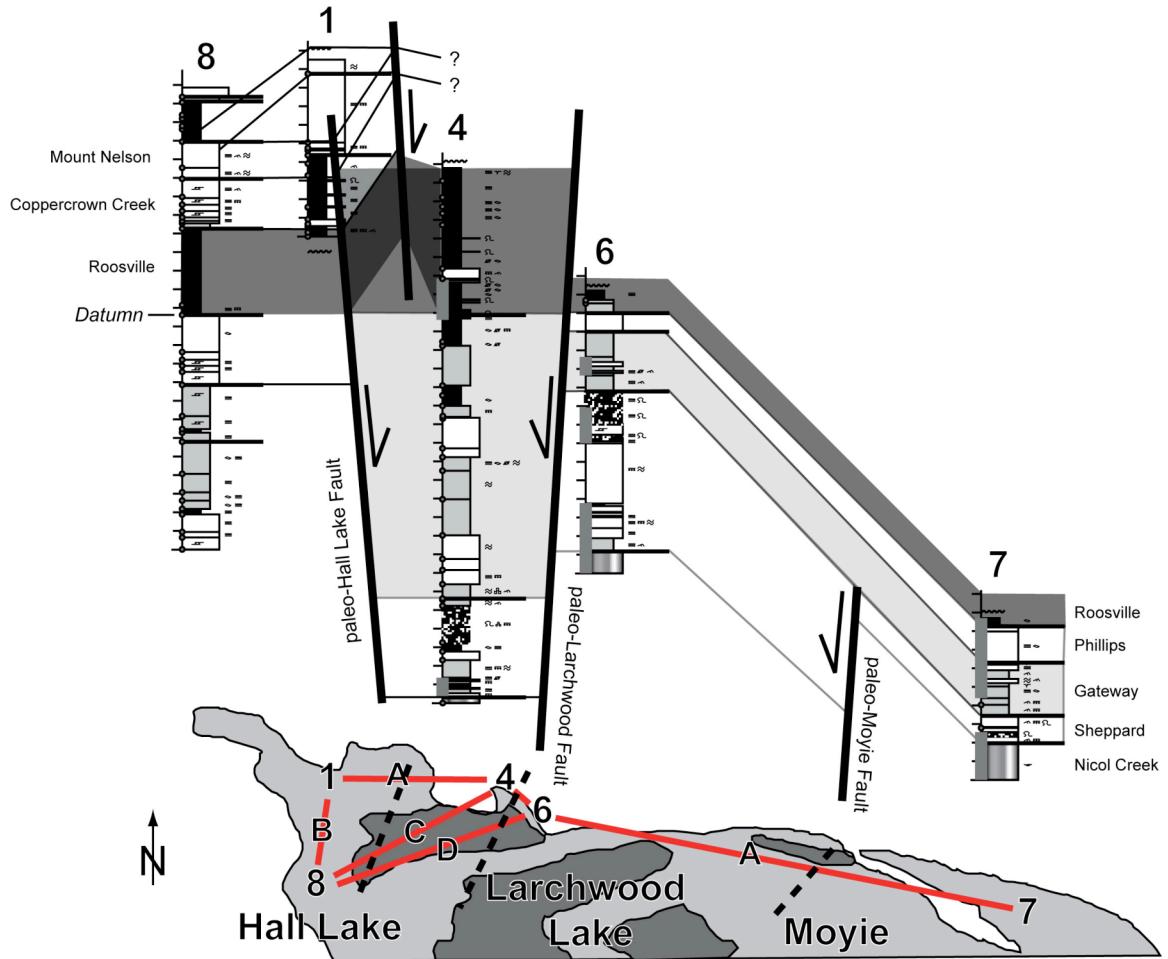
Stratigraphic section D extends east from Grey Creek Pass to Echoes Lakes and cross-cuts the anticlinorium south of stratigraphic section C (Fig. 2.6). Between these two measured sections three changes in formational thickness and lithology are evident: (1) eastward thickening of the Sheppard Formation from approximately 350 m at Grey Creek Pass to approximately 900 m at Echoes Lakes; (2) absence of the Gateway Formation at Grey Creek Pass; and (3) westward pinch out of the Phillips Formation.

## **DISCUSSION: STRATIGRAPHIC SECTIONS AND FENCE DIAGRAM**

Our four stratigraphic sections are combined to form a fence plot (Fig. 2.7 and 2.8). Based on our fence plot, we attribute the observed variations in formational thickness to the presence of a north-northeast trending, fault-bound graben that separates a more tectonically active northwestern portion of the basin from a slowly subsiding southeastern portion of the basin. Our interpretation of the graben is based on: (1) the dramatic thickening of both the Gateway and Roosville formations at Larchwood Lake North; and (2) on thickening of older units (Sheppard Formation) toward the graben. The graben separates a tectonically active western footwall, characterized by significant unconformities from a more quiescent subsiding eastern footwall. Based on these observations the graben may have been characterized by a half-graben geometry, with the footwall to the west beneath an east-dipping detachment that runs beneath the hanging wall to the east. The lack of change in stratigraphy and thickness between measured



**Figure 2.7** Combination of measured and stratigraphic section locations plotted on a palinspastic reconstruction (Price and Sears, 2000; Sears et al., 2004). Numbers depict measured section locations and red lines define the locations of stratigraphic sections, which are labeled with letters.



**Figure 2.8** A fence diagram of the Upper Purcell Supergroup plotted on a palinspastically restored base map (Price and Sears, 2000; Sears et al., 2004). Measured sections (numbers) and stratigraphic sections (red lines and corresponding letters) are marked on the palinspastically restored base map. Plotted in the fence diagram are key sections depicting the distribution of Upper Purcell Supergroup stratigraphic units, and the generalized locations of three large syn-depositional faults: (1) paleo-Hall Lake Fault, (2) paleo-Larchwood Lake Fault, and (3) paleo-Moyie Fault. The paleo-Hall Lake and paleo-Larchwood Lake faults define and bound a north-northeast trending graben.

sections 1 and 8 limits the location and orientation of the main fault bounding the western margin of the graben to being a discrete north- to northeast-trending top down to the east normal fault (the paleo-Hall Lake fault). A significant normal fault, the paleo-Larchwood Lake fault, explains changes between measured sections 4 and 6 and may be an antithetic fault to the main east-dipping detachment. We therefore assume that the paleo-Larchwood approximately parallels to the paleo-Hall Lake fault.

Continuity of the Nicol Creek Formation basalt flows across the study area implies that it erupted prior to development of the graben. Changes in the thickness of Sheppard Formation strata implies that the paleo-Hall Lake and paleo-Moyie faults were active during deposition, controlling the distribution and thickness of sediment; however motion along the faults was apparently insufficient to isolate sediment from either side of the basin. Significant, abrupt changes in Gateway Formation thickness implies that the paleo-Hall Lake and paleo-Larchwood Lake faults were active during deposition, controlling the thickness and distribution of sediment. Development of the north-northeast trending graben isolated distribution of Gateway Formation sediment to the southeast and facilitated the dramatic formational thickening at section 4 relative to section 6. Continued, long-lived motion along the paleo-Larchwood Lake fault appears to have controlled the distribution of the overlying north tapering Phillips Formation, isolating Phillips Formation sedimentation to the southeast of the graben. Despite variations in formational thickness continuity of the Roosville Formation across the study area implies that the paleo-Hall Lake and paleo-Larchwood Lake faults no longer isolated and controlled sediment distribution as they did during Gateway and Phillips formation deposition. The northwest isolation of the Coppercrown Creek Member and the Mount

Nelson Formation implies that northwest oriented block rotation, facilitated by the paleo-Hall Lake fault, isolated distribution of these sediments to the northwest. However, post-depositional tectonism and erosion may also have removed evidence of these units to the southeast.

Syn-depositional growth faults are known sites of SEDEX mineralization. The main detachment fault, forming the west-side of the half-graben, is probably the region with the highest potential, simply because that fault system is thought to be the largest of the syn-depositional faults. One cannot, however, rule out the possibility of there being SEDEX mineralization associated with the antithetic faults bounding the east side of the graben.

Ross and Villeneuve (2003), based on detrital zircon provenance data of the Belt-Purcell Supergroup, inferred that the Belt-Purcell basin developed within an extensional domain in association with a collisional—convergent plate margin. The orientation of the graben provides a first order constraint on the orientation of the stress responsible for basin formation. Assuming that sigma one was aligned parallel with the long axis of the graben, and that the north-south orientation of the margins of the Purcell anticlinorium approximately reflect the original margins of the basin, implies that the upper Purcell Supergroup was deposited within a pull-apart that developed in response to dextral shear. Possible analogues to this Belt-Purcell basin model are Tethyan sedimentary basins such as the Black and Caspian seas, which developed in association with an adjacent convergent margin and associated dextral strike-slip fault systems (Brunet et al., 2003; Ross and Villeneuve, 2003). The transpressional pull-apart basin model also provides a better means through which the impressive approximately 15-20 km thickness of the

Belt-Purcell Supergroup could have accumulated, as the bottoms of pull-apart basins subside rapidly. Construction of tectonic subsidence curves of the Belt-Purcell Supergroup would help to ascertain whether basin subsidence was typical of a large transpressional basin or a continental rift, and provide further constraints on Belt-Purcell basin models.

## **SUMMARY**

Detailed measured sections spanning the Purcell anticlinorium reveal that the upper Purcell Supergroup was deposited in a tectonically active, extensional basin setting dominated by warm, shallow water depositional settings that experienced periodic subaerial exposure and flooding. Measured sections reveal three broad regressive cycles bound by flooding events that followed: (1) eruption of the Nicol Creek basalt flows, (2) deposition of the Phillips Formation, and (3) deposition of the Coppercrown Creek Member.

From our detailed measured sections we constructed four stratigraphic sections spanning the current distribution of the upper Purcell Supergroup. Compilation of stratigraphic sections into a fence plot identified three syn-depositional growth faults: (1) the paleo-Larchwood Lake fault, (2) the paleo-Hall Lake fault, and (3) the paleo-Moyie fault. The paleo-Larchwood Lake and paleo-Hall Lake faults constrain and define a large north-northeast trending graben. Based on the orientation and geometry of the graben and available provenance data, we infer the upper Purcell Supergroup was deposited within a large transpressional basin, in association with a convergent—transpressional plate margin.

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## Chapter 3

**Detrital zircon U-Pb provenance of the upper Purcell Supergroup, southeastern  
British Columbia, Canada; Implications for Belt-Purcell basin models and  
paleogeographic reconstructions**

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### ABSTRACT

This study reports >400 new detrital zircon U-Pb SHRIMP-II ages from the Mesoproterozoic (~1.4 Ga) upper Purcell Supergroup of southeastern British Columbia, Canada. The goal of our study is to constrain the depositional, tectonic and paleogeographic setting of the Belt-Purcell basin. Five samples were collected along the eastern extent of exposed Purcell strata; one sample was collected from the western limit of strata.

All samples are characterized by subordinate numbers of detrital zircons that yield Paleoproterozoic and Archean ages. Detrital zircon ages from the Sheppard Formation are dominated by 1500, 1700, 1750, and 1850 Ma grains. The overlying Gateway Formation is dominated by 1400-1450, 1700, 1850, and 1900 Ma zircon grains. The overlying Phillips, Roosville (east), and Mount Nelson formations are dominated by

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detrital zircon ages between 1375-1450 Ma and 1650-1800 Ma. Detrital zircon ages from the Roosville Formation (west) are dominated by 1500-1625 Ma grains.

