

BULLETIN 17

Regional bedrock geology for Coal River map area (NTS 95D), southeast Yukon

by

Lee C. Pigage, Charles F. Roots and J. Grant Abbott

with contributions from Jim Crowley, Sandy McCracken, Godfrey Nowlan, Mike Orchard and Leanne Pyle

2015





2009 field crew at Grizzly Creek Lodge, upper Toobally Lake - (back row, left to right) Lee Pigage, Mike Dorsey and Grant Abbott; (middle row, left to right) Kristen Kennedy, Beth Hunt and Charlie Roots; (front row, left to right) Gavin Clarkson, Martina Bezzola and Casey Cardinal.

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Cover photo: Waterfall in upper part of Beaver River (NTS 95D/10), immediately upstream from field station 09TOA146 (636 644 E, 6 719 278 N). Cliffs consist of thick-bedded Sunblood Formation.

FOREWORD

Recent collaborative geological mapping by Yukon Geological Survey (YGS) and Geological Survey of Canada (GSC) through the Central Foreland NATMAP project (fieldwork 2000-2002) provided a new and enhanced stratigraphic and structural framework for bedrock and surficial geology in southeast Yukon. Subsequent detailed geological mapping sponsored by YGS (fieldwork 2003-2007) further elaborated on an improved understanding of the bedrock geology for reassessing its mineral and hydrocarbon potential.

This report documents the revised bedrock geology of the Coal River map area (NTS 95D) in southeast Yukon, expanding upon the earlier studies. It results from a helicopter-supported 2009 collaborative mapping project between YGS and GSC which was funded through the Geoscience for Energy and Minerals (GEM) program of Natural Resources Canada. Isotopic dating and paleontology were organized by GSC; geochemical analysis of the igneous rocks was funded by YGS. In 2010, YGS sponsored one week of fieldwork as a follow-up to stratigraphic and structural questions from the 2009 project.

The current publication provides a contemporary bedrock geology framework of the Coal River map area which straddles the southern margin of Selwyn basin and occurs at the southeast end of the 'Tintina gold belt'. Both mineral domains constitute significant mineral resource provinces of Yukon. Bedrock geology consists of Neoproterozoic to Eocene stratigraphic units comprising 6 depositional successions and is described in a lithologic and paleogeographic context. Numerous small Cretaceous granitoid bodies have been identified in the northern half of the map area.

Mineral occurrences include Irish-type and Mississippi Valley-type Zn-Pb replacements in carbonate rock, massive sulfide mantos, tungsten and base metal skarns, and scattered intrusion-related precious-metal veins and replacements. For much of the area, carbonaceous sedimentary rocks appear to be over-mature as hydrocarbon source rocks although potential may exist for unconventional tight-shale gas; a coal resource has been identified locally.



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ABSTRACT

Coal River map area (NTS 95D) encompasses the southern extent of the early Paleozoic Selwyn basin, with Macdonald platform to the south. Neoproterozoic to Triassic strata constitute miogeoclinal sedimentary rocks deposited on the passive margin of Laurentia. Cambrian-Ordovician strata define an east-west facies change from silty limestone in the west to impure quartzose sandstone in the east. Alkali basalt occurs in multiple stratigraphic horizons within Cambro-Ordovician strata. Silurian-middle Devonian strata record a facies change from platform carbonate rocks in the south to deep marine carbonaceous shale in the north. Middle Devonian to Triassic shale and sandstone sequences record three transgressive/regressive cycles. Eocene strata consist of post-orogenic fluvial mudstone, siltstone and sandstone with interbedded coal seams preserved in an extensional half-graben.

Most of the small Cretaceous granitic stocks are highly magnetic and coincide with positive aeromagnetic anomalies. Other aeromagnetic anomalies may correspond to buried or unmapped intrusions.

The Coal River map area is characterized by steeply dipping, northwest to northeast-trending faults and folds. Contractional deformation structures and axial planar fabrics decrease in intensity from west to east. Late extensional deformation is manifested by normal faults. The largest of these structures is the Rock River fault which forms the western margin of the upper Eocene Rock River basin half-graben. Metamorphic mineral assemblages in the pelites regionally range from muscovite-chlorite zone in lower greenschist facies to biotite-garnet-staurolite-chloritoid zone in lower amphibolite facies. Higher grade rocks occur in a northeast-trending belt from the west-central to north-central part of the map area. Deformation and metamorphism are part of the Cordilleran orogeny, a manifestation of the amalgamation of Laurentia with allochthonous terranes.

Southeast Yukon is under-explored although it is geographically situated at the south margin of Selwyn basin and the southeast tail of the Tintina gold belt. Sediment-hosted mineralization may include sedimentary exhalative Zn-Pb±Ba deposits in black shale (SEDEX) and Irish-type or MVT Zn-Pb replacement deposits in carbonate rocks. Intrusion-related mineralization may include massive sulphide mantos, tungsten and base metal skarns, precious metal veins, sheeted veins and replacement deposits.

Carbonaceous sedimentary successions are overmature for source hydrocarbon potential. Conventional oil or gas reservoirs are probably not present. Potential does exist for unconventional tight shale gas resource. Coal resources have been identified in the late Eocene Rock River basin sediments.

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INTRODUCTION

Recent fieldwork by the Yukon Geological Survey and the Geological Survey of Canada (Pigage, 2006; Pigage and MacNaughton, 2004; Pigage, 2009) in southeast Yukon resulted in major revisions to the previously reported stratigraphy and igneous history. Southeast Yukon includes rocks which regionally host SEDEX, MVT/Irish-type and intrusion-related mineralization. The mineral potential of southeast Yukon is under-evaluated both scientifically and economically relative to the central part of the territory; additional discoveries are possible with an updated geological information base.

To this end the Yukon Geological Survey and Geological Survey of Canada completed a helicopter-assisted bedrock mapping program in the Coal River (NTS 95D¹) map area between late June and early August 2009 using federal funds provided by the 'Geo-Mapping for Energy and Minerals' program administered by Natural Resources Canada. A Bell 206B helicopter provided daily set-outs of traverse pairs and enabled spot-checking of isolated rock exposures. An inflatable boat with jet outboard motor provided access to outcrops along the Coal River. The 10-person crew was based for 2 weeks at a mineral exploration camp on the south shore of Quartz (Hulse) Lake, and then at a private facility on the east side of the northernmost (upper) of the Toobally Lakes.

In 2010 the Yukon Geological Survey funded five days of helicopter-assisted field checks to resolve geological inconsistencies arising from the 2009 fieldwork. The 2009-2010 project produced a preliminary bedrock map (Plate 1) and surficial geology report (Kennedy, 2010) as well as a regional aeromagnetic map of the Yukon portion of the adjacent map area immediately to the north (Flat River, NTS 95E; Kiss, 2010a,b,c,d).

This report complements the 1:250 000-scale bedrock geological map (Plate 1) for the Coal River map area by providing descriptions of the rock units, structures, mineral occurrences and discussion of their geologic context; it should be read in conjunction with the bedrock geological map, Yukon Geological Survey Open File 2011-1 (included as Plate 1).

LOCATION, PHYSIOGRAPHY AND ACCESS

The area of study is approximately 100 km east of Watson Lake, Yukon with bounding geographic coordinates of 60° and 61°N latitude and 126° and 128°W longitude (Fig. 1). It occurs largely within southeast Yukon with the northeast corner being in the Northwest Territories. Most of the map area is within the Hyland Highland physiographic region with the northwest corner being within the Logan Mountains (Mathews, 1986). Most of the 12 100 km² area consists of rounded, forest-covered hills with incised stream drainages. The map area is characterized by three broad, north-trending valleys extending the entire length of the area. The Coal (west valley) and Rock (central valley) rivers flow south into the Liard River. The east valley contains the Smith River (south flowing), Beaver River (southeast flowing) and Caribou River (northeast flowing). All rivers ultimately flow into the Mackenzie River and Arctic Ocean. Elevations range from 550 m (1800 ft) to 1980 m (6500 ft). Bedrock exposures constitute about 3% of the area and are restricted largely to ridge tops above timberline, rivers and glacial meltwater channels.

The Alaska Highway traverses the southwest corner of Coal River map area. Abandoned logging roads locally radiate northward from the highway. A few unpaved tracks and winter haulage trails (referred to as the Sulpetro and Smith River trails) cross the southern and central parts of the map area. Extensive forest cover limits places where helicopters can land. The upper Coal, West Coal and Rock rivers are

1 National Topographic System: <https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/maps/9763>

amenable to shallow-draft boats, as is the stream connecting the Toobally Lakes. The Smith River is boulder-strewn and rapid-filled, and class 3 and 4 rapids in downstream canyons on the Coal River prevent boat access from the Alaska Highway. A 500 m long gravel airstrip located near the head of Otter Creek was utilized for mineral exploration (Mel, Jeri, Jeri North, Joni). Float-equipped planes have used Hulse (Quartz), Roy, Gusty and the Toobally lakes to supply camps.

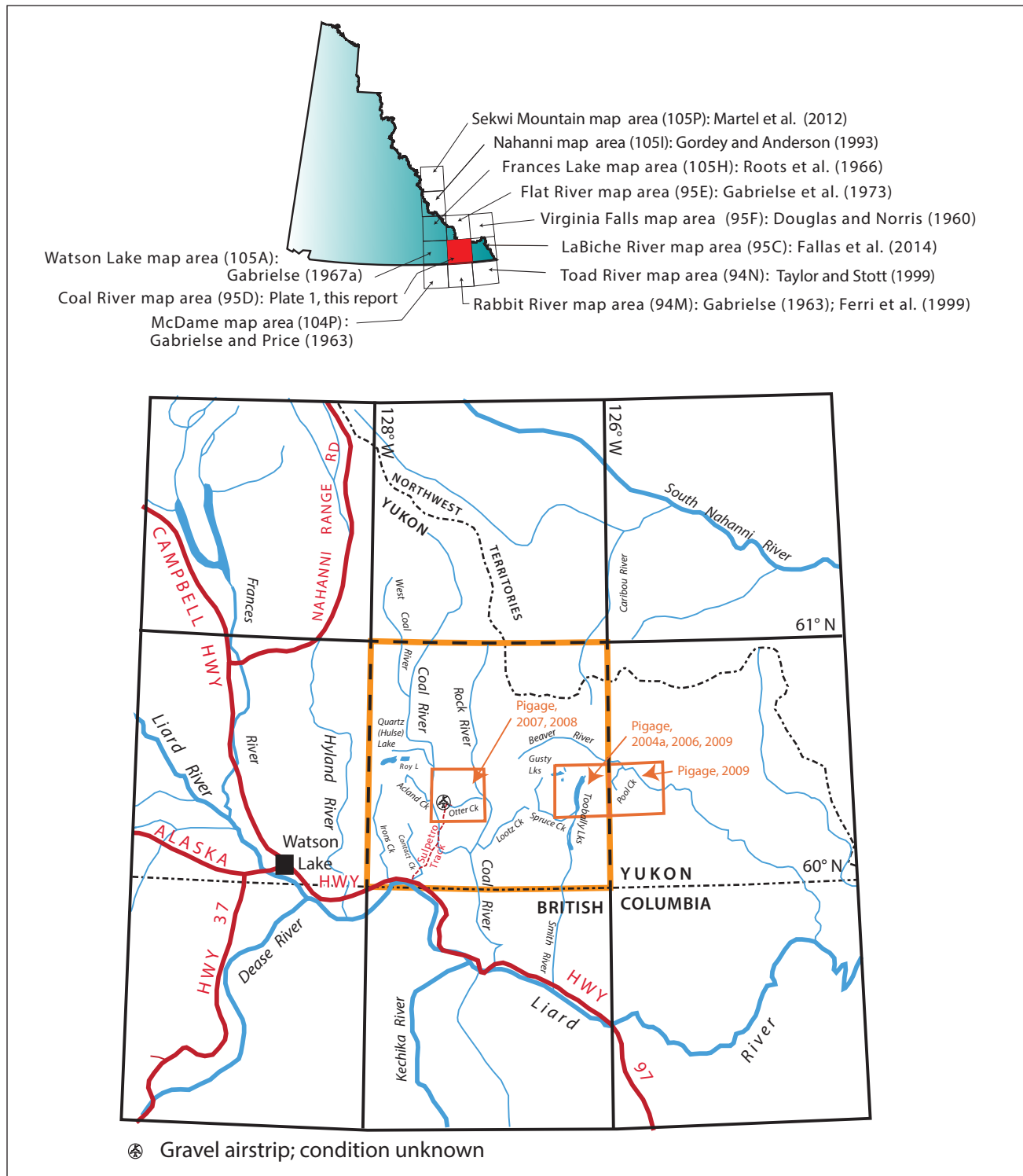


Figure 1. Map areas (with reference to geological reports), roads and water courses surrounding Coal River map area.

GLACIAL HISTORY

Central and southern Yukon has a complex Pleistocene glacial history. Bostock (1966) and Duk-Rodkin *et al.* (2004) documented multiple advances of the Cordilleran ice sheet. Immediately to the west (in the Watson Lake area) Klassen (1987) described a lengthy glacial history with four till units interbedded with four non-glacial units. The uppermost till unit records late Wisconsinan glacial ice that flowed northeastward from the Cordilleran Ice Sheet. He also completed a surficial geology reconnaissance of the west half of the Coal River map area, documenting extensive glaciofluvial and glaciolacustrine sediments (Klassen, 1983). Surficial mapping, to the east of the Coal River project area, by Smith (2000) demonstrated that the continental Laurentide Ice Sheet advanced west and coalesced with the Cordilleran Ice Sheet just east of the Coal River map area along the western margin of the LaBiche River map area during the Wisconsinan glacial maximum. Coalescence resulted in thickening of the ice sheets that likely covered all but the highest peaks in the region (Kennedy, 2010).

Kennedy (2010) indicated that most of the glacial geomorphic features in the Coal River map area are probably related to the most recent Wisconsinan McConnell advance of the Cordilleran Ice Sheet. McConnell Glaciation attained its maximum extent around 23 000 ¹⁴C years BP (Duk-Rodkin *et al.*, 1996) with much of it disappearing by approximately 13 000 ¹⁴C years BP (Jackson *et al.*, 1991). Deglaciation in the Coal River area resulted in the deposition of extensive glaciolacustrine and glaciofluvial deposits associated with glacial lakes formed by the Cordilleran and Laurentide ice masses blocking south and east-flowing drainages. Deep, east-trending meltwater channels became incised and resulted in the formation of large deltas as the meltwater channels debouched into the major south-trending drainages and glacial lakes. The northwest and north-central parts of the map area possibly remained unglaciated during the Cordilleran glacial advances (Klassen, 1987; Kennedy, 2010).

PREVIOUS WORK

Reconnaissance geological mapping by the Geological Survey of Canada (GSC), mostly during 1967, resulted in an outcrop style geology map at 1:253,440 scale and an accompanying report (Gabrielse and Blusson, 1968, 1969). Abbott (1981) conducted a regional mapping program in 1978-1979 which was largely north of the Coal River area, overlapping into the northwestern part of NTS 95D. Subsequent government-sponsored research was limited to visits to mineral exploration camps, until two regional total-field aeromagnetic surveys using a line spacing of 800 m (Natural Resources Canada, 2009) were completed in 1995 and 1996. Yukon Geological Survey conducted detailed (1:50 000 scale) bedrock geology mapping near Toobally Lakes (NTS 95D/8) and surrounding the Mel Pb-Zn occurrence (NTS 95D/6) between 2003 and 2008 (Pigage, 2004a, 2006, 2007, 2008; Pigage and MacNaughton, 2004), culminating in a final report (Pigage, 2009).

Mineral exploration occurred intermittently from the 1960s into the 2000s, but the poor exposure, difficult access and moderately promising results discouraged more extensive activity. As a result regional exploration has been limited, and detailed exploration has focused on the few known targets, namely the McMillan Pb-Zn-Ag replacement deposit (Yukon MINFILE 095D 006), the Hyland Gold intrusion-related Au replacement deposit (Yukon MINFILE 095D 011) and the Mel Pb-Zn-Ba MVT/Irish-type replacement deposit (Yukon MINFILE 095D 005 and associated occurrences - Yukon MINFILE 095D 027, 032, 035). Grassroots regional exploration targets include tungsten skarn, intrusion-related gold, and sediment-hosted zinc, lead and barite.

REGIONAL GEOLOGIC SETTING

The Coal River map area is located along the northwest (present orientation) passive continental margin of Laurentia which formed after the breakup of the Proterozoic supercontinent Rodinia (Colpron *et al.*, 2002). An aggregate total of >14 000 m of miogeoclinal sedimentary and minor volcanic rocks

of Neoproterozoic through Triassic age are present in various parts of the map area. Most of the formations or their time-equivalent correlatives extend along the ancient margin, from east-central Alaska along the Mackenzie and Rocky mountains through the United States into Mexico. They were uplifted and exposed as a result of eastward contraction during the Cordilleran orogeny (Middle Jurassic to Paleocene fold-and-thrust belt; e.g., Gabrielse *et al.*, 1991).

The main Neoproterozoic to Middle Devonian geographic elements (Fig. 2) are shallow water carbonate and clastic strata transitioning westerly to southwesterly to deeper water strata, constituting Selwyn basin (Gabrielse, 1967b; re-defined by Cecile, 1982, and Gordey and Anderson, 1993). Selwyn basin is a 900 km long, up to 350 km wide, northwest-trending area of the central and eastern Yukon underlain by Late Proterozoic to Middle Devonian dark clastic strata. It is flanked to the north and east by the time-equivalent, carbonate-dominant Mackenzie platform (Lenz, 1972; a.k.a., Blackwater platform of Cecile *et al.*, 1997; Mackenzie-Peel shelf of Morrow, 1999). A southern extension of relatively deep-water strata about 50 km wide continues 600 km farther south and is known as Kechika trough (Douglas *et al.*, 1970); it is flanked to the east by Macdonald platform. The southwest margin of both Selwyn basin and Kechika trough is the Tintina fault, and the fault-offset equivalent strata are present in central Alaska (McGrath quadrangle). Coal River is located at the northern margin of Macdonald platform and the southern edge of Selwyn basin.

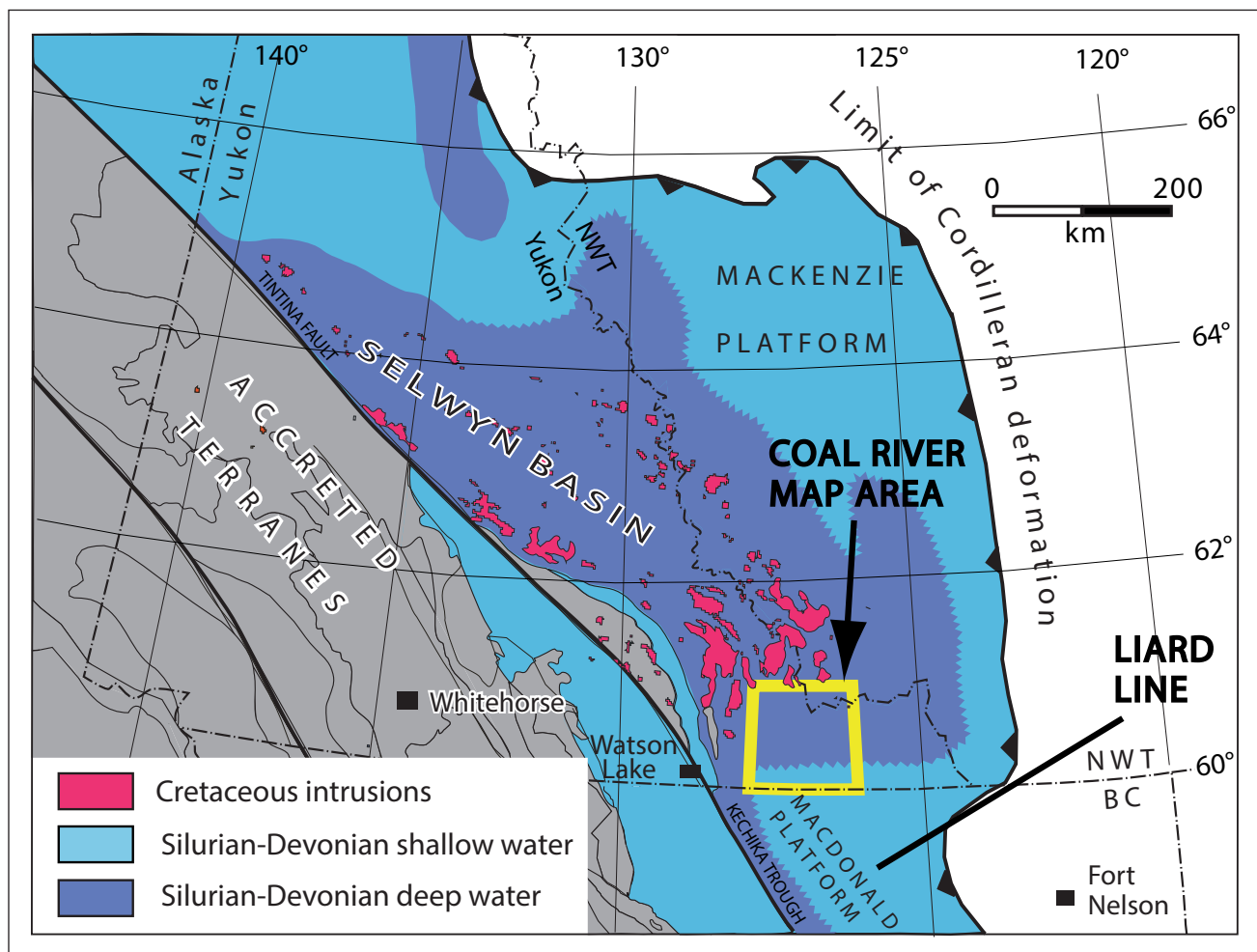


Figure 2. Paleozoic (Silurian-Devonian) tectonic elements of eastern Yukon and northern BC. Accreted terranes are undifferentiated (grey) and movement of Tintina fault is not restored. Terranes adapted from Wheeler and McFeely (1991). Cretaceous intrusions from Gordey and Makepeace (2003).

Middle Devonian to Mississippian transgressive, carbonaceous shale and chert overlying the Mackenzie and Macdonald platform shelf carbonate rocks denote a major change in depositional environment and tectonics (Abbott *et al.*, 1986) and represent the cessation of the Selwyn basin-Mackenzie and Macdonald platform paleogeography. Extensional rifting during this time is indicated by locally sourced conglomerate and the presence of depositional growth faults within the former Selwyn basin (Abbott *et al.*, 1986; Gordey *et al.*, 1982). Late Mississippian deposition in the Coal River area is dominated by silts and sands of a large, prograding marine and fluvial delta complex.

Deposition in Pennsylvanian through Triassic time delineates multiple transgressive-regressive cycles of fine-grained clastic rocks and chert of relatively shallow water, marine origin separated by unconformities (Abbott *et al.*, 1986).

Jurassic-Paleocene deformation is manifested primarily by widely spaced, high-angle reverse faults and asymmetric folds. Intensity of deformation and depth of burial exposed at surface increase from east to west, with penetrative fabrics being well developed only in the west. Metamorphism associated with deformation ranges from lowermost greenschist facies (muscovite-chlorite zone) in the east to upper greenschist facies (biotite-garnet zone) and locally lower amphibolite facies (staurolite zone) in the west.

Numerous small, undeformed, approximately circular Cretaceous intrusions are scattered across the northern half of the map area (Plate 1). These intrusions represent the southeast extent of the Tay River plutonic suite (Mortensen *et al.*, 2000; Plate 1; Fig. 2). Post-orogenic (Upper Eocene) fine-grained, fluvial and lacustrine, coal-bearing deposits occupy a north-trending half graben in the centre of the map area (Rock River basin; Long and Sweet, 1994).

The Coal River map area lies north of the Liard Line (Fig. 2), a northeast-trending zone defined primarily by the absence of Ordovician to Lower Devonian strata southward (Cecile *et al.*, 1997). The Liard Line is interpreted as an ancestral transfer fault zone across which there is an interpreted reversal in the asymmetry direction of the original rift zone along the western edge of Laurentia (Cecile *et al.*, 1997). North of the Liard Line, Selwyn basin exposures are interpreted as being in the footwall of the continental marginal rift, and the Macdonald platform exposures to the south are thought to be in the hanging wall of the continental marginal rift. There is no surface expression of the Liard Line, and its location is poorly constrained.

STRATIGRAPHY OF COAL RIVER MAP AREA

This report divides the miogeoclinal strata into six formation-delineated 'successions' of strata ranging in age from Neoproterozoic through late Eocene (Fig. 3). Each succession consists of one or more formations with related lithologic facies and depositional environments (Table 1). Tectono-stratigraphic relationships markedly differ between successions (*cf.*, Morrow and Geldsetzer, 1991). Internally the successions may locally contain unconformities. North and east-striking schematic correlation charts (Fig. 4) illustrate the regional distribution and stratigraphic relationships of the formations and sedimentary successions.

Succession 1 consists of Neoproterozoic-lower Cambrian siliciclastic sedimentary rocks (Yusezyu, Narchilla and Vampire formations, and an interval of silty phyllite and limestone interbeds considered equivalent to the Sekwi Formation) that are exposed throughout the western half of the map area. Mafic volcanic rocks occur locally near the top of this succession. A small isolated occurrence of Neoproterozoic(?) conglomerate (Toobally Formation) occurs in the immediate hanging wall of the Toobally fault in the east-central part of the map area.

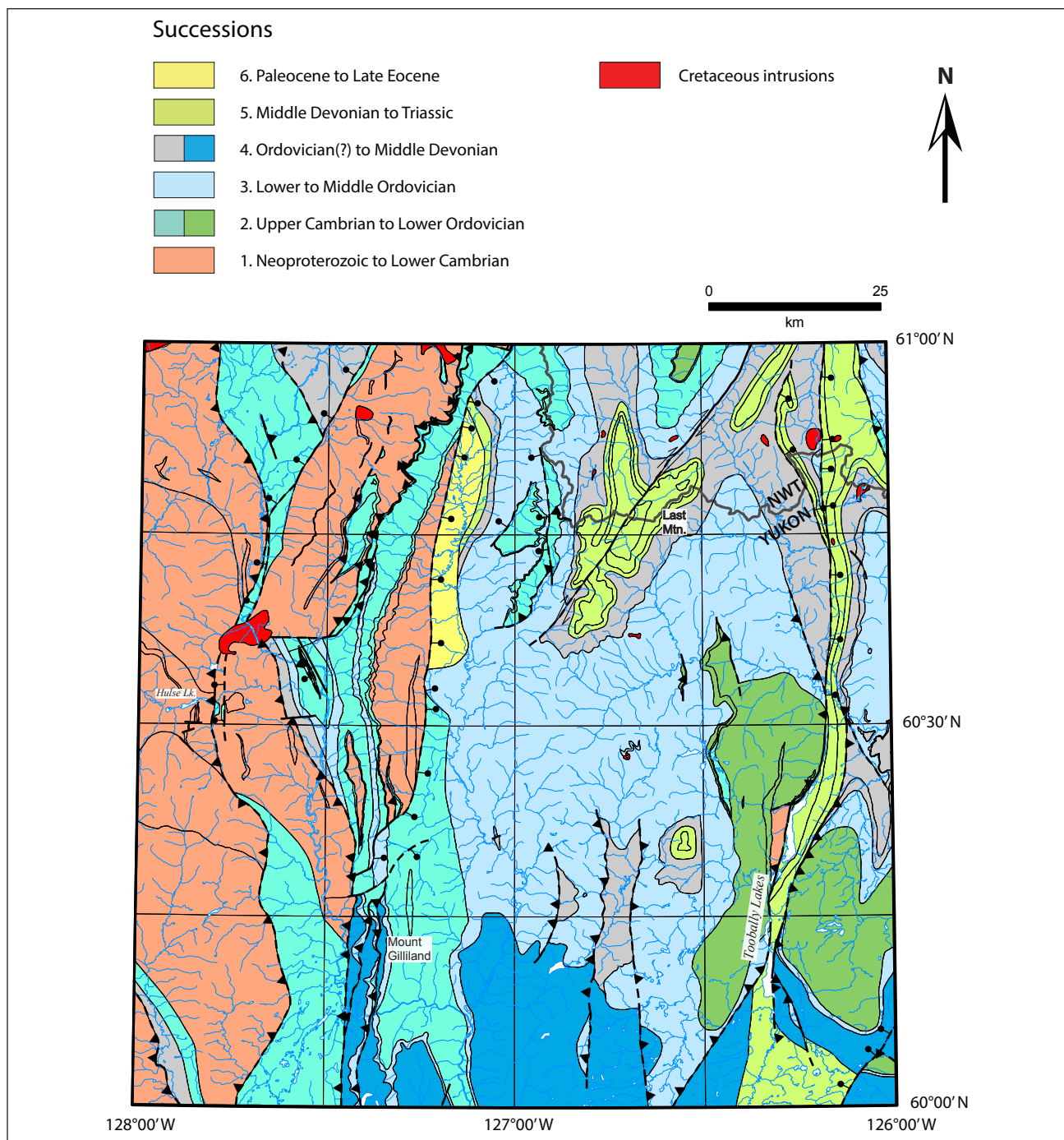


Figure 3. Coal River map area, showing the six stratigraphic successions and Cretaceous intrusions, based upon 2009-2010 fieldwork and previous mapping by Gabrielse and Blusson (1969). The map area at 1:250 000 scale is shown in Plate 1.

Succession 2 is upper Cambrian through Lower Ordovician in age; it exhibits a dramatic facies change from limestone and silty limestone in the west (Otter Creek and Rabbitkettle formations) to shallow water and subaerial strata dominated by subarkosic sandstone and maroon siltstone in the east (Crow Formation). Both facies contain intervals of mafic volcanic rocks.

Succession 3 is presently exposed throughout the eastern two-thirds of the map area and consists of Lower to Middle Ordovician shallow, platformal carbonate (Sunblood Formation). This succession is absent in the southwest and northwest corners of the Coal River map area.

Table 1. Formations in Coal River map area.

Succession	Map Unit	Main Lithology	Thickness (m)
6	Rock River (ERRs)	mudstone	>445 - 1100 ?
6	Paleocene clastic (Pssc)	siltstone, sandstone and conglomerate	160
5	Toad and Grayling (TGT)	shale	>240
5	Fantasque (PF)	shale	1000 - 1700
5	Mattson (MM)	sandstone	500 - 1450
5	Besa River (DMBR)	shale	300
4	Siluro-Devonian carbonate (SDc)	dolostone	100 - 1000
4	Road River (SDRR, SMRR)	shale, siltstone	2000
4	Ordovician-Silurian sandstone (OSs)	sandstone to pebbly sandstone	220
3	Sunblood (OSu)	dolostone or limestone	0 - 2700
2	Rabbitkettle (COR-n, COR-lp, COR-v)	limestone, calc-phyllite	300 - 1500
2	Otter Creek (COOC)	limestone	65 - 500
2	Crow (COC, COC-v)	sandstone	? - >5000
1	Sekwi-correlative (CS)	phyllite to siltstone, sandstone	400
1	Vampire and Narchilla (PCVN, PCVN-m, PCVN-l, PCVN-v)	phyllite to pelite	0 - 2500
1	Yusezyu (PY)	sandstone, pebbly sandstone	3500 ?
1	Toobally (PT)	pebbly mudstone	>1800

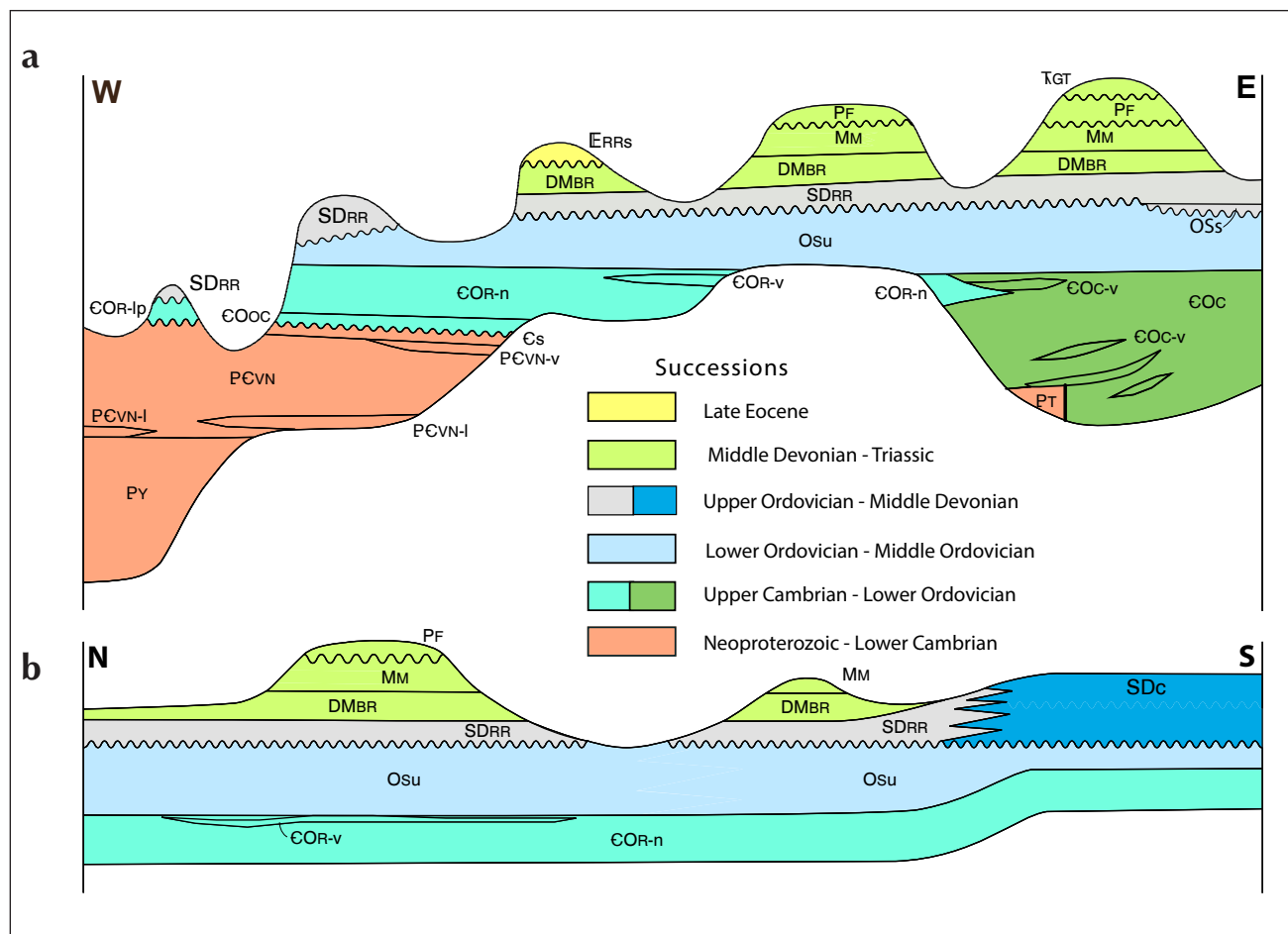


Figure 4. Schematic correlation diagrams of stratigraphic successions, from (a) west to east and (b) north to south across the Coal River map area.

Succession 4 includes the lateral transition from lower Silurian to Middle Devonian carbonate platformal sedimentary rocks of Macdonald platform (single map unit combining the Nonda, Muncho-McConnell, Stone and Dunedin formations) in the southern third of the map area, to fine clastic, basinal sedimentary rocks of Selwyn basin (Road River Group, undivided) northward. A basal coarse-grained, siliciclastic unit (Oss) occurs only in the eastern part of the map area.

Succession 5 comprises Middle Devonian through Triassic shallow marine shale, siltstone and sandstone (Besa River, Mattson, Fantasque and undivided Grayling-Toad formations) that represent multiple regional transgressive-regressive cycles separated by unconformities.

Succession 6 consists of the late Eocene fluvial strata and coal in the intermontane Rock River basin occurring in the north-central part of the map area and a single occurrence of Paleocene basalt and fluvial sediments on the far eastern edge of the map area.

The descriptions of these lithologic units augment those previously published for southeast Yukon (Pigage, 2006, 2009). Regional correlations include more recent information from adjacent regions (specifically northeastern British Columbia). Geographic place names used in the following descriptions are indicated on Plate 1 and Figure 1.

SUCCESSION 1 - NEOPROTEROZOIC TO LOWER CAMBRIAN

Predominantly siliciclastic sediments and minor carbonate and volcanic rocks are exposed extensively in the western third of the Coal River map area. A smaller exposure lies west of the upper Toobally Lake in the east-central part of the area. The western region includes Yusezyu and Narchilla formations of the Hyland Group, Vampire Formation, and silty phyllite, sandstone, and limestone considered equivalent to Sekwi Formation. The areally limited exposures in the east comprise the Toobally Formation. Proterozoic sandstone (unit **Ps** of Pigage, 2009) and argillite (unit **Pa** of Pigage, 2009) are exposed immediately east of Coal River map area, and possibly underlie the Toobally Lakes region.

Toobally Formation (PT)

Introduction

The Toobally Formation (Pigage and MacNaughton, 2004) occurs in scattered exposures immediately west of upper Toobally Lake. It consists of a monotonous succession of orange-weathering, polymictic, matrix-supported conglomerate to pebbly mudstone (Fig. 5) with a minimum thickness of 1800 m (assuming a regional 45° dip). The lower contact is structural as the unit occurs in the immediate hanging wall of the east-verging Toobally reverse fault. The upper contact with the overlying Crow Formation is unconformable.



Figure 5. *Pebbly mudstone of the Toobally Formation, with slaty cleavage, dipping to the left (west). Hammer handle is 33 cm long. West of upper Toobally Lake, station 03LP006.*

Composition

Bedding generally cannot be seen at outcrop scale. In rare cases, normally graded to indistinctly gradational beds can be recognized within the unit. It contains a moderately developed, pervasive slaty cleavage which gradually becomes more intense toward the Toobally fault to the east.

The matrix for the conglomerate to mudstone consists of dark brown to dark grey, brown, buff, or orange-weathering silty shale to siltstone and accounts for 50 to 80% of the total rock volume. Clasts are most commonly within the granule to pebble size range; cobbles are rarely present. They are angular to subrounded, without preferred orientation. Numerous clast compositions were observed, including quartzitic meta-sandstone, calcareous sandstone, lithic sandstone, mudstone, massive lime mudstone and dolo-mudstone, laminated lime mudstone, massive grainstone and rare fragments of vesicular to amygdaloidal basalt. At one locality the formation contains a large olistolith of orange-weathering, unfossiliferous, microcrystalline to very finely crystalline, thinly bedded dolostone at least 20 m thick. The upper contact of the dolostone has not been observed; the lower contact is sharp and stained red (see Pigage, 2009, p. 22, for more description).

The Toobally Formation is cut by dark green, orange-weathering, fine-grained, diabase to gabbro dikes and sills from less than 10 cm to greater than 10 m thick (too small to show on the map). In many outcrops the dikes and sills are extensively altered to a pale grey, orange-weathering, pyritic carbonate-sericite assemblage. The geochemistry of the dikes and sills is similar to that for the Crow Formation volcanic rocks, and they are considered to be feeders for the overlying Crow Formation volcanic rocks (Pigage, 2009); the analyses are listed in Appendix C but are not included in the discriminant diagrams.