Paleoproterozoic and Archean detrital zircon ages from the eastern upper Purcell Supergroup samples could have been derived from source terranes within western Laurentia, including the US southwest. The influx of young (~1375-1450 Ma) zircon grains requires syn-depositional magmatism in a nearby source terrane. Anorogenic granites (~1430 Ma) and related rhyolites of the US southwest are a possible source of these young ages. However the series of ~1380 Ma granitoid intrusions that make up the Salmon River Arch, and related granitic intrusions into Lower Belt-Purcell Supergroup strata constitute a potential local source for young zircons. In contrast, detrital zircons from the western extent of Purcell Supergroup strata are better matched to Northeastern Australian source terranes. Approximately 1576 Ma basement exposed in the Priest River core complex in eastern Washington and northwestern Idaho cannot be correlated with any known autochthonous Laurentian basement and is the likely source of exotic detrital zircon found in the upper Purcell Supergroup. The Priest River basement is interpreted to be allochthonous with respect to North America, and may represent a stranded fragment of the long since departed cratonic terrane which formerly constituted the west margin of the Belt-Purcell basin. We interpret the upper Purcell Supergroup to have been deposited in a transpressional pull-apart basin setting, adjacent to a convergent/translational plate margin bound to the west by terranes now located in northeastern Australia.

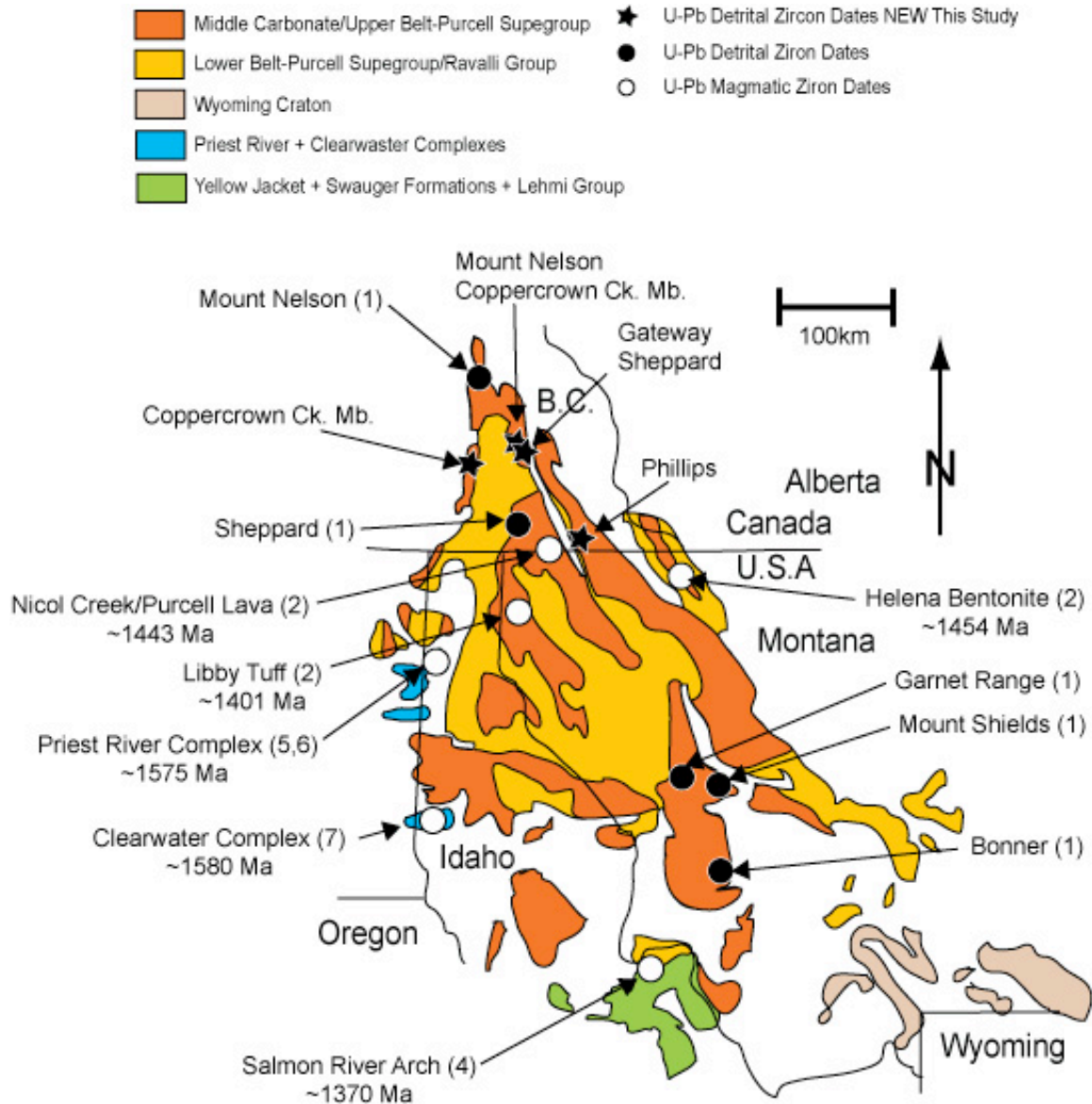
**KEYWORDS:** Belt-Purcell basin; upper Purcell Supergroup; Provenance; Detrital Zircon U-Pb; Paleogeography; Rodinia; Geochronology

## INTRODUCTION

Determining the processes responsible for the formation of supercontinents remains a major goal for the earth sciences (Murphy and Nance, 2003). Mesoproterozoic Earth evolution culminated in the formation of the supercontinent Rodinia. How Earth paleogeography changed during the lead up to and formation of Rodinia at 1.1 Ga is, therefore, a primary constraint on geodynamic models of supercontinent formation (Torsvik, 2003). Central to Rodinia was Laurentia (Hoffman, 1991). The story of how Laurentia came to be incorporated into the centre of Rodinia lies recorded in the ancient rocks that formed the margins of Laurentia at that time. For example, sedimentary rocks of the ~1.4 Ga Belt-Purcell Supergroup in the Cordilleran orogen (Fig. 3.1) are thought to provide a record of sedimentation along the ancient west margin of Laurentia. The provenance of these sediments can, therefore, be used to place limits on the possible sediment source terranes that lay west of Laurentia (Ross, 1999).

The Belt-Purcell Supergroup has subsequently been thrust into the north-northwest trending Purcell anticlinorium, a major fault bend fold that developed above the Cretaceous Lewis thrust ramp (Price, 1964). It is commonly assumed that Belt-Purcell strata exposed in the anticlinorium represent the approximate paleo-margins to the basin, as no Belt-Purcell rocks are exposed in the footwall to the fault. This has led to the primary assumption that Belt-Purcell sediments were deposited in a basin that was autochthonous with respect to western Laurentia.

Divergent and convergent margin and intracratonic models have all been proposed for the Belt-Purcell Supergroup (see references compiled in Ross and Villeneuve, 2003).



**Figure 3.1** Map illustrating the current extent of the Belt-Purcell basin in western Canada and the United States. Upper Belt-Purcell Supergroup and Middle Carbonate rocks are marked in red. Ravalli and Lower Belt-Purcell Supergroup rocks are marked in yellow. Black dots represent the sample locations of detrital zircon U-Pb dates prior to this study (1) (Ross et al., 1991; Ross et al., 1992; Ross and Villeneuve, 2003). White dots represent the sample locations of magmatic zircon U-Pb dates prior to this study Black stars represent the sample locations of detrital zircon U-Pb dates presented in this study (2) (Evans et al., 2000), (3) (Evans and Zartman, 1990), (4) (Doughty et al., 1998), (5) (Doughty and Chamberlain, 2008), and (6) (Doughty and Chamberlain, 2007).

Three salient characteristics of Belt-Purcell strata constrain these models: (1) the bulk of the sediment was fed into the basin across its western, and to a lesser extent southern margins (present orientation); (2) the predominance of the western derived sediments in the >16 km sequence, points to a need for continuous rejuvenation of the western source terrane; and (3) detrital magmatic zircons roughly the same age as deposition indicate significant magmatism within the western source terrane just prior to and during deposition (Ross and Villeneuve, 2003), consistent with the isotopically juvenile nature of the bulk of the sediment (Frost and Winston, 1987). These constraints are, however, based largely on sedimentological and provenance studies of the lower portions of Belt-Purcell stratigraphy. The provenance and depositional setting of the upper Belt Purcell Supergroup remains more poorly constrained. Hence the extent to which paleogeographic and tectonic models developed for the lower Belt Purcell Supergroup apply to the upper Supergroup remains unclear.

Our focus is the upper Purcell Supergroup. Gardner et al. (2008) showed, through the construction of a series of stratigraphic sections across the current extent of the upper Purcell Supergroup in Canada, that lithospheric extension and large-scale block faulting characterized the basin during deposition. Here we report age determinations of detrital zircons separated from samples of five upper Purcell Supergroup formations. Our goal in this study is to elucidate the provenance of the upper Purcell Supergroup and to constrain the timing of changes in basin architecture and source terrane character. Here we summarize available paleogeographic reconstructions of western Laurentia at 1.4 Ga, and review the stratigraphy of the upper Purcell Supergroup. Greater than 400 new U-Pb detrital zircon ages are reported, and these data are used to discuss: (1) the nature and

change of adjacent source terranes to the basin during upper Purcell Supergroup deposition, (2) constraints for Belt-Purcell basin models, (3) basin models, and (4) tectonic—paleogeographic models for the basin.