Age, Correlation and Depositional Setting

Fieldwork in 2003 (Pigage and MacNaughton, 2004) found no definitive evidence for glacial deposition (*i.e.*, dropstone and lonestone in associated sediment, till pellets, striated clasts). This polymictic lithotype can be deposited under glacial or non-glacial conditions (Eyles, 1990). Pigage and MacNaughton (2004) interpreted the Toobally Formation as being deposited from relatively viscous, sediment-gravity flows in a marine slope to toe-of-slope setting.

Pigage (2009) discussed possible depositional ages for this stratigraphic unit. One detrital zircon sample contained a youngest detrital zircon age of about 650 Ma (2 grains; see Pigage, 2009). The preferred depositional age is late Neoproterozoic (post-650 Ma). Rare basaltic clasts indicate an earlier period of volcanism in the paleo-drainage (Pigage, 2009).

In spite of the lack of direct evidence for the Toobally Formation being a glacial deposit, Pigage and MacNaughton (2004) noted that the unit resembles Neoproterozoic Sturtian and Marinoan glacial diamictites previously documented in northwestern Canada: the Shezal Formation (Eisbacher, 1978, 1981) and the Ice Brook Formation (Aitken, 1991). A recent U-Pb single grain dating (CA-ID-TIMS) on a volcanic tuff within the Sayeuni Formation stratified diamictites resulted in a date of 716.5 ± 0.2 Ma for the earlier Sturtian glaciation (Macdonald *et al.*, 2010). A Re-Os date of 662.4 ± 3.9 Ma for the Twitya Formation (Rooney *et al.*, 2014) places a maximum age constraint on the Ice Brook Formation (Marinoan glaciation). Detrital zircon results for the Toobally Formation (see above) are consistent with correlation of the Toobally Formation with the Ice Brook Formation of the Windermere Supergroup.

Hyland Group

The Hyland Group (Gordey and Anderson, 1993) is the oldest widely exposed unit of Selwyn basin. It outcrops nearly continuously from the Alaska-Yukon border north of the Yukon River, southeast to

the Northwest Territories-Yukon border, and extends 130 km into northern British Columbia and the headwaters of the Tuchodi River (59°N; Wheeler and McFeely, 1991). Where defined in the southern Little Nahanni River map area (140 km northwest along structural grain from the northwest corner of Coal River map area; Fig. 1) it consists of pebbly sandstone with interbedded shale of the Yusezyu Formation, overlain by greyish green and maroon shale of the Narchilla Formation. The uppermost part of the Yusezyu Formation contains numerous discontinuous orange-weathering, dark, shaly to silty limestone lenses that Gordey and Anderson (1993) informally called the limestone member. This middle carbonate is increasingly prominent northward, and Cecile (2000) formally established the Algae Formation in Nidderly Lake map area (400 km north of Coal River). Regionally the Yusezyu Formation is Neoproterozoic (Ediacaran), and the Narchilla Formation is Neoproterozoic (Ediacaran) to possibly lower Cambrian (Fortunian; uppermost stage 2?).

The Hyland Group strata are the oldest strata in the western third of the Coal River map area. Only the Narchilla and Yusezyu formations are recognized; a mappable Algae Formation is not present and mappable calcareous strata occur entirely within the Narchilla Formation.

Yusezyu Formation (Hyland Group) (PY)

Introduction

The Yusezyu Formation (Gordey and Anderson, 1993) is exposed in two northwest-trending belts in the westernmost Acland thrust fault panel of the Coal River map area (Plate 1). The base of the formation was not observed; the upper contact with the overlying Narchilla Formation is gradational, although locally faulted (Plate 1). The contact with the overlying Narchilla Formation was placed at the gradational transition demarcated by an up-section decrease in the amount of pebbly sandstone and quartz sandstone and a corresponding increase in green and/or maroon, noncalcareous, silty phyllite; this transition occurs over an interval of tens of metres to hundreds of metres.

At the type section (in the Little Nahanni River map area), the Yusezyu Formation is at least 3000 m thick (Gordey and Anderson, 1993). In the Coal River map area only the upper part of the formation is exposed, and a lack of marker horizons make structural repetition difficult to recognize. An inferred thickness of approximately 3500 m is used in the cross section interpretation (Plate 1).

Composition

In Coal River the Yusezyu Formation consists predominantly of noncalcareous, grey to cream sandstone to pebbly sandstone (Fig. 6) interbedded with brown-weathering, non-calcareous, medium to pale green phyllite and rare fine-grained, grey limestone. In the pebbly sandstones the predominant coarse clasts are clear to bluish quartz with lesser subangular, white feldspar. Bedding is on a scale of centimetres to metres; exposures typically have gentle dips. In contrast to the type area of the Yusezyu Formation (Gordey and Anderson, 1993) no limestone is present at the top of the Yusezyu Formation in the Coal River map area.



Figure 6. Yusezyu Formation sandstone, showing the bedding contact between coarse and fine-grained beds. White granules are quartz in a noncalcareous, coarse-sand matrix. Black bars on scale at right are in cm. From 20 km north of Hulse (Quartz) Lake, station 09RAS058.

Age, Correlation and Depositional Setting

In the Coal River map area the Yusezyu Formation is unfossiliferous. Regionally the upper part of the formation is of latest Precambrian age (Ediacaran) based on primitive trace fossils reported by Fritz *et al.* (1983).

The pebbly sandstone of the Yusezyu Formation is correlated by Fritz *et al.* (1983) with the lower member of the Backbone Ranges Formation (*cf.* MacNaughton *et al.*, 2008) on the basis of trace fossils in overlying strata and stratigraphic position. Moynihan (2014) correlated the Yusezyu Formation with an uppermost member of the Blueflower Formation in the northernmost Selwyn basin area. These two correlations are compatible only if the entire Backbone Ranges Formation indicated by Moynihan corresponds to only the upper member of the Backbone Ranges Formation.

The Yusezyu Formation is a thick succession of coarse-grained turbidite flows that reflect rapid erosion of a sedimentary source terrane of unknown extent and location (Gordey and Anderson, 1993). Scarce paleocurrent indicators suggest that the source area is located to the northwest. The suggested depositional environment is a series of upper or mid-fan submarine channels in shallow to moderate water depth (Gordey and Anderson, 1993).

One sample of Yusezyu Formation (09LP014) from the west side of the Coal River map area was submitted for detrital zircon study. The table of analyses from this sample is contained in Appendix B (Tables B2a,b,c). Figure 7 illustrates the Concordia diagram and the probability distribution plot for the sample. The sample contains two Neoproterozoic to Mesoproterozoic ages, 631 ± 29 Ma and 1115 ± 109 Ma. All other dates are Paleoproterozoic and Archean. The probability distribution plot has a dominant peak centred on 1859 Ma and a lesser peak at 2719 Ma. Scattered peaks range between 1937 Ma and 2606 Ma. The oldest dated grain has an Archean age of 2745 ± 51 Ma. The dominant age distribution of detrital zircons corresponds to the Laurentia Type I signature identified by Hadlari *et al.* (2012); the zircons could be derived from the Wopmay orogen and the Archean Slave province east and northeast (current orientation) of the Coal River map area.

This interpretation contrasts with a northwestern source indicated by the limited paleocurrent data of Gordey and Anderson (1993). The western extent of the Yusezyu Formation is unknown because it is truncated by the Tintina fault. As a result the provenance of Yusezyu Formation remains unresolved.

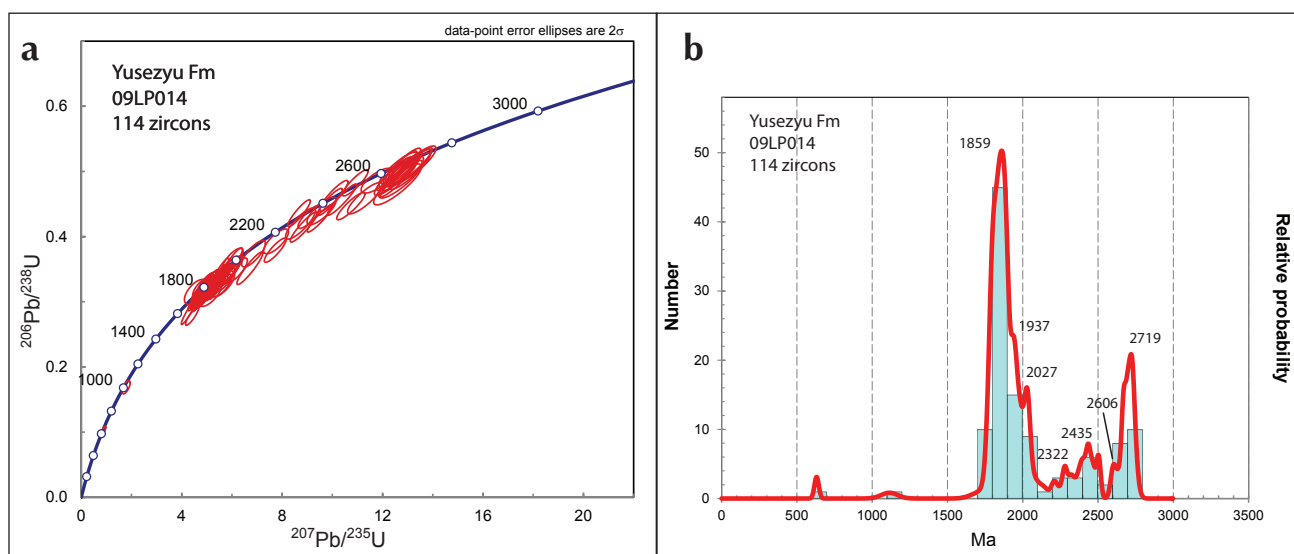


Figure 7. Results of geochronological analysis of 114 detrital zircon grains from sample 09LP014 of Yusezyu Formation sandstone: **(a)** concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B2).

Vampire-Narchilla unit (Hyland Group) (P VN, P VN-m, P VN-l, P VN-v)

Introduction

Shaly strata lithologically similar to both the Narchilla Formation (Gordey and Anderson, 1993) and Vampire Formation (Fritz, 1982) are exposed in the western third of the map area. Observations of previous workers in the northern part of the Coal River map area (Abbott, 1981) and in areas farther north (Fritz, 1982; Gordey and Anderson, 1993) indicate a west-to-east transition from Narchilla Formation (dominantly slate to phyllite) through Vampire Formation (dark weathering siltstone interbedded with quartzose sandstone) to the upper member of the Backbone Ranges Formation (sandstone; MacNaughton *et al.*, 2008). In 2009 we were unable to consistently differentiate the Vampire and Narchilla formations. Consequently we chose to map these units as an undivided Vampire-Narchilla unit.

The lower contact with the Yusezyu Formation is poorly exposed but appears to be a gradational decrease up-section in the amount of subarkosic pebbly sandstone and a corresponding increase in shale and siltstone. In the central part of the map area immediately west of the Rock River, the unit is conformably overlain by siltstone, sandstone and carbonate rocks of unit ** s**, the lower Cambrian Sekwi-correlative unit. The undivided Vampire-Narchilla unit is unconformably overlain by the late Cambrian to Early Ordovician Rabbitkettle or Otter Creek formations in the western part of the map area.

The thickness of the Narchilla Formation at the type section is 828 m (Gordey and Anderson, 1993). The type section of the Vampire Formation is 930 m thick (Fritz, 1982). In the Coal River area the thickness of the Vampire-Narchilla unit is interpreted to be significantly greater, based upon the geometric requirements of a structurally plausible cross section; the thickness of this unit could be as much as 2500 m.

Composition

The predominant lithology (Fig. 8) is a pale olive green, rusty brown-weathering, noncalcareous, laminated, silty phyllite (**P VN**). Bedding within the phyllite is denoted by colour variations and is on the scale of centimetres to metres. Locally the pale green phyllite contains interbeds of reddish maroon to dark maroon phyllite (**P VN-m**; Fig. 9); this maroon phyllite is regionally characteristic of the Narchilla Formation. West of the West Coal River, maroon interbeds are common within the green silty phyllites. In contrast maroon interbeds are rare in the southwestern quadrant of the map area. No maroon intervals were observed in the silty phyllite immediately west of the Rock River.

The phyllite contains interbeds of medium to dark grey, cream-weathering siltstone, cream-weathering, quartzose sandstone (Fig. 10), cream-weathering, pebbly quartzose sandstone and pale to medium grey, thick-bedded to massive limestone (**P VN-l**). The sandstone, pebbly sandstone and limestone intervals locally reach thicknesses of 100 m or more without apparent structural repetition. Only the interbedded limestone units have been differentiated as separate lithologies in the legend.

The Vampire-Narchilla unit consistently displays a pervasive slaty cleavage (Figs. 8, 9, 10). Locally it also contains a later, spaced crenulation cleavage. Throughout most of the area the phyllite contains sericite and chlorite, placing it in the lower greenschist facies of metamorphism. In a north to northeast-trending linear zone extending from south of Roy Lake northeastward to Mt. Skonseng, the phyllite contains ubiquitous biotite with local garnet and staurolite (Fig. 11). The areal extent of the biotite-bearing phyllite was not well defined by the few traverses completed in 2009.



Figure 8. Olive green, silty phyllite of the undivided Vampire-Narchilla map unit. Slaty cleavage (steeply dipping north-northeast) offsets the horizontal bedding, which is marked by a thin, recessive siltstone layer. From 20 km northwest of the eastward bend of the Coal River, station 09LP028. Hammer handle is 33 cm long.



Figure 9. Banded maroon and green phyllite of the undivided Vampire-Narchilla map unit. The colour change represents oxidation-reduction fronts during diagenesis of the muddy sediment and typically follows layering. From east of Coal River and west of the headwaters of Otter Creek, station 07LP003.

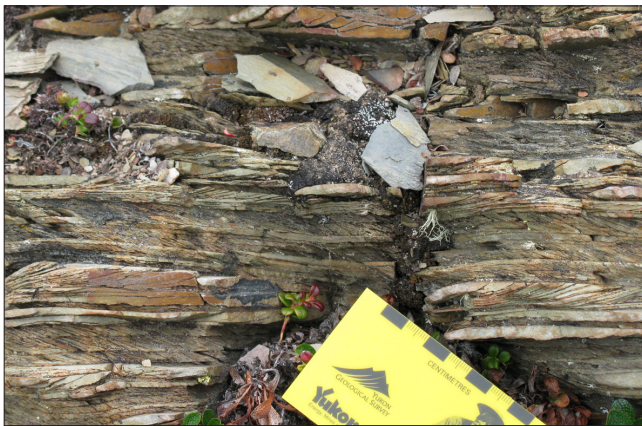


Figure 10. Phyllitic siltstone interbedded with light brown quartz sandstone in the undivided Vampire-Narchilla map unit. Note the centimetre-scale cross-beds (mostly dipping to the left in the photograph) in the sandstone beds and slaty cleavage in the phyllitic siltstone beds (dipping to the right). Outcrop 20 km north of Alaska Highway, station 09LP022.



Figure 11. Staurolite-garnet-biotite schist of the undivided Vampire-Narchilla map unit. From 30 km northeast of Roy Lake, station 09TOA076. The coin is 2.5 cm in diameter.

In the central Coal River map area, immediately west of the Rock River, the upper part of the Vampire-Narchilla unit contains extensive greyish-green to green, fine-grained, locally amygdaloidal to vesicular basalt which we have differentiated as a separate unit (PCVN-v). Lower and upper contacts are not exposed; these could be flows or sills. Locally the basalt is intruded by fine to medium-grained, equigranular, chloritized hornblende diabase that likely represents feeders. The basalt and diabase form a mappable unit up to 1300 m thick. Their geochemistry is discussed in the section on Cambro-Ordovician alkali basalt (see p. 42).

Age, Correlation and Depositional Setting

We did not recognize any fossils in the Vampire-Narchilla unit in the Coal River map area. Regionally the Vampire Formation contains ichnofossils from biozones *Rusophycus avalonensis* and *Cruziana tenella* (Fritz *et al.*, 1983; MacNaughton and Narbonne, 1999). The first appearance (datum) of trilobites and archeocyathids occurs within the very uppermost Vampire Formation and the overlying Sekwi Formation (Handfield, 1968). The age of the Vampire-Narchilla unit is therefore early Cambrian (Terreneuvian: Stages Fortunian and 2). Occurrences of the ichnofossil *Oldhamia radiata* in the upper part of the unit in Niddery Lake map area (Hofmann and Cecile, 1981) are consistent with the upper portion of the unit being within Cambrian Stage 2 (Herbosch and Verniers, 2011).

Time-correlative formations north of the Coal River map area display a complex succession of interlayered coarse and fine siliciclastic formations (Fig. 12) deposited in Selwyn basin.

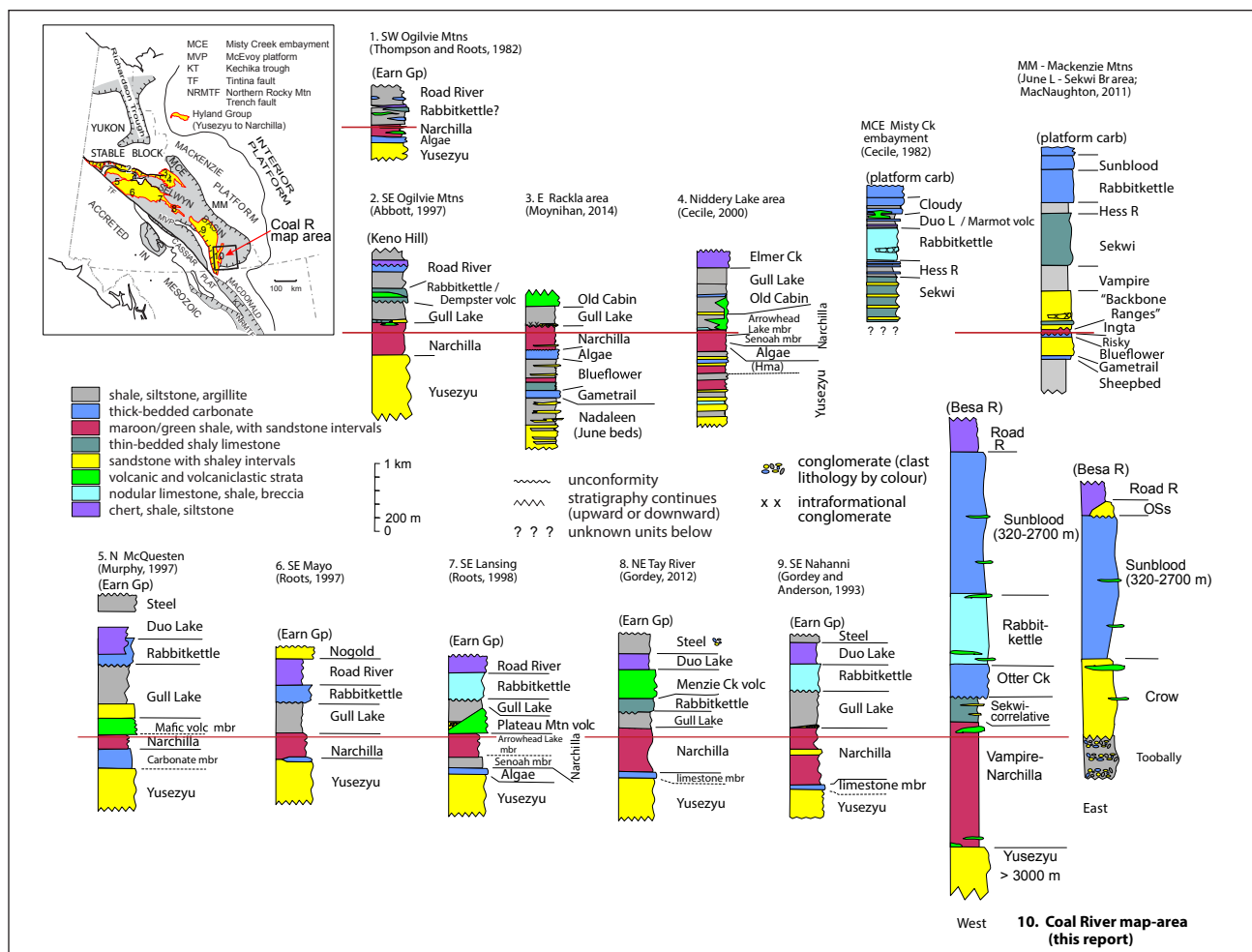


Figure 12. Regional correlation of stratigraphic units that compose Selwyn basin (and Mackenzie Mountains [MM] for comparison). Representative columns were selected from the numbered areas and depict thicknesses as given in the citations; the datum is approximately the Cambrian-Precambrian boundary. Overlying units are labeled in parentheses. This figure is modified from Figure 36 in Gordey and Anderson (1993) and Figure 5 in Cecile (2000).

Two sandstone samples from the undivided Vampire-Narchilla unit were examined for detrital zircon geochronology (09TOA098 and 09TOA094). Results are tabulated in Appendix B (Tables B3 and B4) and illustrated in Figures 13 and 14. Four zircon grains from sample 09TOA098 indicate a maximum

age of 644 Ma, and one grain from sample 09TOA094 indicates a maximum age of 560 Ma for the unit.

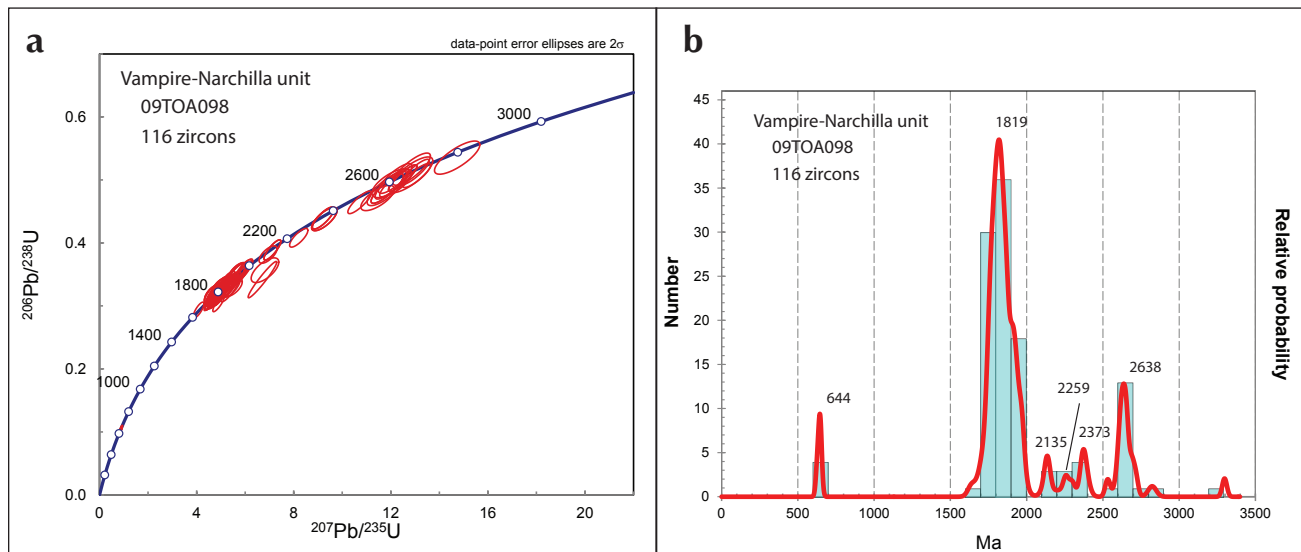


Figure 13. Results of geochronological analysis of 116 detrital zircon grains from sample 09TOA098 of undivided Vampire-Narchilla map unit sandstone: **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B3).

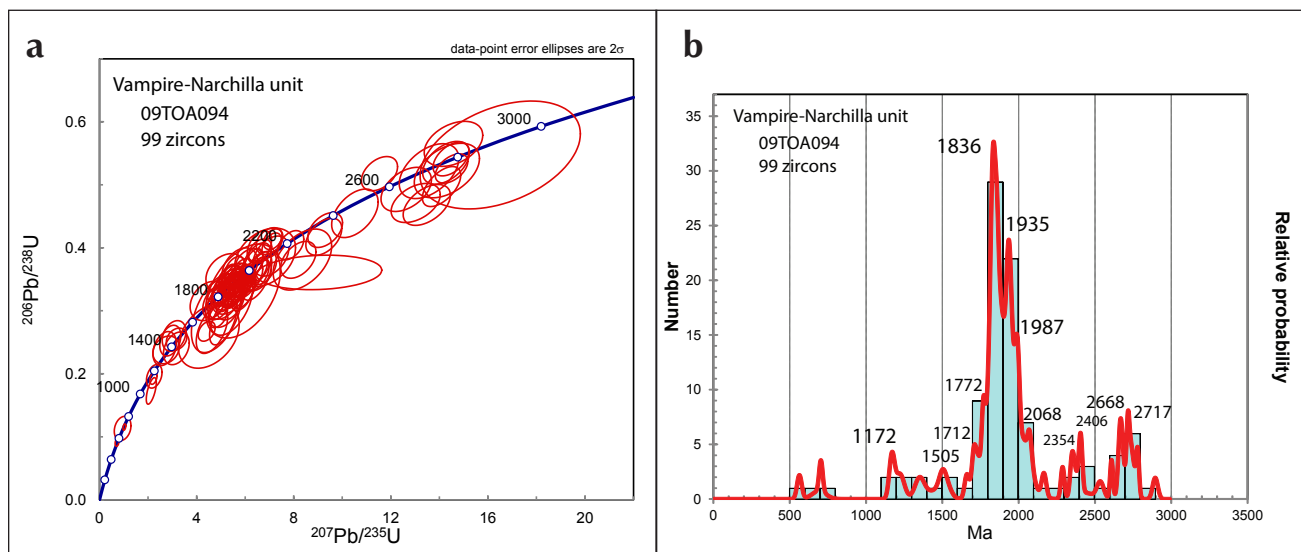


Figure 14. Results of geochronological analysis of 99 detrital zircon grains from sample 09TOA094 of undivided Vampire-Narchilla map unit sandstone: **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B4).

Sample 09TOA098 has a similar probability plot to that of the Yusezyu Formation with a major peak at 1819 Ma and lesser peaks at 2373 Ma and 2638 Ma. In contrast, sample 09TOA094 contains a different zircon age distribution. About 15% of the analyzed grains are within the interval from 1000-1550 Ma. More than 30% of the grains are between 1700 and 1800 Ma.

Hadlari *et al.* (2012) identified two major detrital zircon signatures for Cambrian strata in the Northwest Territories. These signatures closely match those identified above for samples 09TOA094 and 09TOA098. The Laurentia type I signature (sample 09TOA098) is dominated by Paleoproterozoic and Archean detrital zircon ages with potential sources including the Great Bear magmatic zone, Fort

Simpson terrane, Hottah terrane, Coronation margin and Slave craton. The Laurentia type II signature (sample 09TOA094) contains abundant Mesoproterozoic ages. The source area is dominated by Grenville-aged detrital zircons; proximate sources are most likely Proterozoic strata of the Mackenzie Mountains and Shaler supergroups. The fewer grains of Paleoproterozoic and Archean age could have the same source area as the Laurentia type I signature. Both of these source areas are east to northeast of the Coal River map area.

In summary, detrital zircon ages from the two samples are consistent with erosion of Paleoproterozoic and Archean bedrock in northern Alberta and Northwest Territories. A small number of zircon grains are most likely recycled from exposed Mackenzie Mountains Supergroup strata at the time of deposition of this Vampire-Narchilla unit. An easterly source was also determined for the Backbone Ranges Formation (Leslie, 2009).

Although we chose to assign these lithologies to a combined Vampire-Narchilla map unit, in a broader context the Narchilla and Vampire formations are differentiated regionally (Abbott, 1981; Fritz, 1982). For consistency with the regional treatment of this stratigraphic interval we assign our combined map unit to different formations in the Yukon-wide geology compilation according to the structural panel in which it appears. The western-most domain A structural panel is considered to be the Narchilla Formation, and exposures in the two more easterly structural panels have been assigned to the Vampire Formation.

Unit Cs (Sekwi-correlative unit)

Introduction

Ridges west of the Rock River in the north-central map area contain exposures of silty phyllite, silty, archeocyathid-bearing limestone, arkosic sandstone and quartzose sandstone. We have informally called this unit the 'Sekwi-correlative' unit because it is correlative in time with the Sekwi Formation. We are not calling it the Sekwi Formation because lithologies in the Coal River area differ from the predominant carbonate rocks described for the Sekwi Formation at the type section (Handfield, 1968) located 300 km to the north.

Unit **Cs** conformably overlies the Vampire-Narchilla unit and is unconformably overlain by carbonate rocks of the upper Cambrian-lower Ordovician Otter Creek Formation. The overall thickness of unit **Cs** is approximately 400 m where it is most completely exposed. The unit could not be traced beyond a strike length of 22 km; this is a minimum extent because we were unable to recognize it with our limited traverses. Alternatively it may have been removed by the unconformity beneath the overlying Otter Creek Formation.

Composition

Unit **Cs** consists predominantly of pale green to tan, brown-weathering, laminated, locally calcareous, silty phyllite (Fig. 15). Interbedded with the silty phyllite are rusty brown-weathering, thin bedded arkosic sandstone, cream-weathering, fine-grained quartzose sandstone and laminated, silty limestone. The lower contact with the Vampire-Narchilla unit is denoted by the first appearance of recessive-weathering limestone nodules in the siltstone (Fig. 15), the occurrence of trilobites, and the presence of green, argillaceous siltstone. A silty limestone bed occurs at this basal contact. Arkosic sandstone intervals up to 10 m thick occur throughout the lower part of the unit. A cream-weathering, noncalcareous, quartzose sandstone forms a distinctive thick-bedded unit 70 m thick at the top of the unit. Medium to dark grey and orange-weathering limestone near the middle of the unit contains archeocyathids (Fig. 16) and occurs locally as bioherms or bioclastic sediments (Handfield, 1971). Trilobites were found in the silty phyllite stratigraphically below and above the archeocyathid-bearing limestone (Handfield, 1971).

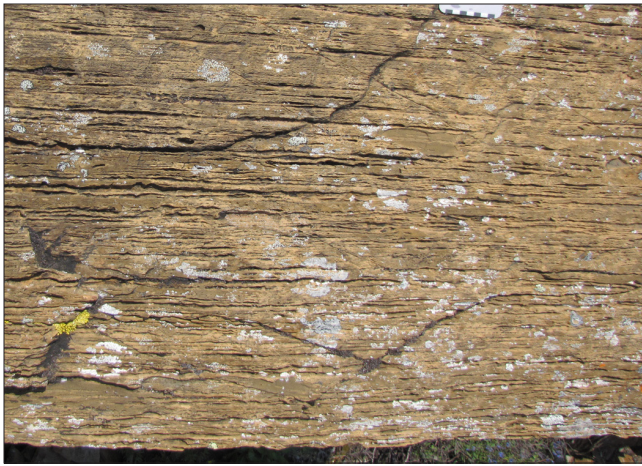


Figure 15. Light brown-weathering, grey, calcareous phyllite at the base of the Sekwi-correlative unit. Dark hollows up to 3 cm long are recessive-weathering carbonate nodules. From 17 km northeast of the confluence of Quartz Creek with Coal River, station 09TOA15. Scale card at top edge of photo is in cm.

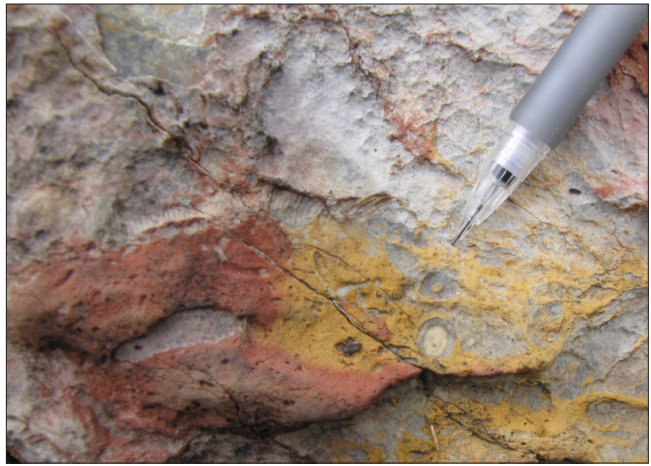


Figure 16. Thick limestone near the middle of the Sekwi-correlative unit (**Cs**) containing archeocyathids. Outcrop is 3 km northeast of the confluence of Quartz Creek with Coal River, station 09TOA017.

Age, Correlation and Depositional Setting

The trilobite and archeocyathid fossils (see Appendix A) indicate the formation is lower Cambrian, contemporaneous with the Sekwi Formation. Although differing in detail, the trilobite identifications by Handfield (1971) and L. Bohach (pers. comm. 2009) indicate the age of unit **Cs** is lower Cambrian Series 2 (Stage 3 or Stage 4). Fritz (1972) delineated three trilobite zones within the type Sekwi Formation (Fallotaspis, Nevadella and Bonnia-Olenellus zones); these correspond to Stages 3 and 4 in Series 2 of lower Cambrian (Peng *et al.*, 2012).

Unit **Cs** is a deeper water facies-equivalent of the Sekwi Formation. In the Selwyn basin area, the lower Cambrian shale facies is known as Gull Lake Formation (Fig. 12; Gordey and Anderson, 1993), but the strata in Coal River map area is more calcareous and siltier than Gull Lake Formation. The unit is envisaged to have been deposited on a westward deepening, homoclinal ramp, similar to that described in Sekwi Mountain map area 100 km to the north (Fischer and Pope, 2012).

The northern part of the Kechika trough southwest of the Coal River map area, contains a facies change from interbedded early Cambrian siliciclastic rocks and carbonate rocks eastward to deeper water siliciclastic rocks, possibly indicative of the western edge of Kechika trough (Ferri *et al.*, 1999). Archeocyathids in the carbonate intervals indicate the package is correlative with the Sekwi Formation (and with Unit **Cs** in the Coal River map area).

Two samples (09TOA095 and 09TOA096) from this unit were analyzed for detrital zircon geochronology. Analytical results are illustrated in figures 17 and 18; analytical tables are listed in Appendix B (Tables B5 and B6). The zircons of both samples can be grouped into three clusters: those consistent with Mesoproterozoic Grenville age (1.0-1.5 Ga); those of Paleoproterozoic age possibly derived from the Hottah terrane and Great Bear Magmatic zone (1.8-2.1 Ga); and those of Archean Slave craton (>2.5 Ga) age. The detrital zircons indicate a mix of the Laurentia type I and type II signatures as identified by Hadlari *et al.* (2012). All three clusters can be attributed to basement and Mackenzie Mountain Supergroup sources that are exposed to the east in Alberta and Northwest Territories.

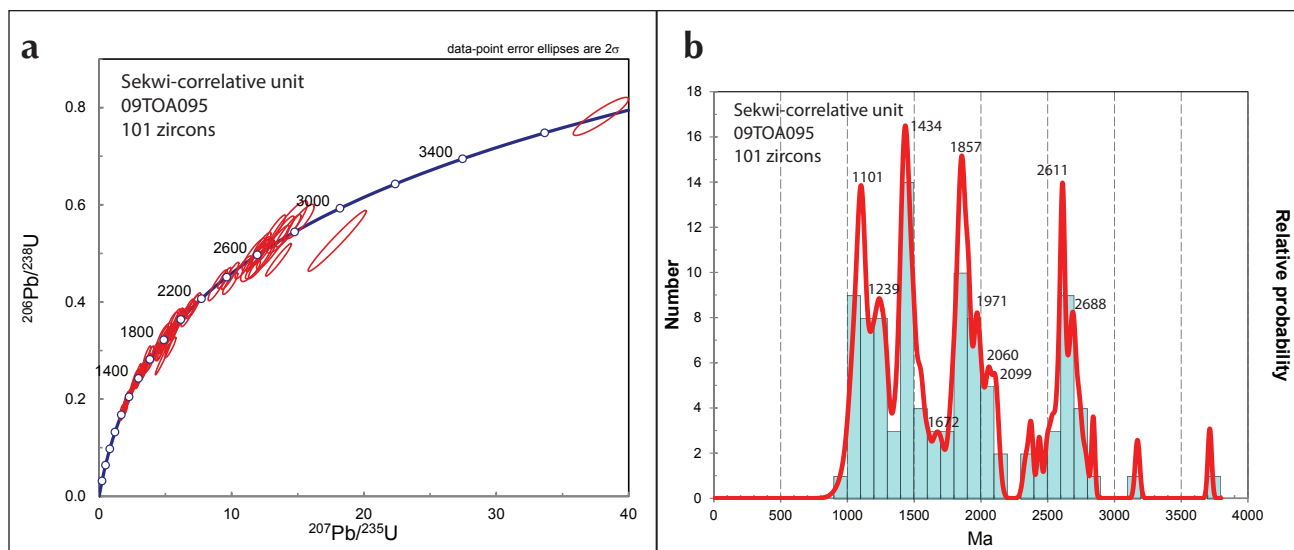


Figure 17. Results of geochronological analyses of 101 detrital zircon grains from sandstone in Sekwi-correlative unit: **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B5), station 09TOA095.

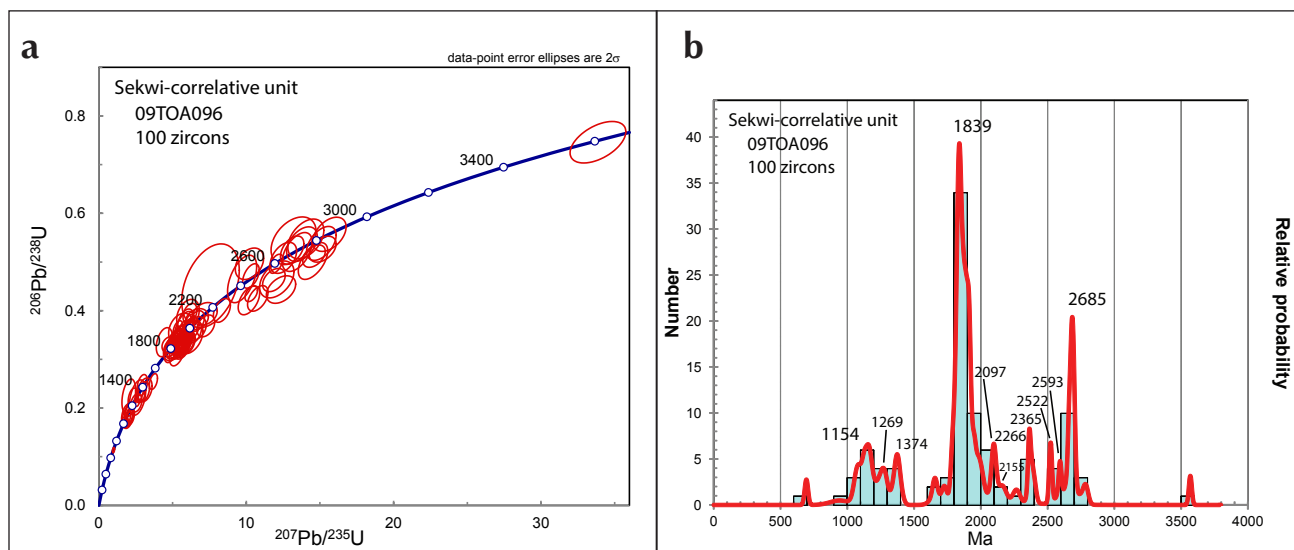


Figure 18. Results of geochronological analysis of 100 detrital zircon grains from uppermost sandstone of Sekwi-correlative unit: **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B6), sample 09TOA096.