## **BACKGROUND**

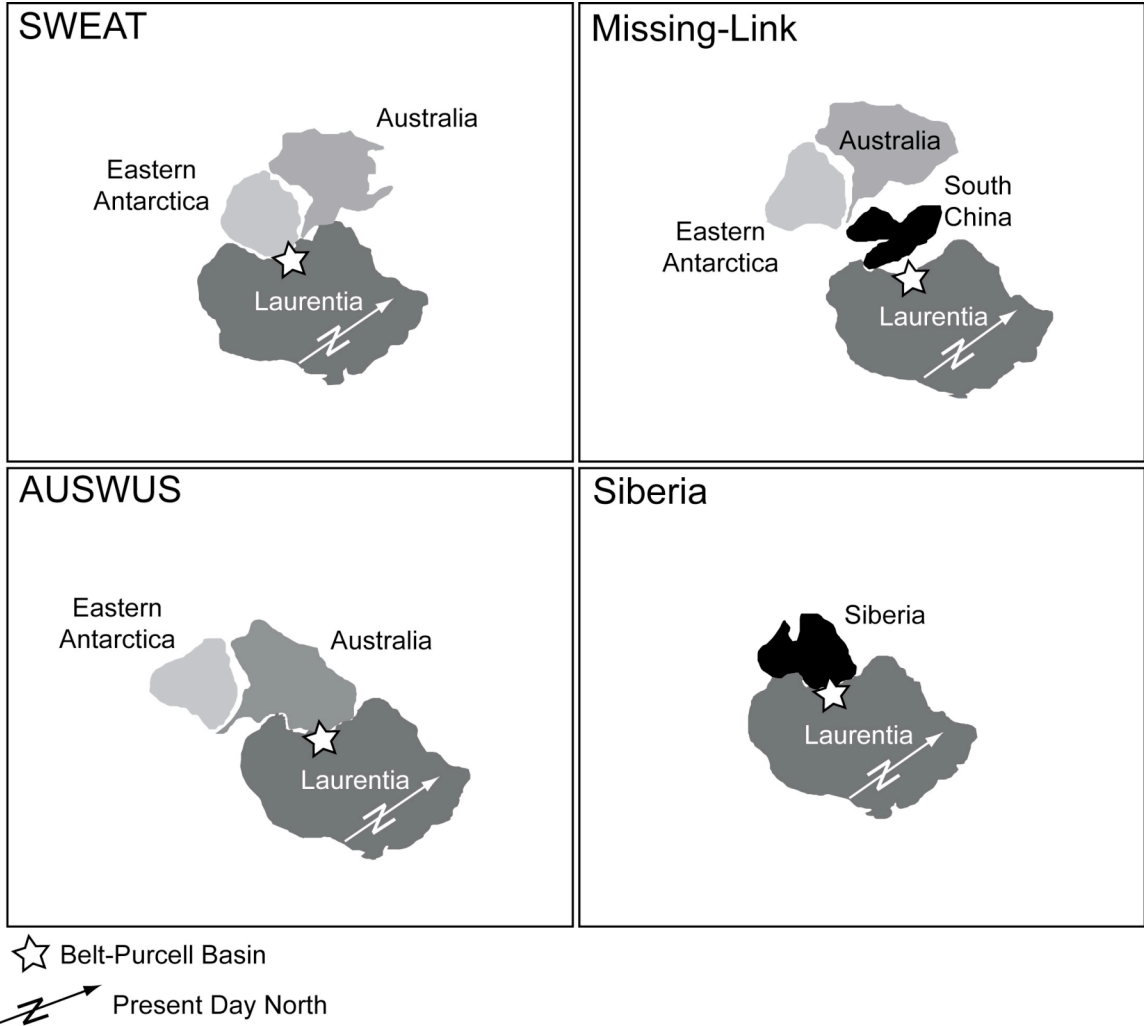
### **~1.4 Ga Paleogeographic Reconstructions of Western Laurentia**

Four paleogeographic models characterizing the western margin of Laurentia during the formation of Rodinia (~1.4 Ga) are: (1) SWEAT (Dalziel, 1991; Hoffman, 1991; Moores, 1991), (2) Missing-link (Li et al., 1995), (3) AUSWUS (Burrett and Berry, 2000; Karlstrom et al., 1999), and (4) Siberia (Sears et al., 2004) (Figs. 3.2, 3.3).

The SWEAT model is based on: (1) stratigraphic links between Neoproterozoic rift related rocks of Laurentia, Australia, and east Antarctica (Dalziel, 1991; Hoffman, 1991; Moores, 1991); (2) correlation of Grenville orogenic belts (Dalziel, 1991; Hoffman, 1991; Moores, 1991), and (3) paleomagnetic data (Powell et al., 1993).

Drawbacks of the SWEAT model are: (1) the lack of 1400-1500 Ma magmatic provinces in east Antarctica and Australia, (2) mismatches of pre-Grenville crustal and basement provinces, (3) disparity of Neoproterozoic mantle plume records, and (4) the absence of a Belt-Purcell equivalent in east-Antarctica ((Li et al., 2007a) references within).

The Missing-link model is based on: (1) matching of crustal provinces between south China, Laurentia, Australia, and east Antarctica, (2) Neoproterozoic mantle plume and rift records, and (3) paleomagnetic data, though the configuration is not unique (Li et al., 2007a; Li et al., 1995). A major flaw in the Missing-link model is that it does not



**Figure 3.2** Paleogeographic models for the western margin of Laurentia during the Proterozoic supercontinent Rodinia: SWEAT, Missing Link, AUSWUS, and Siberia (see text for discussion and references). White stars mark the location of the Belt-Purcell basin on each model.

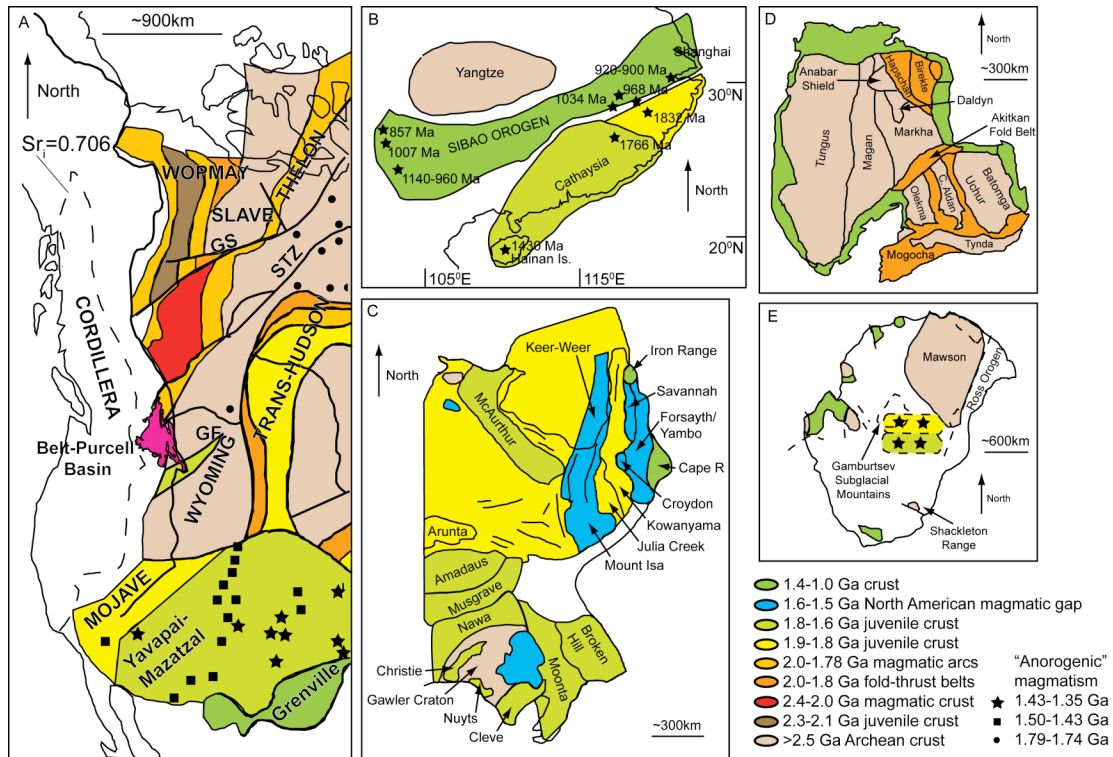
provide any source terrain for exotic, 1490-1610 Ma detrital zircon ages found in the western Belt-Purcell basin (Ross et al., 1992; Ross and Villeneuve, 2003).

The AUSWUS model is a variation on the SWEAT model and is based on: (1) matching of crustal provinces, (2) correlation of large-scale structural features between the southwestern U.S. and eastern Australia, (3) detrital zircon geochronology of the Belt-Purcell Supergroup, and (4) paleomagnetic data (Burrett and Berry, 2000; Karlstrom et al., 2001; Karlstrom et al., 1999; Ross and Villeneuve, 2003). Difficulties with the AUWUS reconstruction are: (1) a misfit between ca. 1200 Ma paleomagnetic poles in Australia and Laurentia (Pisarevsky et al., 2003), (2) the lack of prominent ca. 1400 Ma granite-ryholite provinces in Australia, (3) discrepancies in plume records between Laurentia and Australia, and (4) the presence of Grenville-aged metamorphism in eastern Australia (Li et al., 2007a).

The Siberia reconstruction is based on correlation of the Belt-Purcell Supergroup with sediments of the Udzha and Taimyr troughs in Siberia (Sears and Price, 1978; Sears et al., 2004). Problems with the Siberia model are that it fails to: (1) explain the lack of continuity of juvenile Paleoproterozoic crustal belts of the US southwest into Siberia (Condie and Rosen, 1994), (2) satisfy paleomagnetic data (Pisarevsky et al., 2007), and (3) explain mismatches between available sedimentary provenance data from the Belt-Purcell and correlated Riphean sediments in Siberia (Rainbird et al., 1998).

### **Upper Purcell Supergroup**

The Purcell Supergroup in Canada is commonly split into four informal groups: the Basal, the Lower, the Middle Carbonate, and the upper Purcell. Similarly the



**Figure 3.3** Tectonic framework of: (a) Laurentia (Hoffman, 1989; Ross and Villeneuve, 2003); (STZ= Snowbird Tectonic Zone; GS= Great Slave Lake shear zone; GF= Great Falls Tectonic Zone), (b) south China (Li et al., 2007a), (c) eastern Australia (Burrett and Berry, 2000), (d) Siberia (Pisarevsky et al., 2007), and (e) east Antarctica (Finn and Pisarevsky, 2007).

contiguous Belt Supergroup in the US is split into four informal groups: the Lower, the Ravalli, the Middle Carbonate, and the Missoula. The upper Purcell Supergroup, the focus of our study, consists of, in ascending order, the Nicol Creek, Sheppard, Gateway, Phillips, Roosville, and Mount Nelson formations (Fig. 3.4). The broadly correlative Missoula Group (Gardner and Johnston, 2007; McMechan, 1981) consists of, in ascending order, the Purcell Lava, Sheppard, Mount Shields, Bonner, McNamera, Garnet Range and Pilcher Formations (Fig. 3.4). The Nicol Creek Formation is comprised of amygdaloidal and phenocrystic basalt flows, shallow marine volcanoclastic to siliciclastic sediment, and minor tuff (McMechan et al., 1980). The Sheppard Formation is comprised of fine-grained sandstone and dolomitic limestone, and unconformably overlies the Nicol Creek Formation (Höy, 1992). Sedimentary facies of the Sheppard Formation grade from siliciclastic sediments at the formation base, to stromatolitic and oolitic, dolomitic limestones at the top (Höy, 1992; Gardner et al., 2008; McMechan, 1981). The Gateway Formation overlies the Sheppard Formation and consists of fine-grained, light grey-green, siltstone and sandstone with minor dolomitic limestone (Gardner and Johnston, 2007; Gardner et al., 2008; McMechan, 1981). The base of the Gateway Formation is marked by the first occurrence of salt casts, mud-cracks, ripple marks, and rip-up clast beds within siliceous fine-grained sediments that overlie massive stromatolitic dolomitized limestone beds that mark the top of the Sheppard Formation (Gardner et al., 2008; Höy, 1992; McMechan, 1981). Sedimentary facies of the Gateway Formation fine upwards from predominantly fine-grained sandstone at the formation base to siltstone and argillite at the formation top (Gardner et al., 2008; Höy, 1992). The north tapering Phillips Formation overlies the Gateway Formation and consists of purple,

micaceous sandstone and siltstone (Höy, 1992). The Phillips Formation pinches out at Larchwood Lake, northwest of Skookumchuck, British Columbia (Carter and Hoy, 1987; Gardner and Johnston, 2007; Gardner et al., 2008; Höy, 1992). The Roosville Formation overlies sandstone of the Phillips Formation and predominantly comprises dark grey-black, siltstone and argillite with rare massive stromatolitic dolomitic sandstone beds (Höy, 1992). Pinch out of the north tapering Phillips Formation makes distinguishing between the top of the Gateway Formation and base of the Roosville Formation difficult (Gardner and Johnston, 2007; Gardner et al., 2008). North of Larchwood Lake the base of the Roosville Formation is marked by the first occurrence of massive stromatolite beds within finely laminated, dark grey-black argillite and siltstone (Gardner et al., 2008). In the northwestern Purcell Mountains the top of the Roosville Formation coarsens from predominately dark argillite to a purple-green, dolomitic, medium- to coarse-grained, arkose sandstone unit, known as the Coppercrown Creek Member (Gardner et al., 2008). The Mount Nelson Formation, whose base is marked by a white, well sorted, quartz arenite sandstone, overlies the Coppercrown Creek Member (Gardner et al., 2008). The Mount Nelson Formation consists of shallow marine sandstone, calcareous argillite, and dolomite (Pope, 1991). Root (1987) suggested that a hiatus in deposition explains the dramatic change in sedimentary facies between the top of the Roosville Formation and the base of the Mount Nelson Formation.

Two volcanic units are contained within the upper Purcell Supergroup sedimentary succession: (1) a rhyolitic tuff within the Nicol Creek Formation in southeastern British Columbia, which yielded a zircon crystallization age of 1443 +/- 7 Ma (Evans et al., 2000); and (2) the Libby Tuff, an ash layer at the top of the Bonner

Formation in western Montana, which yielded a zircon crystallization age of 1401 +/- 6 Ma (Evans et al., 2000). In Canada the Phillips Formation sandstone is correlative with the Bonner Formation, however, no equivalent ash layers have been documented. Based on the available geochronological data Evans et al. (2000) estimated that deposition of the upper Belt Purcell Supergroup spanned 70 Ma.

## **METHODS**

Six detrital zircon samples were collected from well-constrained stratigraphic intervals within upper Purcell Supergroup formations. Sample sites were chosen to characterize and constrain sedimentary provenance through the entire upper Purcell sedimentary sequence. Zircons were separated from sandstone samples using standard techniques of crushing and concentration on the basis of density. Zircons were then passed through a Frantz™ isodynamic magnetic separator to concentrate grains with least magnetic susceptibility. Minimal separation was used so to avoid possible discrimination of zircon populations (eg. Older high Uranium grains that will be more magnetic than lower Uranium younger grains). Individual mineral grains were hand picked resulting in the selection of ~120 grains from each sample. No effort was made to separate or select grains on the basis of morphology. Grains were mounted in an epoxy puck along with the 6266 standard zircon (Stern and Amelin, 2003); polished to mid-grain, and examined with scanning electron microscope BSE images. Grains were also examined with cathodoluminescent (CL) images, transmitted, and reflected light. CL reveals the internal growth structures of the zircon and can highlight the presence of xenocrystic cores and additional intra-grain complexities. Grains were analyzed and dated using the Sensitive

High Resolution Ion Microprobe II (SHRIMP) at the Geological Survey of Canada in Ottawa, Ontario, Canada. Data are presented on age-density probability-distribution diagrams of analyses that are less than 5% discordant (Sircombe, 2004).

## **DATA**

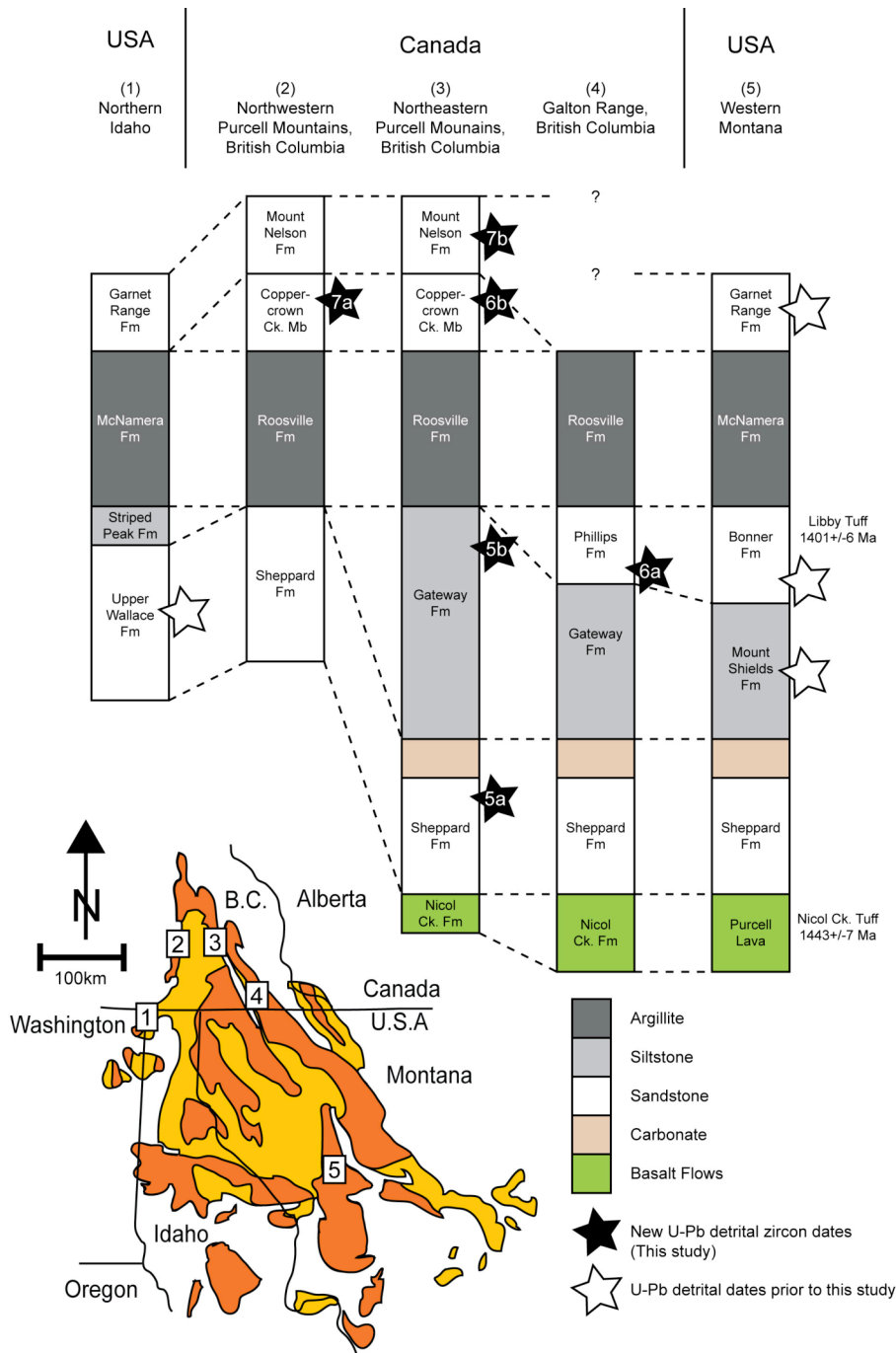
Six new detrital zircon U-Pb provenance samples were collected, one from each of the: (1) Sheppard Formation, (2) Gateway Formation, (3) Phillips Formation, (4) Coppercrown Creek Member (eastern Purcell basin), Roosville Formation, (5) Coppercrown Creek Member (western Purcell basin), Roosville Formation, and (6) Mount Nelson Formation (Fig. 3.1 & 3.4; see supplementary data for sample coordinates and data tables (Stern, 1997) for all samples).

### **Sheppard Formation sample 9345**

We sampled a well-sorted, purple-green, quartz arenite sandstone bed 300 m above the base of the Sheppard Formation. Seventy-one zircon grains in total were analyzed, all of which were sub-rounded to rounded, detrital grains (Fig. 3.5a). The resultant ages were mostly concordant (60/71; 95-105% concordance) and exhibited a dominance of continuous Meso- and Paleoproterozoic grains between 1400-1900 Ma with few subordinate Archean ages. Prominent age populations include: 1425-1450 Ma (4 grains), 1500-1525 Ma (8 grains), 1675 Ma (9 grains), 1775-1800 Ma (11 grains), and 1875 Ma (2 grains). The four youngest grains analyzed average to approximately 1429 Ma.

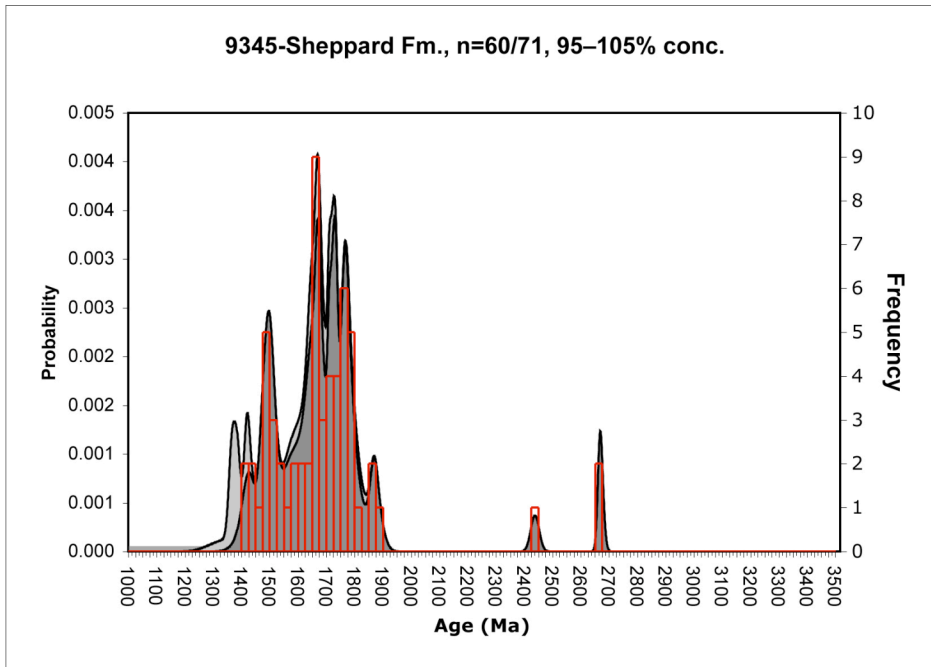
### **Gateway Formation sample 9347**

We sampled a light green-grey, fine-grained sandstone from 760 m above the base of the Gateway Formation. Fifty-nine zircon grains were analyzed, all of which were well

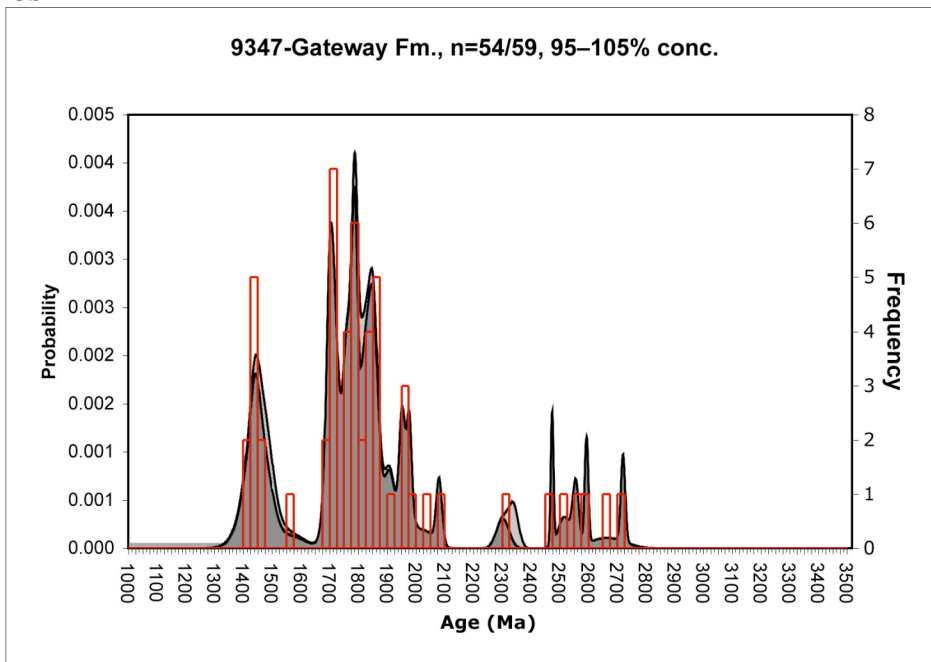


**Figure 3.4** Generalized stratigraphic sections through the Middle Carbonate and Upper Purcell Supergroup—Missoula Group spanning the Belt-Purcell basin after (Gardner et al., 2008) chapter 2 this thesis, (McMechan, 1981; Ross and Villeneuve, 2003). Plotted on sections are the stratigraphic location of: (1) U-Pb detrital zircon samples prior to this study (white star), (2) U-Pb magmatic zircon samples prior to this study, and (3) 6 new U-Pb detrital zircon sample from this study (black star). Numbers in black stars refer to subsequent data figures.