SUCCESSION 2 – UPPER CAMBRIAN TO LOWER ORDOVICIAN

Succession 2 consists of three stratigraphic units having a composite age range of late Cambrian through Early Ordovician and a combined thickness of approximately 5000 m. The lowermost unit in the succession is a thick-bedded to massive limestone and dolostone, outcropping largely in the central part of the map area; this unit is defined in this report as the Otter Creek Formation. Silty to phyllitic limestone of the Rabbitkettle Formation conformably overlies the Otter Creek Formation. The western half of the Coal River map area contains two facies of the Rabbitkettle Formation. In the eastern half of the map area quartzose sandstone of the Crow Formation appears to interdigitate with the time-equivalent Rabbitkettle Formation. The lower contact of this entire succession is unconformable, and the upper contact is conformable.

Otter Creek Formation (EOOC) [new]

Introduction

This unit comprises massive limestone and lesser dolostone (mapped by Gabrielse and Blusson (1969) as unit 5, presumed lower Cambrian), here defined as the Otter Creek Formation. Several narrow belts of exposure lie between the Rock and Coal rivers (Plate 1). The type area for the formation is in NTS 95D/06 at the Mel property (UTM NAD83 587 950 E/6 692 150 N) where a complete section of this formation is exposed (Fig. 19) in the overturned steep limb of an east-verging, asymmetric anticline-syncline fold couplet. The type area is located near the headwaters of Otter Creek, after which the formation is named.



Figure 19. Massive limestone of Otter Creek Formation in the overturned steep limb of an asymmetric syncline. View northward at the head of Otter Creek, near the MEL occurrence, from station 06LP008. This is the proposed type location for the Otter Creek Formation.

Both upper and lower contacts are recessive and not observed at surface in the dense vegetation cover. The contacts were recognized in diamond drill holes on the Mel property. The lower contact is sharp and interpreted as a major unconformity above the lower Cambrian Vampire-Narchilla unit. The conformable upper contact with the calcareous shale and silty limestone of the Rabbitkettle Formation is sharp.

On the Mel property, the Otter Creek Formation is approximately 160 m thick. Thickness estimates in the Coal River map area range from 65 m on the Jeri North property (Yukon MINFILE 095D 035) to 500 m in outcrops west of the Rock River in the northern part of the Coal River map area.

Composition

The Otter Creek Formation weathers light grey to off-white, and consists of finely crystalline, indistinctly bedded to massive, resistant limestone (Fig. 20) with lesser interbeds of buff to tan-weathering dolostone. The limestone typically contains ghosted white calcite and tan siderite veinlets. In at least one location the limestone has ghost textures reminiscent of burrow mottling. In the type area the limestone contains small, irregular lenses of pale green to cream, noncalcareous phyllite to mudstone (Fig. 21).

Dolostone lenses have a massive, sucrosic texture. Miller (1977) described three stratiform, discontinuous dolostone intervals up to 30 m thick and ranging from 60 to 500 m in length. One dolostone occurrence, up to 30 m thick, occurs adjacent to a late steep fault and clearly crosscuts primary bedding.

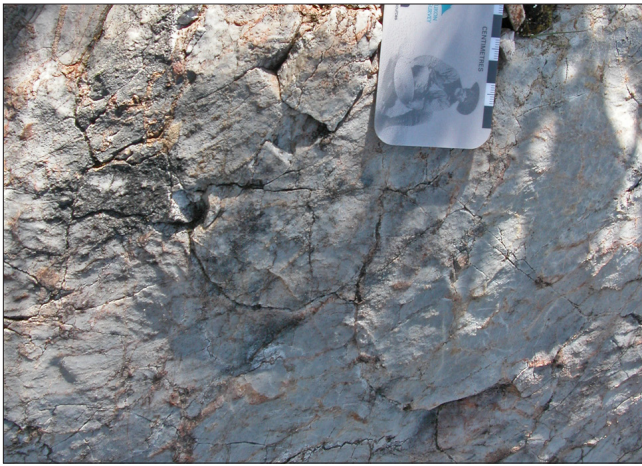


Figure 20. Light coloured, massive, fine-grained limestone with irregular network of buff to tan-weathering dolostone veinlets, Otter Creek Formation. From the headwaters of Otter Creek near the MEL occurrence, station 06LP008.

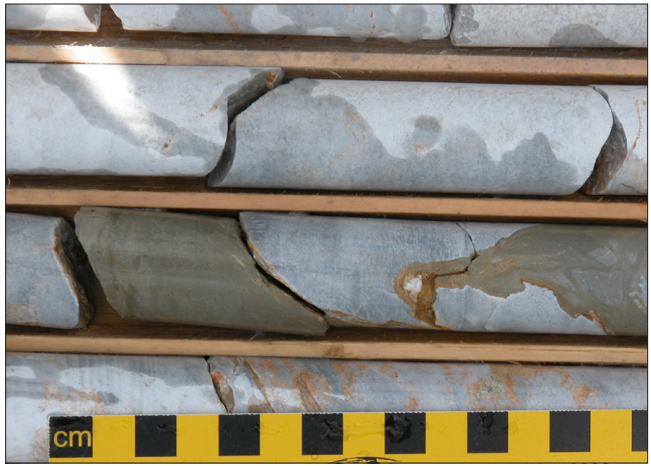


Figure 21. Olive-green mudstone with limestone (light grey), Otter Creek Formation. Drill core from 254 ft depth in Hole 74-6 (Bostock core collection) at the MEL mineral occurrence. Scale bar is in cm.

Age, Correlation and Depositional Setting

Identified brachiopods and trilobite fragments (Norford, 1984; Miller and Wright, 1986) from the limestone are late Cambrian to Early Ordovician; on this basis Pigage (2008) describes the limestone as a basal member of the Rabbitkettle Formation. Additional occurrences recognized during regional mapping in 2009 prompts its reinterpretation as a distinct carbonate unit underlying silty limestone of the Rabbitkettle Formation.

Gordey and Anderson (1993) describe a Cambrian-Ordovician to Silurian dolostone, the Haywire Formation, partially underlying Rabbitkettle Formation in the Little Nahanni River map area. Otter Creek Formation is considered correlative with the lowermost part of the Haywire Formation. It represents the western margin of the shallow carbonate platform during late Cambrian to Early Ordovician.

Rabbitkettle Formation (COR-n, COR-lp, COR-v)

Introduction

Rabbitkettle Formation, as defined by Gabrielse *et al.* (1973) in southwestern Mackenzie Mountains, is a silty limestone widely recognized in Selwyn basin. It occurs in north-trending belts in the western and central Coal River map area, in the core of the Caribou anticline, and in one exposure near the Gusty Lakes. Fissile carbonate outcrops in the northeast corner of the map area were visually identified from the helicopter as Rabbitkettle.

In the western part of the map area, the Rabbitkettle Formation unconformably overlies the undivided Vampire-Narchilla unit and is in turn unconformably overlain by carbonaceous strata of the Road River Group. In the central part of the map area the lower contact with the Otter Creek Formation and the upper contact with the Sunblood Formation are both conformable.

A well-exposed section of the Rabbitkettle Formation, between the Coal and Rock rivers in the north-central part of the map area, is estimated to be 1500 m thick. Its thickness in the Mel property area ranges from 300 to 1050 m.

Composition

The predominant unit of the eastern facies (**COR-n**) consists of a light grey to brownish grey-weathering, silty to argillaceous, nodular limestone (Fig. 22). Nodules are typically up to 10 cm long and 5 cm thick and consist of pale grey, recessive-weathering, fine-grained limestone which is locally parallel laminated. The limestone contains a well-developed, but discontinuous, slaty cleavage which anastomoses around the nodules; because of this texture the formation has previously been informally termed the 'wavy-banded limestone'. The nodular limestone commonly contains lesser interbeds of pale grey, fine-grained, massive limestone up to 2 m thick which constitute 50% or less of any outcrop (Fig. 23). Locally the nodular limestone contains intervals of grey-weathering, interbedded argillaceous limestone and laminated limestone up to tens of metres thick. Alternation of these two limestone types in an outcrop is on a scale of 5-30 cm.



Figure 22. A characteristic texture of Rabbitkettle Formation; eastern facies is nodular limestone with mud-silt interbeds up to 2 cm thick. Near the MEL occurrence at the headwaters of Otter Creek (station 06LP021).

West of the Coal River, the Rabbitkettle Formation has a distinctive shaly facies (**COR-lp**) which consists of a light to medium grey, silvery-weathering, thin-bedded, phyllitic limestone (Fig. 24). This western facies contains a well-developed, pervasive slaty cleavage; primary bedding is only commonly observed in small intervals within the slaty cleavage. Yellow-weathering, silty, laminated limestone exposed along the Coal River near the Sulpetro Road (NTS 95D/03) has been included within the Rabbitkettle Formation shaly facies. In the northwestern Coal River map area, outcrops of typical Rabbitkettle phyllitic limestone are overlain by a dark grey, orange-weathering, pin-striped, silty limestone (Fig. 25); this unit is also included within the western shaly facies of the Rabbitkettle Formation.

Siltstone and silty limestone near the top of the Crow Formation are more than 700 m thick in a stream flowing east to upper Toobally Lake. These strata are considered a tongue of Rabbitkettle Formation within pinkish sandstone of the upper Crow Formation near its western extent (Pigage, 2009). In the Caribou anticline a similar thickness of Rabbitkettle Formation overlies a thin sandstone unit reinterpreted as Crow Formation (see next section).

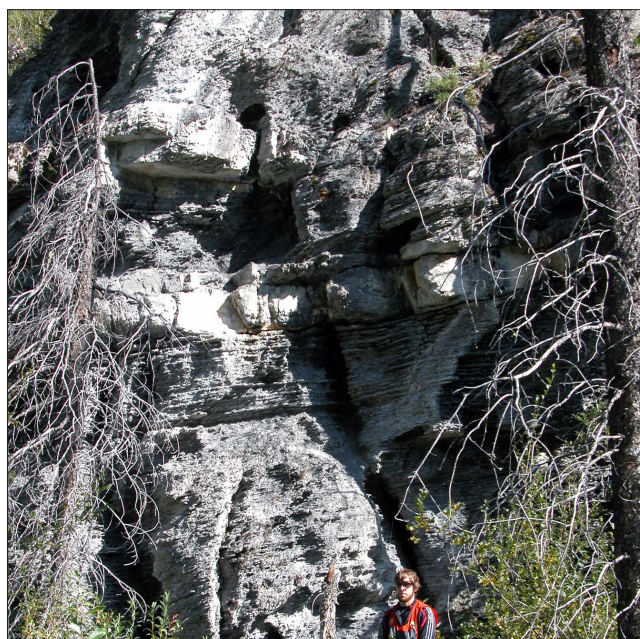


Figure 23. Two massive limestone interbeds within recessive weathering, nodular limestone of the Rabbitkettle Formation. Outcrop at headwaters of Otter Creek near the MEL occurrence (station 07LP010).

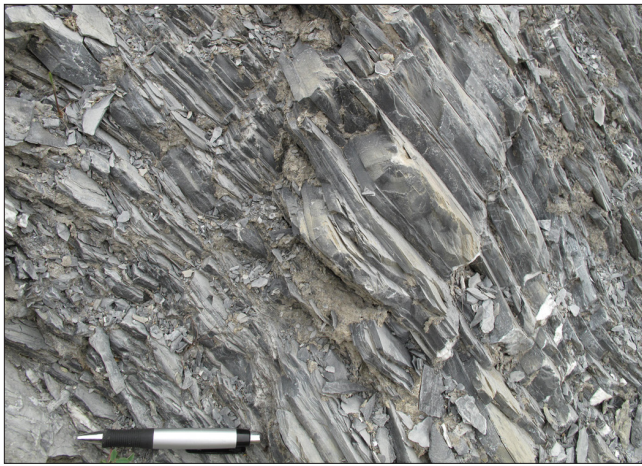


Figure 24. Grey, phyllitic limestone of the west facies of the Rabbitkettle Formation, showing slaty cleavage. View northward at roadcut on the Alaska Hwy at Contact Creek, south edge of the map area (station 09RAS150).

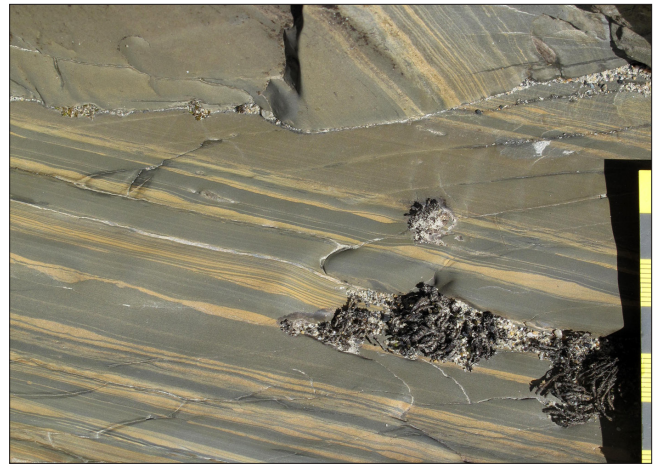


Figure 25. Calcareous, grey mudstone with yellow-weathering silt laminae, assigned to the Rabbitkettle Formation (west facies). Spaced slaty cleavage dips gently to the left in the photograph. Outcrop beside rapids on the Coal River, 15 km north of its confluence with the West Coal River (station 09RAS050). Scale bar (right side) in cm.

A horizon of medium green, silvery green-weathering, alkali basalt, breccia and lithic tuff (€OR-v) occurs near the base of the Rabbitkettle Formation on the Jeri North property (Pigage, 2007; this volcanic horizon is too small to show on the map at 1:250 000 scale). East of the Rock River in the northern Coal River map area, an extensive volcanic horizon is discontinuously exposed for 30 km near the upper contact of the Rabbitkettle Formation; this occurrence is the informal ‘Coal River volcanics’ of Goodfellow *et al.* (1995). It locally contains pillowed basalt flows. Breccia textures with angular basalt clasts in a chloritic fine-grained matrix are common (Fig. 26). Tuffs are interlayered with the flows and coarse breccias. The geochemistry of the basalt is discussed in the section on Cambro-Ordovician alkali basalt.

Figure 26 (right). Angular basalt blocks in a chloritic fine-grained matrix in the volcanic horizon at the top of Rabbitkettle Formation. View northward, on the Yukon-Northwest Territories border, east of the Rock River (station 09TOA164).



Age, Correlation and Depositional Setting

The Rabbitkettle Formation is sparsely fossiliferous. Regionally the brachiopod and conodont collections range from late Cambrian through late Middle Ordovician (Gabrielse *et al.*, 1973; Tipnis *et al.*, 1978; Cecile, 1982; Gordey and Anderson, 1993). Conodont collections in 2007 and 2009 from the Coal River map area are all Early Ordovician, ranging from early Tremadocian to late Floian (Plate 1; Appendix A in this report).

Regionally Rabbitkettle Formation extends across the Selwyn basin during late Cambrian-Early Ordovician time (see Fig. 12). South of the Nahanni River (150 km northwest of Coal River map area) nodular, silty limestone changes southwestward to evenly laminated, argillaceous limestone (Gordey and Anderson, 1993). Shallow shelf (Mackenzie platform) correlatives of Rabbitkettle Formation are

the Broken Skull and Franklin Mountain formations (Gabrielse *et al.*, 1973; Gordey and Anderson, 1993; Martel *et al.*, 2012). South of the Coal River map area and along structural grain, Rabbitkettle correlates with the early Ordovician Kechika Formation. This grey, phyllitic, calcareous shale and thin-bedded, argillaceous limestone and grainstone (Pyle and Barnes, 2000) thickens from 200 to 1400 m in a westerly direction.

Fossil collections (Appendix A in this report) indicate that Rabbitkettle Formation in the northern Coal River map area is laterally correlative with Sunblood Formation in the east-central Coal River map area.

Fine lamination and the dark colour of the carbonate indicate that Rabbitkettle deposition was in a quiet water, sub-wave base, off-shelf setting. Analogous to the Kechika trough located to the south, it accumulated on a broad, gentle ramp, transitioning from shallow to deeper water facies (Cecile and Norford, 1979). These upper Cambrian to Ordovician basinal strata reflect post-rift passive margin thermal subsidence following Neoproterozoic to middle Cambrian extension (Pyle and Barnes, 2000).

Crow Formation (€OC, €OC-v)

Introduction

The Crow Formation (Pigage, 2009) forms two large exposures flanking the Toobally Lakes in the eastern Coal River map area. There it consists of a thick sequence of bedded sandstone with interbeds of amygdaloidal alkali basalt, and maroon, silty argillite.

A third occurrence, in the core of the Caribou anticline, is a 30 m-thick interval of sandy dolostone beneath the Rabbitkettle Formation and above a volcanic and volcanoclastic unit. Gabrielse and Blusson (1969) assigned this latter exposure to the Sekwi Formation. The underlying volcanic rocks are chemically similar to the Rabbitkettle and Crow volcanic rocks, but distinct from the volcanic rocks within the Vampire-Narchilla unit (see section on Cambro-Ordovician alkali basalt). On the strength of general stratigraphic position and the correlation of the underlying volcanic strata, we here reassign the sandy dolostone and the volcanic strata to the upper Crow Formation.

In a limited area immediately west of the upper Toobally Lake, the Crow Formation unconformably overlies the Toobally Formation. Elsewhere in the map area the lower contact of the Crow Formation is not observed; it is truncated by the Toobally fault (western exposure) or a parallel reverse fault east of the Toobally fault (eastern exposure). To the east, the Crow Formation unconformably overlies Proterozoic strata and intrusive rocks (Pigage, 2009). It is conformably overlain by the Sunblood Formation. A minimum thickness of 5000 m is inferred from the extensive outcrops of Crow Formation on the west side of upper Toobally Lakes (Pigage 2009) if the outcrops are considered to be a monoclinical succession dipping westward at 45°; the succession may have been thickened by unmappped thrust fault repetition.

Composition

Pinkish, indistinctly bedded, quartzose to subarkosic sandstone is the predominant lithology (Fig. 27) with interbeds of maroon, noncalcareous, argillaceous siltstone (Fig. 28) up to several tens of metres thick occurring throughout. Bedding thickness of the sandstone typically ranges from 20 to 70 cm. Locally the sandstone contains scattered argillite and quartz pebble clasts (Fig. 29). In several locations the sandstone has well-developed crossbeds; other areas exhibit mudcracks.

West of the upper Toobally Lake, we have interpreted a thick limestone and dolostone interval as being within the upper part of the formation. Alternatively this carbonate horizon may be basal Sunblood Formation structurally overlain by Crow Formation (see Pigage *et al.*, 2012 for discussion). A tongue of

nodular limestone of the Rabbitkettle Formation, within the upper part of the Crow Formation, is also documented in the same general area (Pigage, 2009).



Figure 27. Pink, thick-bedded, quartzose to subarkosic sandstone of the Crow Formation. View looking west, 11 km west-northwest of upper Toobally Lake (station 05LP075).

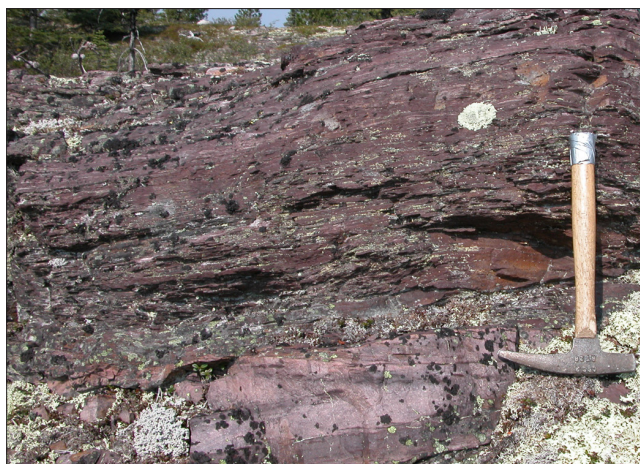
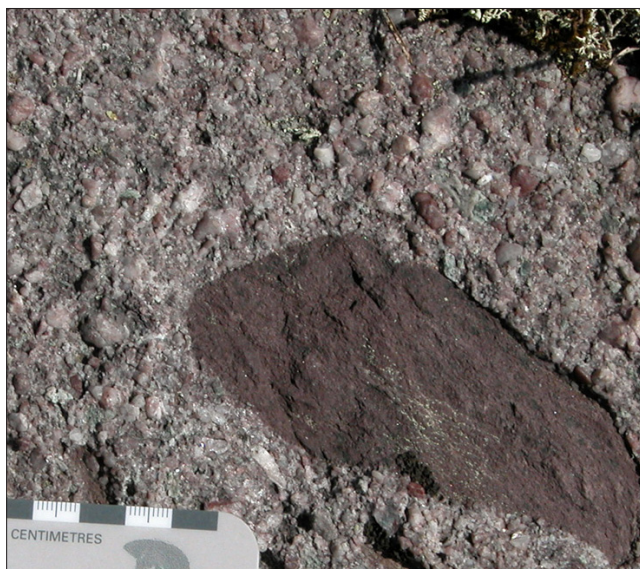


Figure 28. Maroon, non-calcareous, argillaceous siltstone constitutes up to several metre-thick interbeds within Crow Formation sandstone. From ridge approximately 8 km west of north end of upper Toobally Lake (station 04LP053).