5a



5b



**Figure 3.5** (a) Relative probability density plot of detrital zircon sample 9345-Sheppard Formation; (b) sample 9347-Gateway Formation (see data repository for raw data tables for each sample). For each sample, and all following samples we plot: (1) raw histograms (red histograms), (2) all data (light grey curve), and (3) concordant data with in 95-105% concordance (dark grey curve). Samples plotted with Geological Survey of Canada's Age Display.

rounded detrital grains (Fig. 3.5b). The resultant ages were mostly concordant (54/59; 95-105% concordance) and exhibited a range of Mesoproterozoic, Paleoproterozoic, and Archean grains. Prominent age populations include: 1400-1475 Ma (11 grains), 1725 Ma (7 grains), 1800 Ma (6 grains), 1875 Ma (5 grains), and 1975 Ma (3 grains). The four youngest grains analyzed average to approximately 1429 Ma.

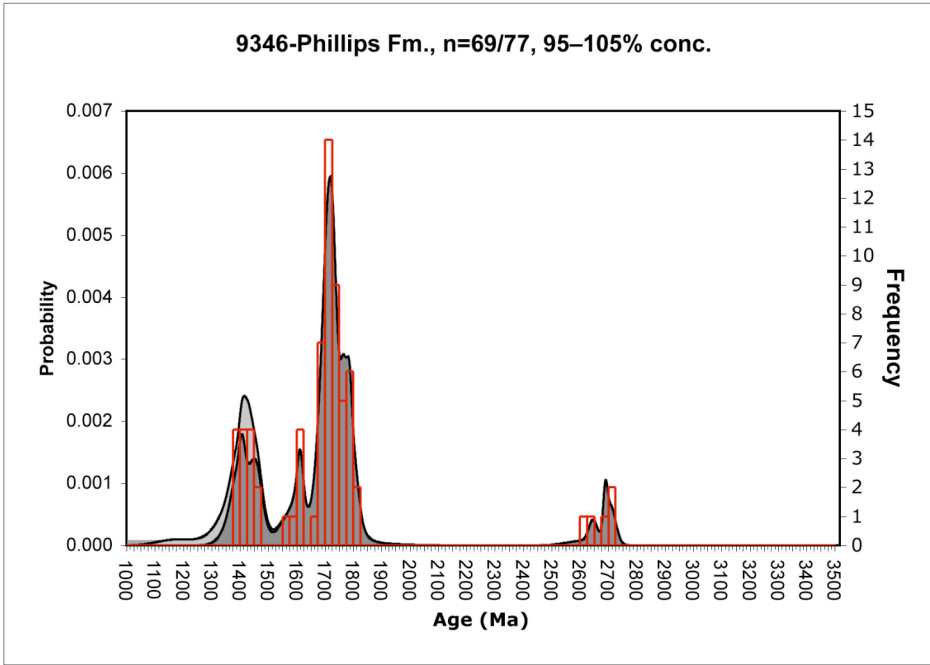
#### **Phillips Formation sample 9346**

We sampled a maroon-purple, micaceous sandstone from 2 m above the base of the Phillips Formation. Seventy-seven zircon grains in total were analyzed, all of which were sub-rounded to rounded, detrital grains (Fig. 3.6a). The resultant ages were mostly concordant (69/77; 95-105% concordance) and exhibited a dominance of Paleoproterozoic ages, with lesser subordinate Mesoproterozoic ages. The most prominent age populations are: 1400-1450 Ma (12 grains), 1625 Ma (4 grains), and 1700-1750 Ma (30 grains); and subordinate 2625-2725 Ma ages (5 grains). The four youngest grains analyzed average to approximately 1386 Ma.

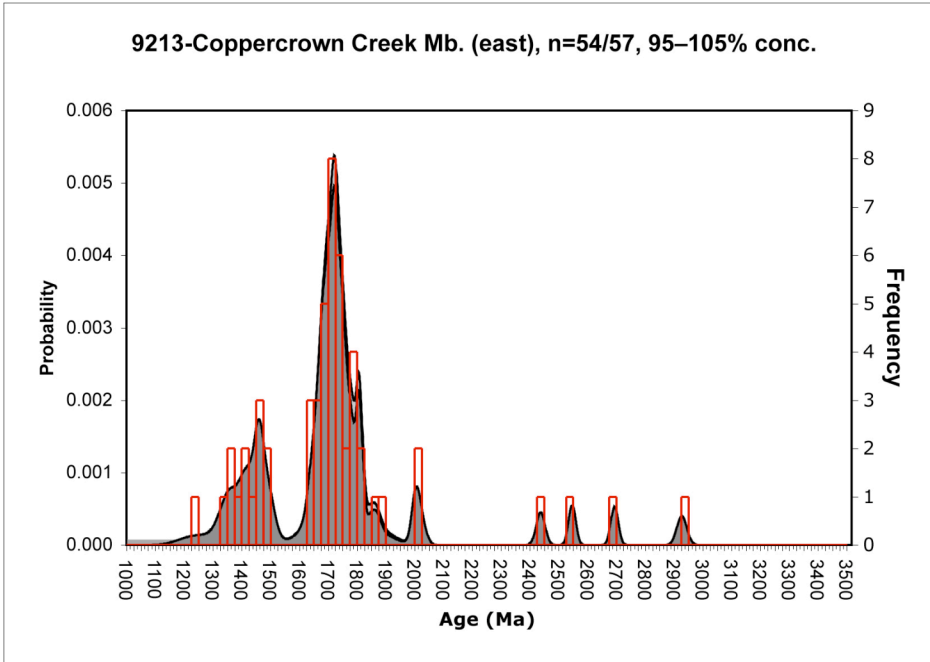
#### **Coppercrown Creek Member (east), Roosville Formation, sample 9214**

In the eastern Purcell Mountains, BC we sampled a sandstone layer 2 m from below the top of the Coppercrown Creek Member, a purple-grey, poorly sorted, generally coarse-grained arkosic sandstone at the top of the Roosville Formation. Fifty-seven zircon grains in total were analyzed, all of which were well rounded, detrital grains (Fig. 3.6b). The resultant ages are all nearly concordant (54/57; 95-105% concordance) and the sample data exhibit bimodal relative probability density distributions with a dominance of Meso- and Paleoproterozoic ages. The most prominent ages are: 1350-1500 Ma (13 grains) and 1650-1825 Ma (30 grains), with subordinate Paleoproterozoic and Archean ages. The four youngest grains analyzed average to approximately 1365 Ma.

6a

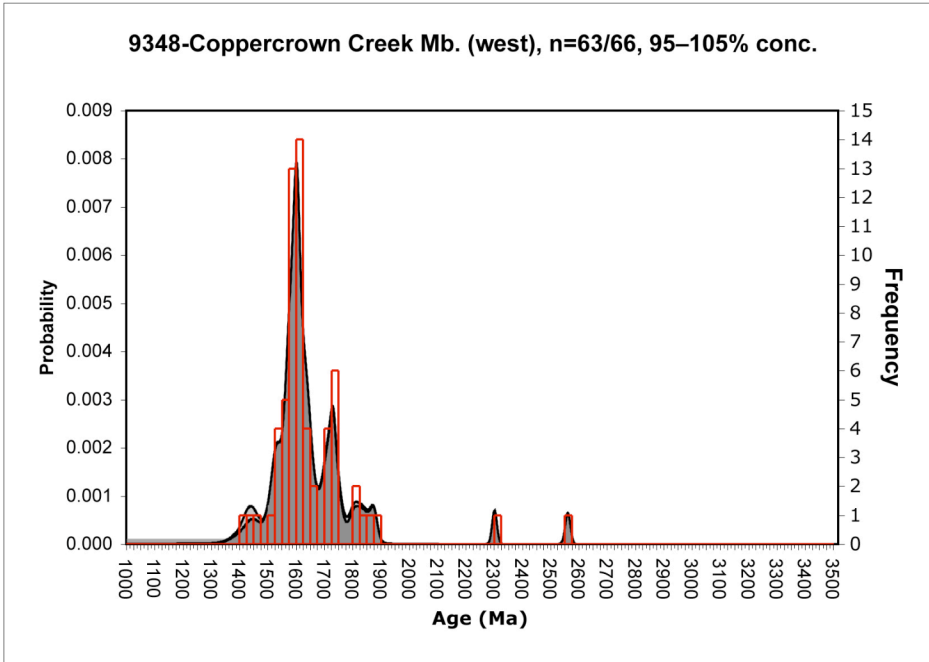


6b

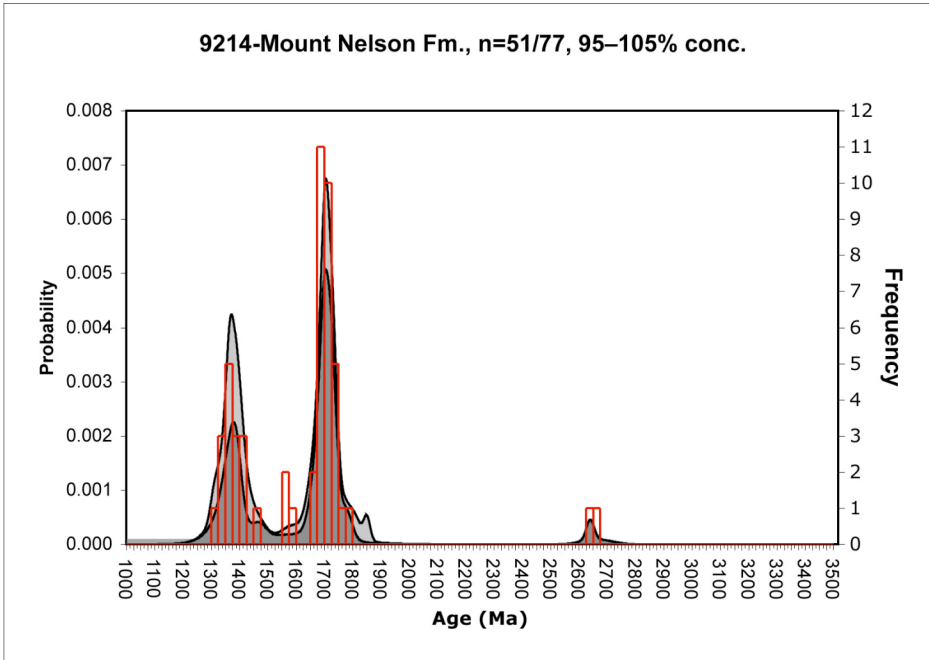


**Figure 3.6** (a) Relative probability density plot of detrital zircon sample 9348-Phillips Formation; (b) sample 9214-Coppercrown Creek Member, upper Roosville Formation, eastern Purcell basin.

7a



7b



**Figure 3.7** (a) Relative probability density plot of detrital zircon sample 9346-Coppercrown Creek Member, upper Roosville Formation, western Purcell basin; (b) sample 9213-Mount Nelson Formation, basal quartzite.

**Coppercrown Creek Member (west), Roosville Formation, sample 9348**

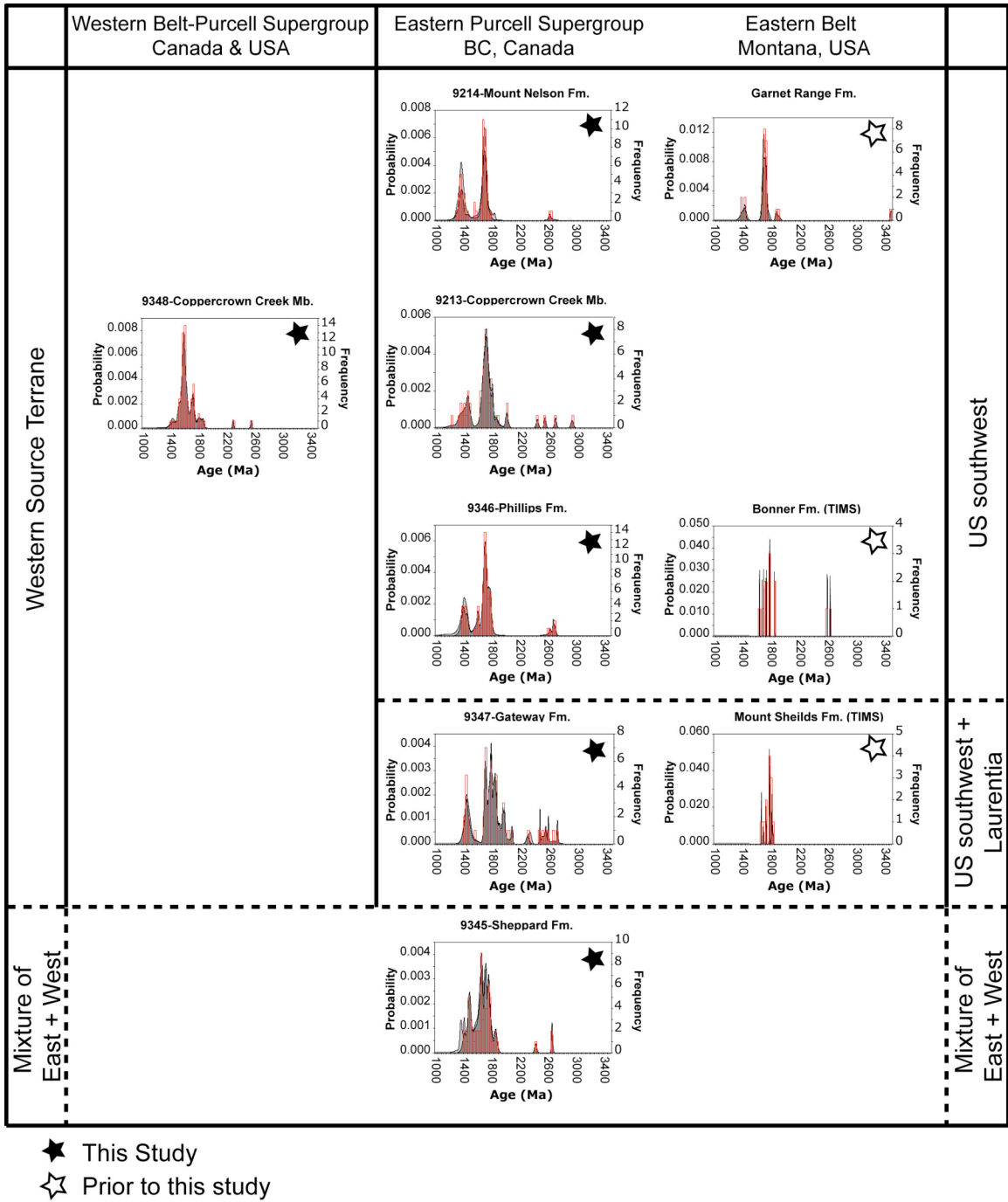
In the western Purcell Mountains, BC we sampled a light green to grey, well sorted, slightly dolomitic sandstone ~225 m from the top of the Coppercrown Creek Member, of the Roosville Formation. Sixty-six zircon grains were analyzed in total, all of which were rounded, detrital grains (Fig. 3.7a). The resultant ages are all nearly concordant (63/66; 95-105% concordance) and the sample data exhibited a dominance of Meso- and Paleoproterozoic ages, with subordinate Paleoproterozoic and Archean ages. The most prominent ages are: 1550-1650 Ma (40 grains) and 1725-1750 Ma (10 grains). The three youngest grains analyzed average to approximately 1439 Ma.

**Mount Nelson Formation sample 9213**

We sampled a white, well-sorted quartz arenite sandstone of the Mount Nelson Formation collected approximately 1 m above the base of the formation. 77 zircon grains in total were analyzed, all of which were well rounded, detrital grains (Fig. 3.7b). The resultant ages are all nearly concordant (51/77; 95-105% concordance) and the sample data exhibit bimodal relative probability density distributions with a dominance of Meso- and Paleoproterozoic ages. The most prominent ages are: 1350-1425 Ma (14 grains) and 1675-1750 (28 grains), with subordinate 1575-1600 Ma (3 grains) and one single Paleoproterozoic/Archean boundary age grain. The youngest grains scatter around 1300 Ma; however the youngest analyzed was 1237 +/- 56 Ma.

**SEDIMENTARY PROVENANCE**

From our six detrital zircon samples, we identify three distinct sedimentary provenances: (1) a 1400-1900 Ma source terrane that characterizes the Sheppard



**Figure 3.8** Compilation of all the available detrital zircon geochronology from the Upper Purcell—Missoula Group from this study and past studies spanning the Belt-Purcell basin. Data from this study are marked with black stars. Data from past studies are marked with white stars (Ross et al., 1991; Ross et al., 1992; Ross and Villeneuve, 2003).

Formation, (2) an eastern source terrane that characterizes samples from the east limb of the Purcell anticlinorium overlying the Sheppard Formation, and (3) a western source terrane that characterizes the Coppercrown Creek Member sample from the west limb of the Purcell anticlinorium (Fig. 3.8). Here we first discuss the sedimentary provenance of the Sheppard Formation and then discuss possible source terranes for the eastern and western upper Purcell Supergroup samples.

### **Sheppard Formation**

Detrital zircon ages of the Sheppard Formation, sampled from east limb of the Purcell Anticlinorium, are continuous from 1400 to 1900 Ma with prominent ages at: 1425-1450 Ma, 1500-1525 Ma, 1675 Ma, 1775-1800 Ma, and 1875 Ma. Detrital zircon ages from the Sheppard Formation match those of the underlying Middle Carbonate, Wallace Formation (Lewis et al., 2007; Ross and Villeneuve, 2003). Possible source terranes for detrital zircon grains include crustal provinces within: (1) eastern Australia (Burrett and Berry, 2000; Karlstrom et al., 2001; Karlstrom et al., 1987), (2) western Laurentia (Ross and Villeneuve, 2003), and (3) southern China (Li et al., 2007a; Li et al., 1995). The occurrence of exotic (non-Laurentian) detrital zircon ages, between 1490-1610 Ma, indicates that some of the Sheppard Formation sediment was derived from non-Laurentian source terranes. Possible source terranes for exotic zircon grains exist within the Gawler, Keer-Weer, Mount Isa, Savannah, Croydon, and Forsayth/Yambo crustal provinces of eastern Australia (Fig. 3.3). We interpret the broad array of 1400-1900 Ma detrital zircon ages as indicating that the upper Purcell basin received sediment from a number of source terranes spanning western Laurentia, including the crustal provinces of

the southwestern US, and from western exotic sources now located within eastern Australia.

A significant population of grains yield crystallization ages that are the same as the inferred stratigraphic age of the upper Purcell Supergroup (~1400-1450 Ma), placing a maximum constraint on the depositional age of the Shepard Formation of approximately 1400 Ma, and requiring syn-depositional magmatism in a nearby source terrane. A series of approximately 1380 Ma granitoid plutons that define the Salmon River Arch (Figs. 3.1, 3.4) and which locally intrude lower Belt-Purcell Supergroup strata constitute a potential local source for the youngest zircon grains (Doughty and Chamberlain, 1996; Lund et al., 2004; Ross and Villeneuve, 2003). If the Salmon River arch plutons are the source of syn-depositional zircon grains, then the granites must have been exhumed almost immediately after intrusion. Alternatively, related volcanoes may have showered the basin with zircon-bearing tuff and ash. No intrusions older than 1380 Ma have been identified in the Salmon River Arch, and it cannot have been the source of zircons ranging in age from 1475 to 1400 Ma. These zircons may have been derived from reworking of Lower Purcell Supergroup and the Nicol Creek Formation volcanics, although the significant number of these zircons argues against their having been derived from reworking of older sediments. Anorogenic granites (~1430 Ma) and related rhyolites of the US southwest (Nyman and Karlstrom, 1997; Nyman et al., 1994) and granite intrusions in southern China (Li et al., 2007b) are a possible source of these young ages.

### **Eastern Upper Purcell Supergroup**

Samples acquired from the east limb of the Purcell Anticlinorium in the Gateway, Phillips, Coppercrown Creek Member, and Mount Nelson formations show a predominance of Paleoproterozoic detrital zircon ages (~1650-1750 Ma) and Mesoproterozoic, syn-depositional aged detrital zircon grains (~1335-1475 Ma). Possible source terranes for Paleoproterozoic detrital zircon ages (~1650-1750 Ma) include crustal provinces in: (1) eastern Australia (Burrett and Berry, 2000; Karlstrom et al., 2001; Karlstrom et al., 1987); (2) southern China (Li et al., 2007a; Li et al., 1995); (3) the US southwest (Ross and Villeneuve, 2003); and (4) local unexposed basement provinces. The presence of unexposed Paleoproterozoic basement is inferred from: (1) the presence of a component of inherited Paleoproterozoic zircon grains found within the Cretaceous Idaho Batholith in central Idaho (Foster and Fanning, 1997), and (2) correlation with Paleoproterozoic metamorphic rocks of the Clearwater Complex exposed to the north in northern Idaho (Doughty and Chamberlain, 2007). As discussed above, the source of young, syn-depositional zircons can be attributed to local granitic intrusions within the Salmon River Arch of south-central Idaho (Doughty and Chamberlain, 1996; Lund et al., 2004; Ross and Villeneuve, 2003). Potential sources for the significant number of 1450 – 1400 Ma zircons include: (1) granite intrusions in southern China (Li et al., 2007b), and (2) granite-rhyolite provinces in the US southwest (Nyman and Karlstrom, 1997; Nyman et al., 1994).