Figure 29 (right). Argillite and quartz pebble clasts within sandstone of the Crow Formation. From ridge approximately 8 km west of north end of upper Toobally Lake (station 05LP057).

Pigage (2009) mapped four alkali basalt horizons (COC-v) within the Crow Formation. Massive to pillowed, amygdaloidal flows and lapilli tuffs are the predominant lithologies. These horizons have previously been informally termed the Gusty Lakes and Toobally volcanics (Gabrielse and Blusson, 1969; Goodfellow *et al.*, 1995). The geochemistry of the basalt was presented in Pigage (2009) and is further described in the subsequent section on Cambro-Ordovician alkali basalt.



A 2 m-thick interval of medium green, fine-grained, porphyritic, rhyolitic tuff occurs along the Beaver River within sandstone of the Crow Formation (see Appendix C, Table C2c, sample 10TOA024), slightly below the uppermost alkali basalt horizon. It contains approximately 15% K-feldspar phenocrysts and 15% subhedral quartz phenocrysts, both 1-3 mm in diameter. About 25% of the tuff consists of brown, fine-grained volcanic lithic fragments containing feldspar microlites and small broken quartz microphenocrysts. The matrix consists of a fine-grained mixture of chlorite and sericite with small broken phenocrysts of K-feldspar and quartz. Flow banding and spheroidal textures are apparent in hand sample and thin section.

A basalt occurrence at this stratigraphic level in the core of the Caribou anticline in the northeast corner of the Coal River map area (McDougall, 1976; Stammers, 1983) is included in unit COC-v. Both amygdaloidal flows and several lithic tuff horizons (Fig. 30) are present. The lower contact of the basalt is not exposed, and its thickness is undetermined.



Figure 30. Planar cross-bedded tuff in the core of Caribou anticline, assigned to Crow Formation because it underlies a thin sandstone unit. The subangular to subrounded basalt clasts are enclosed in a fine-grained, chlorite-rich matrix. Outcrop is 2 km northwest of the main fork in the upper Caribou River (station 09LP083). Scale card is 9 cm wide.

Age, Correlation and Depositional Setting

Conodont collections from the Crow Formation in the Coal River area are Early to Middle Ordovician (Pigage, 2009; Plate 1; Appendix A). Zircon grains from the rhyolite tuff (sample 10TOA024), interpreted as primary volcanic crystals, give a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 491.04 ± 0.13 Ma (Early Ordovician or late Cambrian; Pigage *et al.*, 2012). The Crow Formation is time correlative with the Rabbitkettle Formation (see Fig. 12) and the two are interpreted to be interdigitated in the subsurface of the eastern Coal River map area.

Mud cracks and ripple marks in the Crow Formation indicate deposition in a shallow water to subaerial environment (Pigage, 2009). The limited lateral extent and unusual thickness of the Crow Formation suggest deposition in a river delta complex with sediments derived from a granitic and quartz-rich source. Detrital zircon studies from the Crow Formation (Pigage, 2009) indicate that the zircon provenance could be the Archean Slave province and the adjacent Wopmay orogen. A small number of zircon grains from one Crow Formation sample (05LP034) are ~1000-1350 Ma, similar in age to those found in the Mackenzie Mountains Supergroup, possibly representing erosion of these strata (Hadlari *et al.*, 2012; Rainbird *et al.*, 1992, 1997).

SUCCESSION 3 – LOWER TO MIDDLE ORDOVICIAN

Succession 3 consists solely of the Sunblood Formation which records shallow water carbonate deposition in a shelf environment. The carbonate unit is exposed in the central and eastern part of the Coal River map area; in the western third it is not present, and carbonaceous shale of the Road River Group occurs in the same stratigraphic position.

Sunblood Formation (OSu, OSu-v)

Introduction

The Sunblood Formation (Kingston, 1951; the updated reference section by Gabrielse *et al.*, 1973 is 110 km north of the Coal River map area) outcrops extensively along the Rock River and several smaller streams and meltwater channels in the central and eastern parts of the map area. In the west-central part of the map area it is preserved in north-trending synclinal fold keels. Gabrielse and Blusson (1969) concluded that the Sunblood Formation was presumably removed by erosion beneath unit SDC in the southern quarter of the Coal River map area. Mapping in 2009, however, confirmed that the unit is thin but present beneath unit SDC, and probably extends farther south into British Columbia. Sunblood Formation is not present in the southwestern corner of the map area (Irons Creek drainage) and the northwest corner of the map area (Coal River and West Coal River drainage). In both areas black shale

of the Road River Group overlies the Rabbitkettle Formation and is likely a facies equivalent of the Sunblood Formation.

The Sunblood Formation conformably overlies the Rabbitkettle Formation in the west and the Crow Formation in the east within the map area. It is unconformably overlain by a dolomitic sandstone unit (OSS) in the east, while in the southern part of the area it is unconformably overlain by massive carbonate (SDc). Elsewhere it is unconformably overlain by shales of the Road River Group. The Sunblood Formation ranges from 2700 m thick in the Caribou anticline northeast part of map area to 320 m thick near Mount Gilliland in the southwest part of the map area. It attains its greatest thickness in the central part of the map area. Immediately to the east in NTS 95C/5 it has a minimum thickness of 150 m (Pigage, 2006).

Composition

In the northern part of the Coal River map area, the Sunblood Formation consists of medium grey, thick-bedded, finely crystalline limestone (Fig. 31). The limestone is typically tan to pink, flaggy or platy, with silty intervals and chert nodules locally. Bedding ranges from 2 to 60 cm in thickness. Bedding planes have a mottled appearance indicating extensive bioturbation (Fig. 32a,b). Macrofossils, including brachiopods, bryozoans, trilobites, ostracods, cephalopods, and gastropods (especially *Maclurites* sp.) are common (Gabrielse and Blusson, 1969). Recent karst solution cavities are conspicuous on limestone-topped ridges north of the Beaver River.



Figure 31. Well-bedded limestone of the Sunblood Formation. Bedding planes are mottled grey and tan from bioturbation. This unit locally develops modern, karst sinkholes. From ridge 5 km north of upper Beaver River (station 09LP075). Hammer for scale.

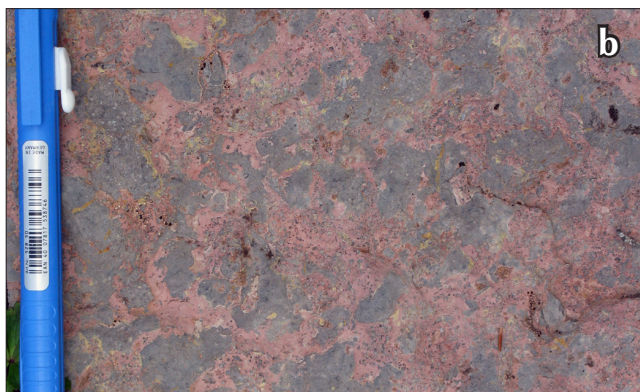
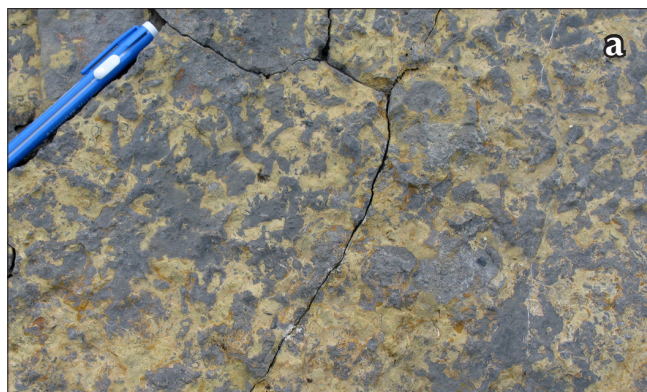


Figure 32. Bioturbation on bedding plane of Sunblood Formation limestone; (a) tan-weathering; (b) pink weathering; a defining characteristic of this formation farther north (Gabrielse et al., 1973). From ridge 5 km north of upper Beaver River (station 09LP075). Eraser for scale is 1 cm wide.

In the southern part of the Coal River map area, the Sunblood Formation consists largely of thick-bedded, pale grey, laminated to bioturbated dolostone interbedded with thick-bedded, dark grey, bioturbated dolostone (Fig. 33). Bedding ranges from 10 cm to 2 m in thickness. These rocks are

typically tan to buff-weathering, although locally they weather to a brownish-orange (the distinctive colour of the Sunblood Formation where it was named in the Nahanni River region). Bedding planes have a mottled appearance due to bioturbation (similar to the limestone). This southward transition from limestone to dolostone is attributed to secondary dolomitization of the primary limestone.

The Sunblood Formation contains green, brown-weathering, alkali basalt breccia and flows (OSu-v) in two localities, one near the headwaters of Spruce Creek and the other northeast of Lootz Lake. Flows are commonly pillowed. Breccia consists of angular clasts in a dark green, fine-grained, chloritic matrix (Fig. 34). The volcanic rocks in the headwaters of Spruce Creek occur at the top of the unit. North of Lootz Lake the volcanic rocks occur at a lower stratigraphic level within the Sunblood Formation. The chemistry of the basalt occurrences is described further in the Cambro-Ordovician alkali basalt section.



Figure 33. Pale grey, tan-weathering, laminated dolostone interbedded with dark grey, orange-grey-weathering, bioturbated dolostone, Sunblood Formation. Cliff is approximately 70 m high. From Rock River 3 km north of the mouth of Otter Creek (station 06LP043).



Figure 34. Altered basalt breccia within the Sunblood Formation. Looking north at outcrop (2 m high), 12 km northeast of Lootz Lake (station 08RAS304).

Age, Correlation and Depositional Setting

In the type area the Sunblood Formation is of Middle Ordovician age (Gabrielse *et al.*, 1973; Ludvigsen, 1975). Age dating of conodonts collected more recently from the Coal River (NTS 95D) and LaBiche River (NTS 95C) map areas document an age range from Early Ordovician (Tremadocian) to Late Ordovician (Sandbian) (Pigage, 2009; Plate 1; Appendix A). The range in fossil ages for the Sunblood and Rabbitkettle formations indicates that the basal Sunblood contact is diachronous, varying in age from Tremadocian to Floian. The older Tremadocian ages occur in the east-central part of the area (NTS 95D/8 and 10); the younger Floian ages are represented farther north (NTS 95D/10 and 15) and south (NTS 95D/02 and 03). The diachroneity means that lower Sunblood Formation overlying the Crow Formation in the east-central part of the map area undergoes a lateral facies transition to Rabbitkettle Formation in the northeast part of the map area. Pohler and Orchard (1990) described a similar lateral transition between Haywire Formation and Rabbitkettle Formation north of Coal River map area. An analogous diachronous age variation of the lower contact of the Sunblood Formation was noted in Pigage (2009), varying easterly from Tremadocian to Floian.

Conodont collections from near the top of the formation suggest an Upper Ordovician (Sandbian to Katian) age for the upper contact in the eastern part of the map area. This younger age is also recorded in some of the fossil samples in the Pool Creek map area immediately to the east (Pigage, 2009). The

youngest ages for the upper contact appear to be restricted to the same general area as the older ages for the lower contact. The variation in age range for the upper contact can be interpreted to indicate that the Sunblood carbonate platform was restricted to a small geographic area in Upper Ordovician time, or that subsequent erosion has removed younger Sunblood strata in most areas except for the eastern Coal River and western LaBiche River map areas.

The Sunblood Formation is absent in the southwestern and northwestern parts of the map area. Although the contact is not exposed, carbonaceous, siliciclastic sediments of the Road River Group appear to directly overlie Rabbitkettle calcareous phyllite in these areas. An early Ordovician age for Road River Group strata north of Coal River (Abbott, 1981) indicates that the absence of Sunblood Formation in northwest Coal River results from a lateral facies change from Sunblood carbonate rocks to Road River Group clastic strata on the western margin of the Ordovician Sunblood carbonate platform.

The Sunblood Formation was deposited in a widespread sub-tidal, carbonate platform environment up to 100 km wide (Ludvigsen, 1975). It records a transgressive high-stand tract which terminated with a period of erosion in latest Ordovician-Early Silurian time.

It is widely distributed in the southeast Yukon and southwest Northwest Territories. Its western limit lies in the Coal River map area where Road River Group shale occurs in the same stratigraphic position (overlying Rabbitkettle Formation). In the Little Nahanni River map area (150 km northwest) it is in part correlative with the Cambro-Ordovician to Silurian Haywire Formation (Gordey and Anderson, 1993) that is an outer-shelf equivalent of the Rabbitkettle, Broken Skull, Sunblood, and possibly Whittaker formations (Gabrielse *et al.*, 1973). The schematic relations of these units are shown in Figure 17 of Gordey and Anderson (1993) where the Sunblood conformably overlies Broken Skull Formation and is unconformably overlain by Whittaker Formation. All three are relatively thick shelf carbonate units.

On the Macdonald platform in northeastern British Columbia, thick-bedded dolostone of the Middle Ordovician Skoki Formation is equivalent to the Sunblood Formation (Cecile and Norford, 1979; Pyle and Barnes, 2000).

The Sunblood Formation, in the Coal River map area, represents a westward extension of the Mackenzie platform during early and middle Ordovician, including overlap of the Crow Formation. It may also represent a northward extension of the Macdonald platform during the same time interval. Conodont fauna from near its base document its local transgression (expansion) away from the east-central part of the Coal River map area during the early Ordovician to middle Ordovician.

SUCCESSION 4 – ORDOVICIAN(?) TO MIDDLE DEVONIAN

Succession 4 indicates a south to north facies transition, from thick-bedded carbonate of the Macdonald platform in the south to siliciclastic, marine shale, laminated to thin-bedded limestone, and sandstone of Selwyn basin in the north. In the Coal River map area, carbonate rocks are represented by the undivided Nonda, Muncho-McConnell, Stone and Dunedin formations (collectively map unit **SDc**) which comprise Macdonald platform. The carbonaceous shale and limestone belong to the Road River Group (map units **SDRR** and part of **SMRB**) which represent the southeastern extent of the classic Selwyn basin (see below). In the east-central part of the map area, the Road River Group is underlain by a thin succession of quartzose sandstone to pebbly sandstone (unit **OSS**) of uncertain age.

Sandstone of Ordovician and/or Silurian age (OSs)

Introduction

Creamy white, tan to pale grey-weathering, fine-grained, dolomitic sandstone (Unit OSs; Fig. 35) is discontinuously exposed near the eastern edge of the Coal River map area and extends farther east into the adjacent map area. In contrast to Pigage (2009), this unit is assigned to Succession 4 because it is interpreted to represent easterly derived clastic sedimentation in concert with the eastward transgressive extension of Selwyn basin. Known as Meilleur River embayment (Basset and Stout, 1966), this eastward expansion began north of the Coal River map area in the Middle Ordovician and extended more than 200 km into the southwestern Northwest Territories during the Silurian (Cecile and Norford, 1993).

Figure 35 (right). Pale grey and light brown-weathering, dolomitic sandstone of Ordovician and/or Silurian age (map unit OSs). From the north bank of a west-flowing stream, 30 km east of Last Mountain and 5 km west of east edge of map area (station 09LP096).

The base of unit OSs is an abrupt change from thick-bedded dolostone of the Sunblood Formation to sandstone, and is probably unconformable (see Fig. 12). At the top, the unit is overlain by the Road River Group. A maximum thickness of 220 m has been estimated from mapping along the Beaver River (Fig. 36, below; NTS 95D/09).



Figure 36 (left). Dark-weathering sandstone of unit OSs is estimated to be 220 m thick in this exposure just north of the Beaver River, 1 km northeast of upper Toobally Lake.

Composition

Quartz-rich, non-calcareous to slightly calcareous, quartzose to arkosic sandstone forms beds from 10 cm to 2 m thick. The sandstone weathers with a tan to orange-brown surface coating. Fine to medium, subround to round, sand clasts are predominantly monocrystalline quartz. Other clasts, in minor amounts, include black shale, quartz sandstone, K-feldspar, plagioclase, volcanic rock and chert.

Interbedded with the sandstone are lesser amounts of recessive-weathering, bioturbated, dolomitic siltstone and minor pebbly sandstone to conglomerate. The dolomitic siltstone is light grey and weathers tan. It contains minor, discontinuous, dark grey, shaly partings. Pebbles in the pebbly sandstone to conglomerate consist predominantly of white, blue and lesser pale green quartz pebbles in a quartz sand matrix. Typically they are matrix-supported, although locally they are extensive enough to be clast-supported.

Age, Correlation and Depositional Setting

Diagnostic fossils constraining the depositional age have not been found. The unit is broadly constrained by the known ages of the underlying Sunblood Formation (Middle Ordovician) and overlying Road River Group (early Silurian). Its age range is probably much less as the lower contact is an unconformity.

In northeastern British Columbia, a 180 m-thick interval of interbedded shale and quartzite with minor dolostone occurs in the Road River Group (unit **ORD** of Cecile and Norford, 1979; Ware member of the Ospika Formation of Pyle and Barnes, 2000); it is of upper Middle Ordovician to Upper Ordovician age and may be a correlative unit. Sandstone is also present on the Macdonald platform within lower Silurian strata in places where the Nonda Formation rests directly on Precambrian basement rocks (Cecile and Norford, 1993).

Unit **OSs** coarse sandstone and conglomerate are proximal clastic facies, representing a transitional depositional environment from platform carbonate sedimentation to euxinic, basinal siliciclastic sedimentation. Abundant bioturbation in shaly intervals (Pigage, 2009) indicate a below-wave base environment. The unit is missing to the west in the central Coal River map area, and the source provenance is considered to be to the north or east. Primary sedimentary features indicating source direction were not observed.

Detrital zircon geochronology on one sample from unit **OSs** (09LP093) is shown on a probability density plot and concordia diagram (Fig. 37; analyses in Appendix B). This age distribution corresponds to the Laurentia type I signature of Hadlari *et al.* (2012), consistent with a Canadian Shield provenance.

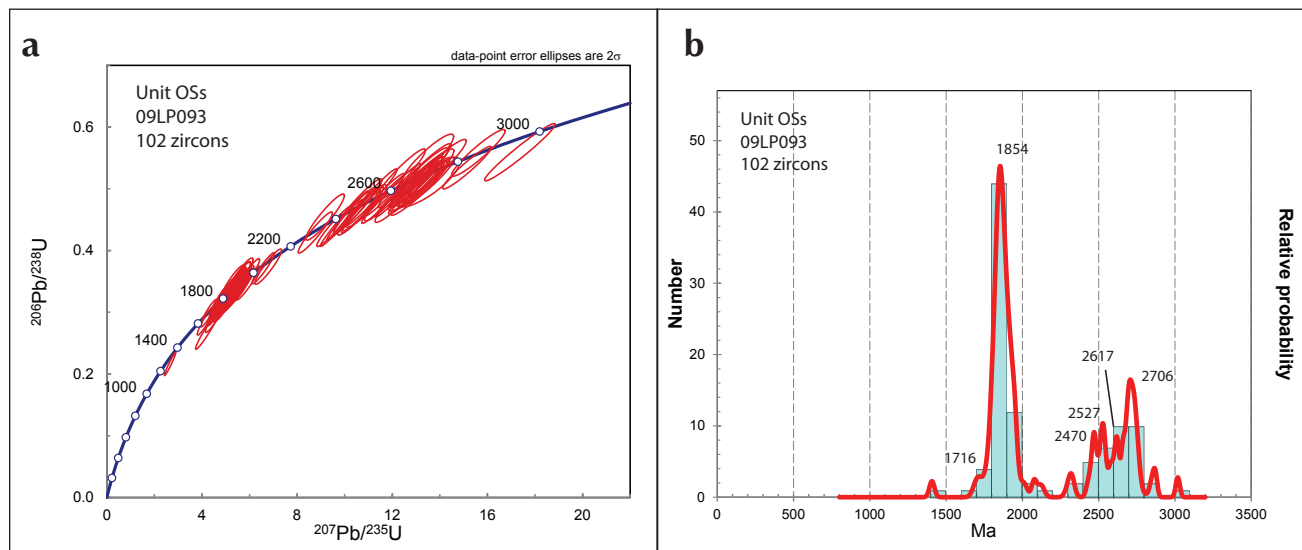


Figure 37. Results of geochronological analysis of 102 detrital zircon grains from OSs unit sandstone (sample 09LP093): **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B7).

Silurian-Devonian massive carbonate (SDc)

Introduction

The southern part of the Coal River area contains cliff-forming exposures of thick-bedded, pale grey to cream-weathering dolostone and limestone (Fig. 38), representing the northern extent of the Macdonald platform. They form resistant ridges which exhibit modern karst features. The medium to coarsely crystalline secondary dolostone alteration obliterates distinction of the Nonda, Muncho-McConnell, Stone and Dunedin formations described for the Macdonald platform to the south (Thompson, 1989; Cecile and Norford, 1991, 1993; Taylor and MacKenzie, 1970).

Figure 38 (right). *Thick-bedded, pale grey to cream-weathering limestone of unit SDc forms the high-standing hills that constitute the northern extent of the Macdonald platform along the south edge of the map area. Looking northeast near Barney Lake (station 09TOA120).*

The lower contact with the underlying Sunblood Formation is sharp. The upper contact is eroded from much of the southern half of the Coal River map area. The thickness of the remaining strata is approximately 1000 m near Mount Gilliland, immediately east of the Coal River fault. In the southeast, near Smith River, the carbonate succession is many tens to hundreds of metres thick; the upper contact with the overlying Besa River Formation is abrupt.

Composition

Bedding in the carbonate rocks is locally visible and generally ranges from 1-10 m in thickness. Metre-scale, convex-upward domes in the beds likely represent algal mounds, while darker bands commonly contain lighter-coloured macrofossils, including pelecypods, brachiopods, corals and crinoid hash. Areas of white to grey dolostone are totally recrystallized and sucrosic in places, reflecting diagenetic alteration. Post-depositional brecciation (Fig. 39) is extensive, with development of vugs up to 2 cm across. Vugs and clasts commonly are enclosed by cream hydrothermal dolomite.

Internal stratigraphic divisions within the carbonate could not be readily distinguished in the Coal River area. Strata comprising this unit can be separated into multiple formations to the east (e.g., Pigage, 2009) and to the south on the Macdonald platform (e.g., Taylor and MacKenzie, 1970; Morrow, 1978; Ferri *et al.*, 1999).



Figure 39. *Limestone of the undifferentiated SDc unit that has been brecciated with abundant secondary calcite (white). Hilltop 1 km northwest of Mount Gilliland (station 09TOA178). Hammer handle is 45 cm long.*

Age, Correlation and Depositional Setting

Two fossil collections in the lower part of the unit northwest of Mount Gilliland are of Silurian age (Appendix A); Road River shale and limestone in the same stratigraphic position contain Silurian graptolites. A collection near the top of Mount Gilliland is Early Devonian. Near Tropical Creek, in the southeast, the carbonate locally contains recognizable crinoid columns with twin axial canals (2-hole crinoids), indicating their Early to Middle Devonian age. Contiguous carbonate in the Rabbit River map area to the south are of Early and Middle Devonian age (Gabrielse, 1963).

Unit **SDC** constitutes the northern edge of the Macdonald platform, which in British Columbia ranges in age from Ordovician through Middle Devonian. It includes the Nonda, Muncho-McConnell, Stone and Dunedin formations as a dominantly carbonate tract extending 500 km south-southeast from the Coal River map area. Regionally the Macdonald platform strata unconformably overlie Cambrian and older units (e.g., McMechan *et al.*, 2012), implying preceding uplift and erosion. The northward transition to Road River Group shale appears to be abrupt with the shale facies being present near Lootz Lake. Time-equivalent rocks of the Mackenzie platform (nearest point is 260 km north of unit **SDC**) include the Camsell, Sombre, Arnica, Grizzly Bear, Funeral, Delorme, Whittaker, Tsetso, Mount Kindle, Franklin Mountain, Nahanni, Headless, Bear Rock, Hume and Natla formations (Gabrielse *et al.*, 1973; Gordey and Anderson, 1993; Cecile and Norford, 1993; Morrow and Geldsetzer, 1991).

Road River Group (SDRR, SMRB)

Introduction

Jackson and Lenz (1962) defined the Road River Formation as Lower Cambrian to Lower Devonian strata in northern Yukon (Richardson trough) with a type section where the base was faulted. Gabrielse *et al.* (1973) extended the unit into the Selwyn basin and later into the Northern Rocky Mountains. Fritz (1985) and Gordey and Anderson (1993) elevated the Road River Formation to formal group status, although some regional publications (e.g., Cecile, 2000) avoid the term in favour of more precise formation nomenclature. In this report the breadth of Road River Group is appropriate because internal stratigraphic boundaries and defining paleontologic control are lacking.

Recessive weathering, carbonaceous, silty shale, limestone, dolostone, siltstone, and chert of the Road River Group are exposed along rivers, streams and glacial meltwater channels in the Coal River map area. The base is abrupt and marked by the first appearance of a carbonaceous, locally graptolitic unit. In most areas it unconformably overlies the Sunblood Formation. In areas where Unit **OSs** is present, carbonaceous strata abruptly overlie this sandstone unit. In the westernmost part of the map area it abruptly overlies the Rabbitkettle Formation. In much of the northern Coal River area carbonaceous shale of the Road River Group is conformably overlain by carbonaceous shale of the Besa River Formation.

In northern British Columbia the Kwadacha Formation (Pyle and Barnes, 2000) consists of tan-weathering, dolomitic, bioturbated siltstone forming the uppermost unit in the Road River Group. The Steel Formation (Gordey and Anderson, 1993) in the Little Nahanni map area (NTS 1051) is a similar unit that occurs in the same stratigraphic position. This distinctive lithology is a useful marker horizon for delineating the top of the Road River Group and the base of the overlying shale (like the Besa River Formation). Tan-weathering siltstone outcrops that resemble the Steel Formation were observed along the Coal River in the northwest corner of the map area. We were not able to identify this siltstone unit along Spruce Creek and in the northern part of the map area, resulting in the use of a combined map unit (**SMRB**) encompassing Road River and Besa River strata.

Near Spruce Creek the estimated thickness of the Road River Group is approximately 200 m and the estimated thickness of the Besa River Formation in the same general area is approximately 300 m. The combined unit has a similar thickness in the Last Mountain area. In the northeastern quadrant of the map area its broad extent and deep exposure in the Caribou River canyon suggests structural thickening by internal reverse faults and folds.

Composition

The dominant lithology of the Road River Group in Coal River map area is a dark grey to black, noncalcareous to calcareous, locally graptolitic, silty shale (Fig. 40). Another major lithology is a dark grey, thin-bedded, silty limestone or dolostone (Fig. 41), locally containing thin black, discontinuous chert lenses or beds (Fig. 42). Intervals of dark grey to black, bedded chert also occur locally. The common distinctive characteristics of the Road River Group are the dark grey to black colour related to high organic material and the local occurrence of graptolites, especially near the base of the unit.



Figure 40. Dark grey, locally graptolitic, silty shale of the Road River Group. From glacial meltwater channel about 9 km north of Lootz Lake (station 09LP074).



Figure 41. Dark grey, silty, parallel-laminated limestone of Road River Formation. From 7.5 km north of Lootz Lake (station 09LP062).

Age, Correlation and Depositional Setting

Fossil collections from previous work in the Coal River and LaBiche River map areas indicate an age range of lower Silurian to Lower Devonian for the Road River Group (Gabrielse and Blusson, 1969; Pigage, 2009). Fossil collections from the 2009 fieldwork are consistent with that age assignment (Appendix A). Lenses of limestone containing two-hole crinoids (Fig. 43) were observed in outcrops on the Coal River in the northwest part of the Coal River map area, indicating an Early to early Middle Devonian (Emsian to Eifelian) age. Abbott (1981) reported a Lower Ordovician conodont sample collected from the Road River Group from NTS 95E (north of the Coal River area), indicating that in the northwestern part of the Coal River map area



Figure 42. Grey dolostone with discontinuous black chert layers, Road River Group. On Spruce Creek (station 09LP091). Scale divisions are in cm.

the lower Road River Group probably includes Ordovician carbonaceous strata. Northwestward across Selwyn basin Road River Group is widespread, in some areas divided into Duo Lake or Elmer Creek formations, overlain by Steel Formation (see Fig. 12).



Figure 43. Limestone containing two hole crinoids indicative of Early to Middle Devonian age, undivided Road River-Besa River map unit. Outcrop on the Coal River 4 km west of Mt. Skonseng (station 10TOA005). Canadian coin is 2.5 cm in diameter.

The Macdonald platform units – Skoki, Nonda, Muncho-McConnell, Wokkash, Stone and Dunedin formations (Morrow and Geldsetzer, 1991) are time-correlative with Road River Group. On the Mackenzie platform, Camsell, Sombre, Arnica, Grizzly Bear, Bear Rock, Funeral and Natla formations (Morrow and Geldsetzer, 1991) are time-correlative with Road River Group.

Road River Group abruptly overlies sandstone and carbonate, attesting to a rapid change to a deeper water depositional environment. The dark, thin-bedded shale reflects reduced conditions, although the presence of deep-water limestone indicates deposition above the carbonate compensation depth. Chert deposition suggests that the basin was relatively starved of clastic input.

SUCCESSION 5 – MIDDLE DEVONIAN TO TRIASSIC

The single depositional entity Selwyn basin was destroyed by uplift (locally block faulting) in Middle Devonian time (Gordey and Anderson, 1993). Subsequent Middle Devonian through Triassic strata are preserved in the eastern half of the Coal River map area as three sequences separated by regional unconformities. They record alternating regional transgressions and regressions in a broad, shallow marine depositional environment. Map units are the Middle Devonian to Lower Mississippian Besa River Formation (DMBR, SMRB), the Mississippian Mattson Formation (MM), the Permian Fantasque Formation (PF) and the Triassic undivided Grayling and Toad formations (TGT).

Besa River Formation (DMBR, SMRB)

Introduction

Recessive, dark grey to black, pale grey-weathering, noncalcareous, silty shale with lesser interbeds of tan-weathering sandstone and limestone (Fig. 44) outcrop extensively along streams and rivers in the southeast part of the map area, constituting the Besa River Formation (Kidd, 1963). In the southeast Coal River map area, the lower contact with the underlying SDC unit of the Macdonald carbonate platform is sharp. In the northern Coal River map area, the similar units of the Besa River Formation and the underlying Road River Group mean that the lower contact of the Besa River Formation is not accurately located, and the nature of the contact is unknown. Exposures of dark silty shale lacking stratigraphic context could not be attributed with certainty to either Road River Group or Besa River Formation and thus were mapped as a combined unit (SMRB). The upper contact with the overlying

Mattson Formation is gradational over tens of metres; the contact is placed at the first major bed of indurated, grey, quartzose sandstone.

The type section, about 200 km southeast of Coal River map area, is 672 m thick (Kidd, 1963). Besa River Formation thins northwestward (Bamber *et al.*, 1968) and a thickness of greater than 300 m is estimated from exposures in the Spruce Creek area. Greater thicknesses in the northern part of the map area most likely result from structural thickening.

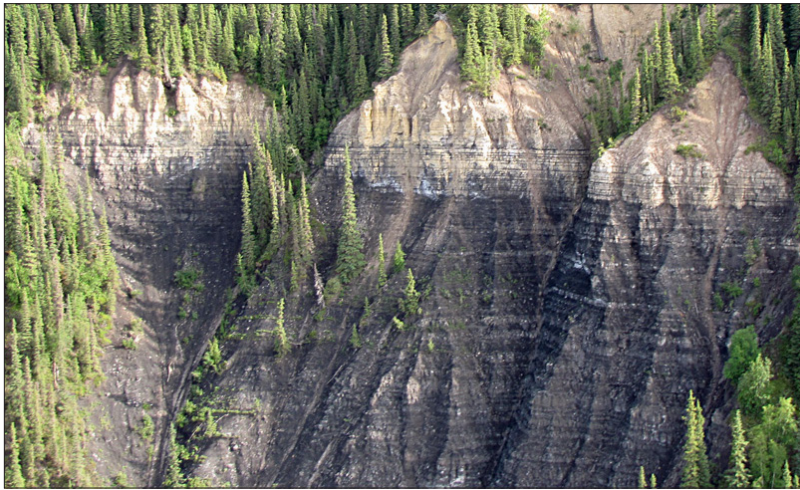


Figure 44. Outcrop exposure of the Besa River Formation, consisting of brown and grey-weathering, noncalcareous, silty shale with interbeds of tan-weathering sandstone and limestone. Looking northward at cliffs above Spruce Creek, 14 km west of Toobally Lakes (station 09TOA131).

Composition

The predominant lithology consists of dark grey to black, thin-bedded, noncalcareous, silty shale that locally is pale grey or rusty brown-weathering (Fig. 45). Bedding is typically on a scale of 1-5 cm. Some intervals are siliceous enough to be considered porcellanites. The silty shale commonly contains limestone nodules up to 2 m in diameter (Fig. 46). Interbeds of dark grey limestone up to 10 m thick occur locally.



Figure 45. Rusty brown to dark grey-weathering exposure of black, silty shale of the undivided Road River-Besa River map unit. Outcrop is 3 m high. Exposure on the Beaver River 2 km north of upper Toobally Lake (station 09LP077).



Figure 46. Limestone nodules or concretions in silty shale of the undivided Road River-Besa River map unit in the headwaters of the Coal River (southern Flat River map area; station 10TOA006). Hammer handle is 45 cm long.

Age, Correlation and Depositional Setting

Two conodont samples collected immediately east of Coal River map area are Devonian to Mississippian (Table IV-10 in Pigage, 2009). Both upper and lower contacts are diachronous with the age range decreasing in an eastward direction (Bamber and Mamet, 1978; Richards, 1989); the maximum age range is from Middle Devonian (Giventian) to Middle Mississippian (Viséan). Bamber and Mamet (1978) described the westward shaleout of Dunedin Formation carbonate rocks to Besa River Formation in northeastern British Columbia.

In southeast Yukon and southwest Northwest Territories Besa River Formation is laterally equivalent to the carbonate rocks of the Pekisko, Prophet and Flett formations and the clastic sediments of the Yohin, Clausen and Golata formations (Richards, 1989). In northeastern British Columbia, Besa River Formation is correlative with carbonate rocks of the Upper Keg River, Slave Point, Kakiska, Trout River, Tetcho, Kotcho, Banff, Pekisko, Shunda and Debolt formations and with shales of the Horn River, Muskwa, Fort Simpson, Exshaw and Golata formations (Ferri *et al.*, 2011). In Selwyn basin and Kechika trough, Besa River Formation is laterally equivalent to the Earn Group (Gordey, 1991; Ferri *et al.*, 2011).

The western margin of Laurentia was inundated by dark clastic sediments between Middle Devonian and Middle Mississippian time; this diachronous transgression eastward extended well into the North American interior. The dark clastic sediments overlie early Paleozoic platform and basin depositional elements.

Three Devonian-Mississippian clastic assemblages were deposited in Yukon: the Earn assemblage, the Imperial assemblage and the Besa River assemblage (Gordey, 1991). In northern Yukon the Imperial assemblage shale, siltstone and sandstone delineate the westward and southwestward influx of coarse foreland clastic sediments from the Ellesmerian orogeny (Pugh, 1983; Norris, 1985). Northwest and southwest of the Coal River map area the Earn assemblage consists of black shale and siltstone interbedded with sandstone and chert pebble conglomerate; the clasts were derived from eroded Selwyn basin units and deposited in submarine channels and fans (Gordey *et al.*, 1982; Gordey and Anderson, 1993; Gordey, 2013). Extension and local contraction in the outer parts of Selwyn basin and Kechika trough (Abbott *et al.*, 1986; Gordey *et al.*, 1982) during rifting or transtensional extension can account for the northwest to west provenance of Earn Group sediments. In contrast the Besa River Formation occurs immediately northwest (outboard) of barrier reefs (Ferri *et al.*, 2011) with extensive back-reef evaporates and sediments to the southeast. Richards (1989) considered the fine-grained, clastic sediments of the Besa River Formation to be derived from a north to northeast source.

Mattson Formation (MM)

Introduction

Pale grey and rusty-brown-weathering sandstone interbedded with shale is exposed in the Caribou syncline and comprises a strip trending north from Toobally Lakes. These are the westernmost outliers of the Mattson Formation (Patton, 1958) that is widely exposed in southeast Yukon and eastward to the Liard River in the Franklin Mountains. Reddish orange transported gossans are common where streams incise this unit.

The lower contact is conformable, placed at the base of the first major sandstone bed (Fig. 47) above Besa River shale. Shale-rich strata of the middle Permian Fantasque Formation unconformably overlie the Mattson Formation. Near Last Mountain the Mattson Formation is estimated to be 500 m thick. At the type locality, 31 km west of Nahanni Butte, it is 1138 m thick (Patton, 1958), and the greatest known thickness, 1410 m (Richards, 1989), is 60 km east of the Coal River map area near the Yukon-NWT border.

Composition

Grey, thick-bedded, fine-grained, quartz sandstone (Fig. 48) is the predominant lithology. Bedding is rarely observed and few other primary sedimentary features are visible in the sandstone. The sandstone contains minor interbeds of dark grey to black, noncalcareous shale. In the northeastern part of the map area, the middle of the formation consists of thick, noncalcareous, black shale with quartzose sandstone above and below it. The Last Mountain barite occurrence is at, or near, the base of the Mattson Formation.



Figure 47. Grey and brown-weathering sandstone interbedded with recessive shale of the Mattson Formation. Looking northward at Last Mountain, northeast Coal River map area.



Figure 48. Thick-bedded, quartz sandstone of Mattson Formation. From ridgetop 5 km north of Spruce Creek (station 09LP090).

Age, Correlation and Depositional Setting

Fossils were not found in the Mattson Formation in the Coal River map area. East of the map area conodonts from the carbonate-bearing upper part of the formation are Viséan to Serpukhovian (Table IV-4 in Pigage, 2009), similar to those from thicker intervals farther east, indicating a Middle to Late Mississippian age (Richards *et al.*, 1993).

The Mattson Formation correlates with the Stoddart Group (Rutgers, 1958; Bamber and Mamet, 1978) in northeastern British Columbia. Time-equivalent and lithologically identical units to the north and northwest are the Heritage Trail Formation of the Tishu Group (Cecile, 2000; Martel *et al.*, 2012) on the Northwest Territories-Yukon border, and the Keno Hill quartzite, north of Dawson City, Yukon (Tempelman-Kluit, 1970; Gordey and Anderson, 1993).