The sedimentary provenance of the Gateway Formation differs from those of the overlying formations sampled along the east limb of the Purcell anticlinorium, as it contains detrital zircon grains that crystallized between 1850-2100 Ma. The Gateway Formation also exhibits greater quantities of subordinate Archean aged zircon grains;

however the frequency of Archean ages is low. Early Paleoproterozoic detrital zircon ages match the Trans-Hudson orogenic province within western Laurentia (Ross et al., 1992; Ross and Villeneuve, 2003). Alternatively, crustal provinces of eastern Siberia also provide a match for these detrital zircon ages (Fig. 3.3).

### **Western Upper Purcell Supergroup**

Detrital zircon ages from the Coppercrown Creek Member, upper Roosville Formation of the western limb of the Purcell Anticlinorium are dominated by detrital zircons that crystallized between 1550-1650 Ma (Fig. 7a). A local, but non-Laurentian source of these zircons is provided by the Priest River Complex, ca. 1576 Ma (Doughty, 1998), in northern Idaho and eastern Washington (Figs. 3.1, 3.4). More distant source terranes for these exotic detrital zircon ages include: the Gawler, Keer-Weer, Mount Isa, Savannah, Croydon, and Forsayth/Yambo crustal provinces of eastern Australia (Fig. 3.3). Despite the presence of young, syn-depositional zircons grains in the Copper Crown Creek Member sample collected from the east limb of the anticlinorium, no such young grains were documented from the western limb Copper Crown Creek Member sample. Instead, the youngest zircons (1550 Ma) predate deposition by 175 Ma.

## **DISCUSSION**

Based on our new detrital zircon data we now discuss: (1) the nature of and change within adjacent source terranes over the course of upper Purcell Supergroup deposition, (2) Belt-Purcell basin model constraints, (3) a basin model, and (4) a tectonic—paleogeographic model of the basin.

### **Interpretation of Provenance Data**

Our Sheppard Formation sample, collected from the east limb of the Purcell Anticlinorium, includes 1490-1610 Ma detrital zircons that can only have been derived from an exotic source terrane located west of the exposed extent of the Purcell Supergroup. From this we conclude that during the time of Sheppard Formation deposition the basin was small with westerly-derived sediment spreading across the entire basin. A modern analogue is provided by the Caspian Sea (Ross and Villeneuve, 2003). Gardner et al. (2008) demonstrated, based on detailed sedimentological studies, that the Sheppard Formation recorded widespread, uniform deposition with no indication of any sub-basins or grabens. Our detrital zircon results corroborate these findings; the continuum of zircon ages between 1400-1900 Ma points to the sampling of a large, heterogeneous source region, spanning the eastern through western margins of the basin (Fig. 3.8).

The Gateway Formation lacks the exotic detrital zircon ages (1490-1610 Ma) present within the Sheppard Formation (Fig. 3.8) requiring a change in either the sediment source region or the basin architecture. We attribute the loss of exotic detrital zircon ages to the development of isolated sub-basins, including at least one large syn-depositional graben (Gardner et al., 2008), fed by streams draining restricted source areas from the south and/or east. Alternatively, the crustal source of the exotic zircons may have been removed by tectonic transport away from Laurentia and was no longer available as a sediment source. The juvenile crustal provinces of western Laurentia, including the US southwest, are an excellent match for the detrital zircons contained in Gateway Formation sediment, which indicates that a southern and southeastern source region could have been the main source of sediment at this time. Detrital zircon samples

from the overlying Phillips, Coppercrown Creek member (Roosville Formation), and Mount Nelson formations, all collected along the east limb of the Purcell Anticlinorium, imply a sedimentary provenance similar to that of the Gateway Formation. However, these younger formations lack Paleoproterozoic (>1850 Ma) and Archean detrital zircons. This somewhat perplexing finding implies isolation of the basin from the central Laurentian basement that bounds the east margin of the Purcell Supergroup, and requires restriction of the source region to the US southwest (Fig. 3.8).

Ross and Villeneuve (2003), based on detrital zircon ages, suggested that the initiation of upper Purcell—Missoula Group deposition was coincident with a major reorganization in Belt-Purcell basin sediment sourcing. Our detrital zircon data point to ongoing change during upper Purcell Supergroup deposition, with the source region becoming increasingly restricted over time, until only the US southwest appears to have been providing sediment.

A significant population of syn-depositional aged detrital zircon grains characterizes all upper Purcell Supergroup formations sampled in the eastern limb of the Purcell Anticlinorium. These syn-depositional zircons require magmatism along or adjacent to the margins of the Belt-Purcell basin. Granite intrusions of the 1380 Ma Salmon River Arch intrude the southern margin of the Belt Purcell Supergroup (Evans and Zartman, 1990), and volcanoes located above, and fed by these intrusions seem the most likely zircon source. The Salmon River Arch cannot have provided source for the range of young ages (1375-1450 Ma) exhibited by our samples. This range of ages is, however, found in the anorogenic granites of the US southwest, consistent with a US southwest sediment source terrane throughout Upper Purcell Supergroup deposition.

In contrast, our sample of the Coppercrown Creek Member collected from the western limb of the anticlinorium not only entirely lacks syn-depositional zircons, but is devoid of zircons younger than 1550 Ma (Fig. 3.7a). This is in stark contrast to the samples from the eastern limb of the anticlinorium which are rich in zircons that crystallized between 1375 Ma and 1475Ma. It is difficult to explain how apparently contiguous Mesoproterozoic strata cropping out on opposite limbs of a Cretaceous anticlinorium could be characterized by such different detrital zircon populations. More samples of strata from the western limb are required to ensure that our sample is not anomalous. Barring that, our data may indicate that the western limb of the anticlinorium is far-traveled relative to the eastern limb, requiring the presence of a major, as yet unidentified fault within the anticlinorium.

Exotic, zircons characterize the Coppercrown Creek Member sampled on the western limb of the anticlinorium and the Sheppard Formation. The 1576 Ma augen gneiss exposed in the Priest River complex in eastern Washington and western Idaho (Doughty et al., 1998) may be the source of these non-Laurentian zircons. The Priest River augen gneiss cannot be correlated with any known autochthonous Laurentian basement, has been interpreted to be allochthonous with respect to North America (Doughty et al., 1998), and is geologically similar in age to the Forsayth/Yambo and Mount Isa provinces of northeastern Australia. Based on Belt-Purcell detrital zircon data and on the match in ages between the Priest River complex and terranes in northeastern Australia, we interpret the Priest River basement as a stranded fragment of the cratonic terrane that currently underlies northeastern Australia. This model places the Australian

cratonic basement along the western margin of the Belt-Purcell basin in the Mesoproterozoic during Belt-Purcell Supergroup deposition.

### **Belt-Purcell Basin Setting**

Ross and Villeneuve (2003), based on the significant numbers of young to syn-depositional detrital zircon grains in the Lower Belt-Purcell Supergroup, concluded that a convergent margin model best explains Belt-Purcell basin formation. The occurrence of syn-depositional detrital zircon grains in our samples from the eastern limb of the Purcell anticlinorium imply a continued convergent margin setting throughout Upper Purcell Supergroup deposition.

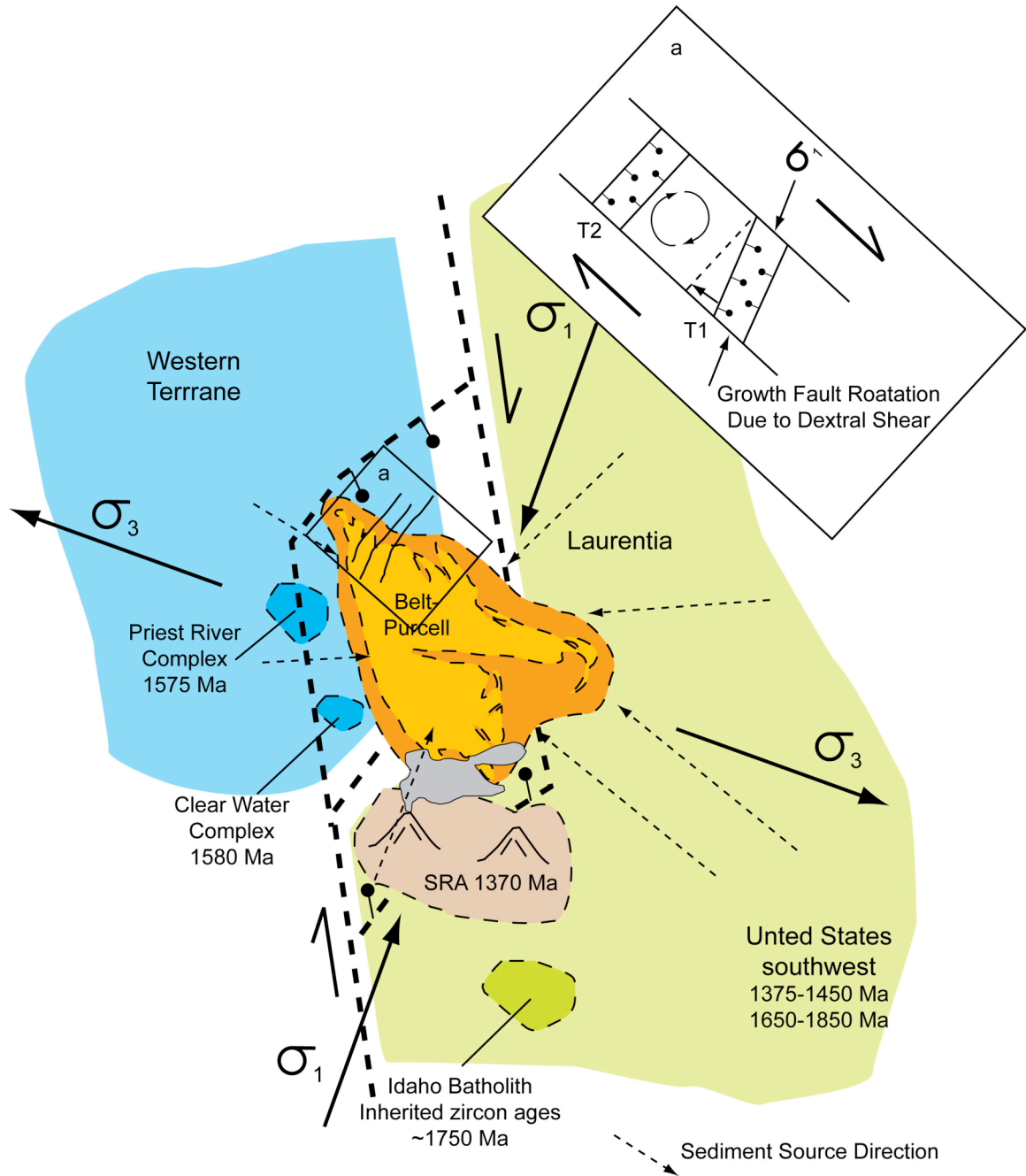
Gardner et al. (2008) showed, through a series of stratigraphic sections spanning the Purcell Anticlinorium, that active syn-depositional graben growth was coincident with upper Purcell Supergroup deposition. The grabens trend north to northeast, implying a northeast–southwest oriented principal stress axis, oblique to the presumed north-trending margin of the continent (Fig. 3.9). The obliquity between the trend of the grabens and the orientation of the presumed convergent margin bounding the continent to the west implies an overall dextral transcurrent to transpressional setting. The Lower and Upper Belt-Purcell supergroups may, therefore, record pull-apart basin development in response to dextral shearing of the convergent continental margin (Fig. 3.9).

### **Paleogeographic Model**

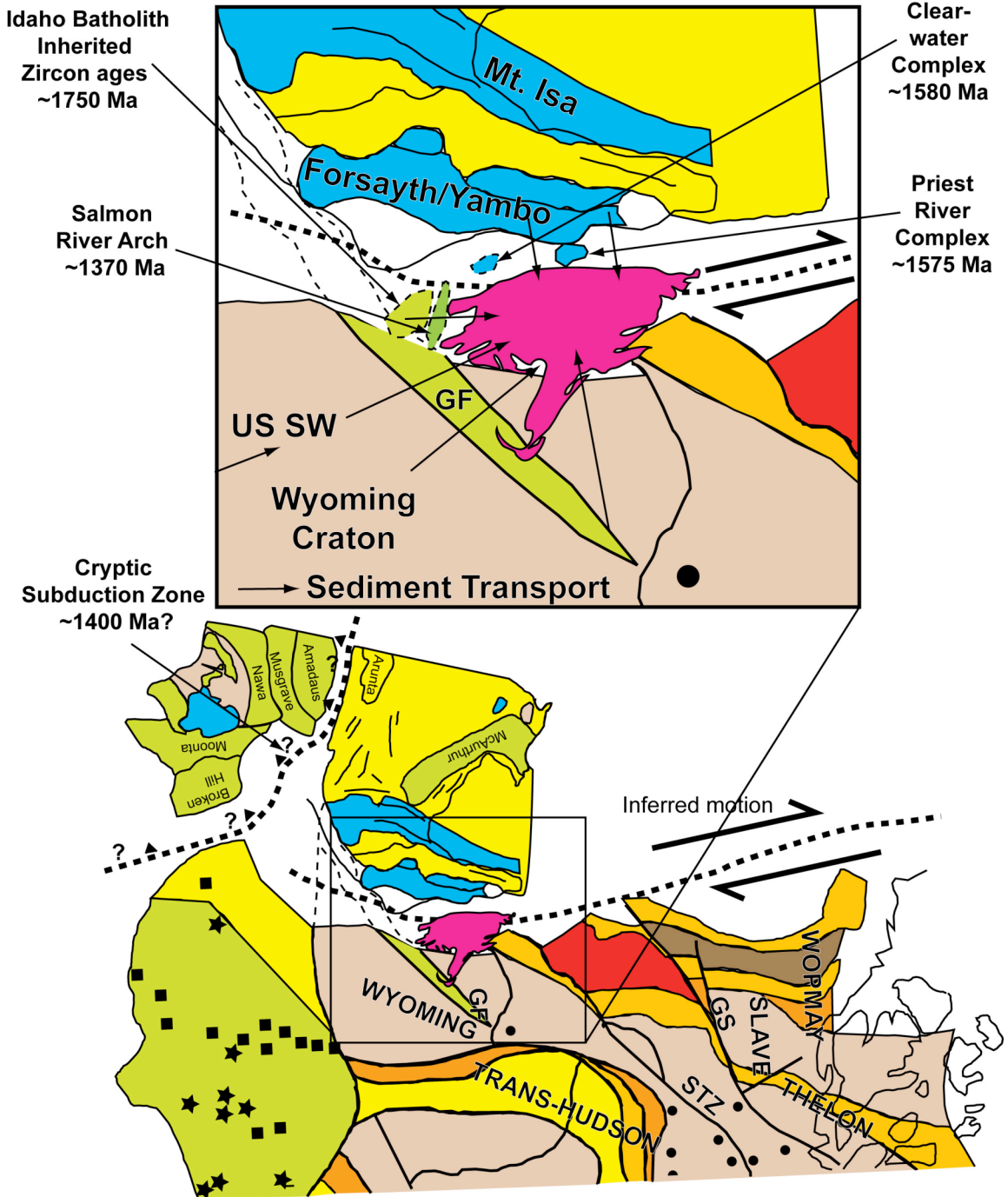
Eastern Australia, of all the cratons suspected of laying adjacent to western Laurentia at Belt-Purcell time (Fig. 3.2), is the only one that contains significant early Mesoproterozoic crustal provinces, capable of providing a source for exotic detrital zircons (Fig. 3.3). Our model explains the provenance data by employing a

paleogeographic reconstruction similar to the AUSWUS reconstruction. The Priest River complex is, therefore, interpreted as a stranded fragment of basement left behind during dextral translation of the Mesoproterozoic terranes of northeastern Australia past the west margin of the Purcell basin (Fig. 3.10). Dextral translation between northeastern Australia and western Laurentia was perhaps a result of convergence associated with closure of an ocean between the Amadaus and Arunta terranes in east-central Australia (Payne et al., 2006; Ross et al., 1992).

Approximately 1.1 Ga metamorphic rocks, attributable to a continental collision, form the eastern boundary of the Forsayth/Yambo provinces in northeastern Australia (Fig. 3.3). The Forsayth/Yambo must therefore have moved away from the west margin of North America after providing detritus to the Upper Purcell basin, but prior to their involvement in a Grenvillian collisional orogenic event. Two hundred and fifty million years separates the end of upper Purcell Supergroup sedimentation and formation of Rodinia. Hence there is ample time for the Australian terranes to have moved a significant distance from Laurentian prior to their incorporation into Rodinia. The ancient western passive margin of Laurentia may therefore have formed by the rifting away of the Australian terranes at or soon after 1.35 Ga. The occurrence of 1100-1300 Ma rocks along the length of the North American Cordilleran (Johnston, 2008) may indicate involvement of this passive margin in a Grenvillian orogenic event.



**Figure 3.9** A transpressional pull-apart basin model illustrating sediment source directions into the basin, basin growth fault rotation, and the approximate strain directions (sigma 1 and 3) associated with basin growth.



**Figure 3.10** A transpressional pull-apart basin paleogeographic model for the Belt-Purcell basin between northeastern Australia and Laurentia at approximately 1400 Ma, with an adjacent cryptic subduction zone (Payne et al., 2006; Ross et al., 1992). The Belt-Purcell basin, in pink, is located between the two cratons.

Alternatively, the assumption that the Belt-Purcell Supergroup is autochthonous with respect to Laurentia may be incorrect, as suggested by a recent paleomagnetic study by Harlan et al. (2008). They studied 1450 Ma mafic dykes which intrude the Wyoming Craton (Laurentia) in the Tobacco Root Mountains of Montana, and the Moyie Sills which intrude sediments of the Lower Purcell Supergroup. The results require  $29.1 \pm 8.1^\circ$  (>2000 km) of latitude separation between the basin and the Wyoming Craton during emplacement of the intrusions, and implies that the Belt-Purcell basin is allochthonous to Laurentia. Interestingly if the Belt-Purcell Supergroup was deposited approximately 2000 km further south with respect to Laurentia it would have lay adjacent to basement provinces of the US southwest, and would more easily explain the lack of Laurentian provenance in our samples. Understanding Belt-Purcell basin development and evolution, and resolving Earth paleogeography during the formation of Rodinia, both require reconciliation of provenance data which are most easily reconciled with a Laurentian source terrane for the Belt-Purcell basin, against paleomagnetic and geological data (Johnston, 2008) pointing to an allochthonous origin for the basin.

## **CONCLUSIONS**

Four main constraints on the basin during upper Purcell Supergroup sedimentation can be drawn from the available provenance data. (1) Sheppard Formation sediment was derived from erosion of a diversity of Laurentian source terranes, giving rise to a broad 1400-1900 Ma array of detrital zircon grains. 1490-1610 Ma detrital zircons require a non-Laurentian source. (2) Block faulting, and the development of isolated sub-basins (Gardner et al., 2008) during Gateway Formation deposition was

coincident with isolation of the basin from the Laurentian basement bounding the basin to the east, and narrowing of the sediment source region to the US southwest. (3) A magmatically active source terrane provided syn-depositional zircons throughout upper Purcell deposition. (4) A western source terrane consisting of early Mesoproterozoic crust provided 1550-1650 Ma aged zircons through out Belt-Purcell Supergroup deposition.

Two distinct sedimentary provenances can be distinguished in the upper Purcell Supergroup: (1) an eastern provenance, dominated by detrital zircon ages that match crustal provinces with in western Laurentia and the US southwest; and (2) a western source, dominated by detrital zircon ages that are exotic with respect to Laurentia, and which best match crustal provinces within northeastern Australia. The upper Purcell Supergroup, like the lower Purcell Supergroup, was deposited within a pull-apart basin that developed behind a transpressional convergent—plate margin. Crust between the basin and the margin now constitutes the cratonic basement of northeastern Australia.

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## Chapter 4

### CONCLUSIONS

Detailed measured sections spanning the Purcell anticlinorium reveal that the upper Purcell Supergroup was deposited in a tectonically active, extensional basin setting dominated by warm, shallow water depositional settings that experienced periodic subaerial exposure and flooding. Our measured sections reveal three broad regressive cycles bound by flooding events that followed: (1) eruption of the Nicol Creek basalt flows, (2) deposition of the Phillips Formation, and (3) deposition of the Coppercrown Creek Member.

From our detailed measured sections we constructed four stratigraphic sections spanning the current distribution of the upper Purcell Supergroup. We compiled our stratigraphic sections into a fence plot with which we identify three syn-depositional growth faults: (1) the paleo-Larchwood Lake fault, (2) the paleo-Hall Lake fault, and (3) the paleo-Moyie fault. The paleo-Larchwood Lake and paleo-Hall Lake faults constrain and define a large north-northeast trending graben.

Two distinct sedimentary provenances can be distinguished for the upper Purcell Supergroup: (1) an eastern provenance, dominated by detrital zircon ages that match crustal provinces in southwestern Laurentia; and (2) a western source, dominated by detrital zircon ages that are exotic with respect to Laurentia, and which best match crustal provinces within northeastern Australia. Influx of young detrital zircons (1450-1375 Ma), including syn-depositional zircons (1375-1380 Ma), within eastern Purcell basin samples requires that a magmatically active source terrane was in proximity to the basin during

upper Purcell Supergroup sedimentation. The range of these young ages is best explained in a convergent margin setting. Based on the orientation and geometry of the grabens, and on available provenance data we infer the upper Purcell Supergroup was deposited within a pull-apart basin that developed behind a transpressional convergent plate margin.

## **SUGGESTIONS FOR FUTURE RESEARCH**

Unresolved issues concerning the origin and evolution of the upper Belt-Purcell Supergroup that are highlighted by the results of our study include the: (1) lack of tectonic subsidence curves for the Belt-Purcell Supergroup testing basin models; (2) paucity of geochronological data spanning the extent of the supergroup, in particular from the western limb of the Purcell Anticlinorium; (3) lack of central Laurentian source signature within upper Purcell Supergroup sediments; (4) lack of preserved strata that indicate a Cordilleran passive margin between 1350 Ma and 1100 Ma, as predicted by our model (5) difficulty in producing a paleogeographic model that results in reasonable distances between the basin and the associated convergent margin; (6) origin of Salmon River Arch magmatism—is it an arc or the result of lithospheric thinning?; and (7) specific origin of syn-depositional zircons (~1375 Ma)—are they from the Salmon River Arch or from anorogenic granites? Analysis of zircon chemistry will perhaps help to distinguish between the two source terranes.

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