Regionally the Mattson Formation constitutes a large, south to southwest-prograding delta complex with interbedded eolian sand, coal, fluvial deposits, channel-fill deposits, submarine channels, and delta shoreline deposits (Richards *et al.*, 1993). The scarcity of heavy minerals and non-quartz clasts in the sandstone suggests the grains are multicyclic, representing more than one weathering cycle. Paleocurrents and spatial relationships between delta plain and marine lithofacies indicate a northern provenance (Richards, 1989; Fallas, *et al.*, 2002).

Detrital zircon geochronology was completed on one sandstone sample (09LP090) from the Mattson Formation. Analytical results are listed in Appendix B; the probability distribution and Concordia plots are shown in Figure 49. The youngest zircons form a peak at 432 Ma. The distribution of zircon grain ages, from Mesoproterozoic to Archean, is consistent with the Laurentia type II signature of Hadlari

et al. (2012); the detrital zircon grains are likely recycled from erosion of Paleozoic and Proterozoic strata. Lemieux *et al.* (2011), Beranek, *et al.* (2010) and Leslie (2009) noted that early Paleozoic to Neoproterozoic detrital zircon ages first appear in Cordilleran strata in Late Devonian to Mississippian time with the influx of clastic sediments from a northern exotic source region contributing detrital zircons. Suggested exotic source regions include Baltica, Siberia, or the east Greenland Caledonides (Lemieux *et al.*, 2011; Beranek *et al.*, 2010).

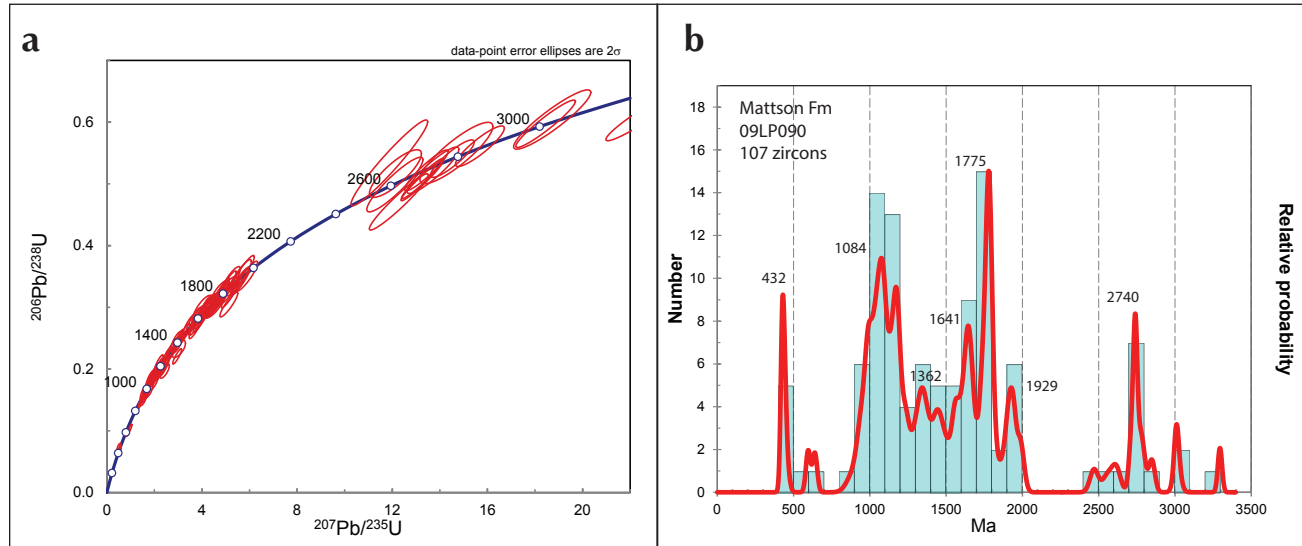


Figure 49. Results of geochronological analysis of 107 detrital zircon grains from Mattson Formation sandstone (sample 09LP090): **(a)** Concordia diagram; **(b)** probability distribution diagram. Data and methods are shown in Appendix B (Table B8).

Fantasque Formation (PF)

Introduction

Rusty brown-weathering, dark grey, siliceous shale in the eastern part of the Coal River map area is assigned to the Permian Fantasque Formation (Harker, 1961). It unconformably overlies the Mattson Formation and is in turn unconformably overlain by the Triassic Grayling-Toad unit. Its thickness ranges from 1000 m (northeast Coal River map area) to 1700 m (upper Toobally Lake area). At its type section (about 100 km east of Toobally Lakes) however, its thickness is 180 m. It is therefore possible that in the Coal River map area it is tectonically thickened or may include some of the underlying Tika unit (K. Fallas, pers. comm., 2014).

Composition

The formation consists predominantly of rusty brown-weathering, dark grey, siliceous shale (Fig. 50). The shale is internally bedded on a scale of 5 to 20 cm. Beds with abundant limestone nodules are scattered through the shale succession (Figs. 50 and 51). In the upper Toobally Lakes area the formation contains a thin-bedded, dark grey limestone interval estimated to be 800 m thick (Pigage 2009); poor outcrop precludes determining where this carbonate interval occurs within the formation. This limestone was not encountered elsewhere in the Coal River map area.



Figure 50. Rusty brown-weathering, dark grey, siliceous shale of the Fantasque Formation. Bedding dips steeply to the right in the photograph; slaty cleavage dips moderately to the left. Limestone nodules visible locally. From the core of the Skinboat syncline, in northeastern Coal River area (station 09TOA203).



Figure 51. Large limestone nodule in siliceous shale of Fantasque Formation. From 700 m east of upper Toobally Lake (station 04LP013). Hammer head is 20 cm long.

Age, Correlation and Depositional Setting

A conodont sample from the east side of upper Toobally Lake was broadly Permian; another three were of indeterminate age (Table IV-12 in Pigage, 2009). Regionally the Fantasque Formation is upper Artinskian through Wordian (early Permian through middle Permian) (Bamber *et al.*, 1968; Henderson *et al.*, 1993). Sponge spicules are the diagnostic fauna for this unit although an elasmobranch fish impression was found near the base of the formation (Harker, 1961).

The Fantasque Formation is a thin but laterally persistent unit from Pine Pass throughout northeastern British Columbia and extends to the southern Mackenzie Mountains. Regionally the shale is typically interbedded with chert, and siltstone interbeds contain lag deposits of phosphate, chert pebbles, and chert nodules. It reflects a slope to basinal environment.

Correlative strata in the Rocky Mountains to the southeast include the Ranger Canyon and Mowich formations of the Ishbel Group (Henderson *et al.*, 1993). In central Yukon correlative strata include the Mount Christie Formation, defined in Little Nahanni River map area (100 km north of the Coal River), consisting of buff to orange weathering shale, siliceous shale, chert, and minor sandstone of Early Permian age (Gordey and Anderson, 1993). In the southern Ogilvie Mountains correlative units are a mid-Permian limestone, the Takhandit Formation, and overlying green and red slate with minor chert (Green, 1972). The Fantasque Formation was deposited in a shallow water marine environment, below wave base.

Undivided Grayling and Toad formations (TGT)

Introduction

A single locality of Triassic strata in the Coal River map area occurs on the northwest side of upper Toobally Lake in the immediate footwall of the Toobally reverse fault. Outcrops of Triassic strata are sparse in southeast Yukon and previously mapped as undivided Grayling and Toad formations (Kindle, 1944; Fallas and Lane, 2001). It lies unconformably on the Fantasque Formation (Permian), and is unconformably overlain by Cretaceous strata to the east. In its type area, Grayling Formation (Lower

Triassic) is 305 m thick, conformably overlain by up to 730 m of Toad Formation (Middle Triassic) (Kindle, 1944).

Composition

The exposure consists of dark grey, soft, recessive shale (Fig. 52) and lesser interbedded thin, tan-weathering sandstone. Mica is locally visible on the slaty cleavage surfaces of the shale. Thin interbeds of greenish grey, very fine grained sandstone reveal small load clasts, possible gutter casts and poorly preserved horizontal burrows. Both the shale and sandstone are locally concretionary (Pigage, 2009).



Figure 52. Dark grey, soft, recessive shale interbedded with thin, tan-weathering sandstone comprise the undivided Grayling-Toad unit. In the immediate footwall of the Toobally fault on the west side of upper Toobally Lake (station 03LP008).

Age, Correlation, and Depositional Setting

Pollen samples for this unit in the Coal River area were identified as Lower Triassic with abundant Middle and Upper Devonian reworked spores (Pigage, 2009).

The unit is unlikely to be present elsewhere in the eastern Coal River map area, but is extensive (although poorly exposed) to the east and southeast. Correlation in the subsurface to the southeast includes the gas-bearing Montney and Doig formations (Gibson, 1993; Dixon, 2009). Northwest of the Coal River map area, the Jones Lake Formation, of late Middle to Late Triassic (Ladinian to Norian) age, is a correlative siltstone, sandstone and shale unit about 750 m thick (Gordey and Anderson, 1993).

Five facies associations are recognized in detailed sections measured to the east in NTS 95C/1 and NTS 95C/2 (MacNaughton, 2002). These facies associations are interpreted to represent depositional environments on a wave-dominated shelf, ranging from relatively distal, sand-poor settings below storm wave base to high-energy, proximal sand-rich, mid to upper shoreface settings. Sandstone from the Jones Lake Formation yielded Mississippian detrital zircons, a likely indication that Yukon-Tanana terrane elements were contributing to the shallow marine shelf sediments (Beranek *et al.*, 2010).

SUCCESION 6 – PALEOCENE TO LATE EOCENE

Two widely separated exposures constitute this succession. The western tip of an east-trending ridge projects into the Coal River map area at 60°28'N. In the north-central part of the map area, the Rock River valley contains exposures of poorly consolidated sediments over a 50 by 4 km area.

Paleocene unconsolidated sediments (PSSC)

Introduction

A greater than 160 m-thick succession of flat-lying, siltstone, sandstone and conglomerate unconformably overlies folded Road River Group strata. The upper extent of the unit is eroded.

Composition

This outcrop extends eastward into the Pool Creek map area (NTS 95C/5), where its greater exposure permitted more thorough observation of bedding and lithologic variation (Pigage, 2009). There it consists predominantly of poorly consolidated pebbly sandstone with thinner interbeds of clay siltstone to mudstone and highly variable 'red beds'. Siltstone intervals are discontinuous across the section, occurring as thin lenses up to 20 m long. The uppermost sedimentary unit is a coarse, clast-supported conglomerate up to 21 m thick. The dominant clast component in the conglomerate is grey quartzite. The succession is capped by remnants of a Paleocene trachytic, locally columnar-jointed, olivine alkali basalt flow up to 20 m thick.

Age, Correlation and Depositional Setting

A whole rock sample of the basalt flow was dated at 56.7 ± 0.7 Ma using $^{39}\text{Ar}/^{40}\text{Ar}$ methods (Pigage, 2009), providing a minimum late Paleocene age for the sediments.

The strata indicate a subaerial, fluvial depositional environment. Imbrication and bar forms indicate an east to southeast paleoflow direction (Pigage, 2009).

Eocene Rock River basin, coal-bearing sediments (ERR)

Introduction

Eocene strata are poorly exposed along the banks of the Rock River, and in diamond drill core from coal exploration in the Rock River valley in 1986 and 2006. Drill holes penetrated Cenozoic sediments to a depth of 445 m (Aurora Geosciences Ltd., personal communication 2014). Gravity surveys on east-west lines were used to calculate an 1100 m thickness for the poorly consolidated sediments overlying lower Paleozoic sedimentary rocks in the northern part of the basin (Wright and Miller, 1986). The lower contact is unconformable, and there are no overlying units recognized.

Composition

The succession is dominated by drab, dark to light grey, poorly consolidated mudstone with thin sandstone beds and thick lenses of coal (Long and Sweet, 1994; Wright and Miller, 1986). The coal horizon in the single outcrop exposure is over 5 m thick; in two drill holes, coal seams up to 4.7 m thick amounted to about 50% of the core (Wright and Miller, 1986). Bedding in the single outcrop of Tertiary strata dips about 15° westward.

Age, Correlation and Depositional Setting

Cenozoic strata encountered in the drill holes have a late Eocene age based on palynology (Long and Sweet, 1994). They were deposited in floodplains or wetlands associated with a stable single or multiple-channel fluvial system (Long and Sweet, 1994).

In early Cenozoic time several intermontane depositional basins or half-grabens developed along active extensional faults in eastern Yukon and adjacent Northwest Territories (320 km north-northwest; see Martel *et al.*, 2012). The west side of the poorly consolidated sediments in the north-central part of the Coal River map area is a postulated normal fault; the eastern limit is eroded. We interpret these to be remnants of a depositional basin whose strike length is approximately 50 km (based upon its gravity expression; Wright and Miller, 1986), and maximum width is 4 km.

IGNEOUS ROCKS

Introduction

Coal River map area contains several volcanic rock horizons within Proterozoic through Late Ordovician strata. The exposures range from approximately 50 m to about 1300 m thick, consisting of multiple flow units, breccia and tuff. Similar textural characteristics and geochemistry warrant their treatment together in this section.

Fifteen plutons are currently known in the northern half of the Coal River map area. Most are small and poorly exposed, underlying heavily forested areas. Age dating and chemical analysis indicate that most of the plutons have a similar chemistry, with crystallization ages between 97 Ma and 100 Ma (Pigage *et al.*, 2014).

Cambrian-Ordovician Alkali Basalt (PЄVN-v, ЄOC-v, ЄOR-v, and OSu-v)

Introduction

Lenticular belts of volcanic rock are present within the undivided Vampire-Narchilla unit, Crow Formation, Rabbitkettle Formation, and Sunblood Formation. Based upon the ages of the sedimentary units that overlie and underlie them they range from early Cambrian to Late Ordovician, thus representing a protracted interval of intermittent volcanism. Texturally the flows include massive, pillowed, and autobrecciated variants; these intercalations have been described previously with their respective stratigraphic units. Their volumetric abundance is minor and few dikes were noted outside of the immediate area of the volcanic rocks. It is surmised that these occurrences are remnants from many isolated extrusions, rather than a few eruptions of widespread extent.

The geochemical character of the different volcanic units is presented in this section. Whole rock and trace element analyses were completed on samples from the different volcanic units (Fig. 53); the analyses are presented in Appendix C. Samples were selected to avoid amygdules, veins, or alteration in fractures. All volcanic exposures contain secondary minerals, likely resulting from seawater alteration and burial and subsequent metamorphism. Volcanic rocks in the map area have been metamorphosed to at least lower greenschist facies based upon ubiquitous chlorite. Typical alteration includes modification of the alkali content, increase in carbonate and water (volatiles) and oxidation of the iron content (e.g., Rollinson, 1993). The moderate to large loss-on-ignition (LOI) contents in these samples attest to mobilization of some major and trace elements. Immobile elements during alteration and metamorphism have been utilized to minimize the effects of alteration and metamorphism and eliminate errors of classification (Pearce and Cann, 1973; Wood, 1980; Jenner, 1996).

Undivided Vampire-Narchilla unit volcanic rocks (PЄVN-v)

Two diabase dike samples and two samples from a flow within the Vampire-Narchilla unit differ in subtle ways from the other Paleozoic igneous rocks. They were selected from outcrops in a 17 km long, 1300 m wide area of this unit west of the Rock River fault (Plate 1). Based upon these samples, the total-iron to magnesium ratio is ~4; Cr and Ni content are below 20 ppm; and Nb is low (80-115 ppm).

TiO₂ is low (2.06-2.8%) and Zr ranges from 24 to 401 ppm (the latter may reflect the presence of a zircon crystal in the sample). These rocks contain high Ba (826-1095 ppm), and the Na₂O to K₂O ratio is 1.5-2. On the Zr/Ti vs Nb/Y composition plot (Pearce, 1996) these few samples occupy the alkali basalt field (Fig. 54a); trace element values normalized to primitive mantle broadly have an ocean island basalt (OIB) signature; the samples show significant depletions in Zr, Hf and Ti (Fig. 54b). The low vanadium content of all samples places them well away from the volcanic arc trend (Fig. 54c; Shervais, 1982).

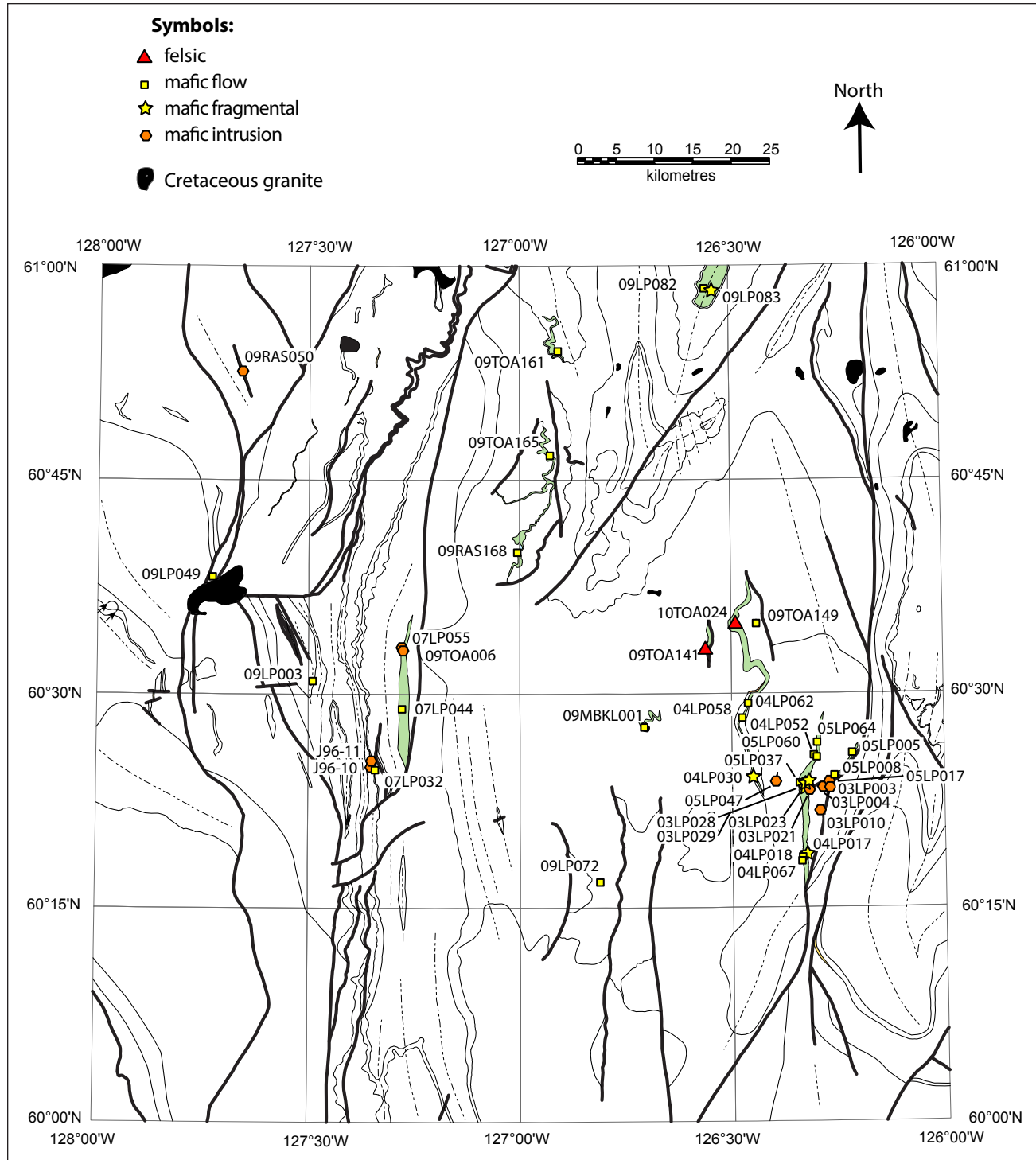


Figure 53. Distribution of volcanic rocks intercalated within four formations of the Coal River map area. Numbers indicate sample locations for geochemistry (Appendix C, Tables C1-C4).

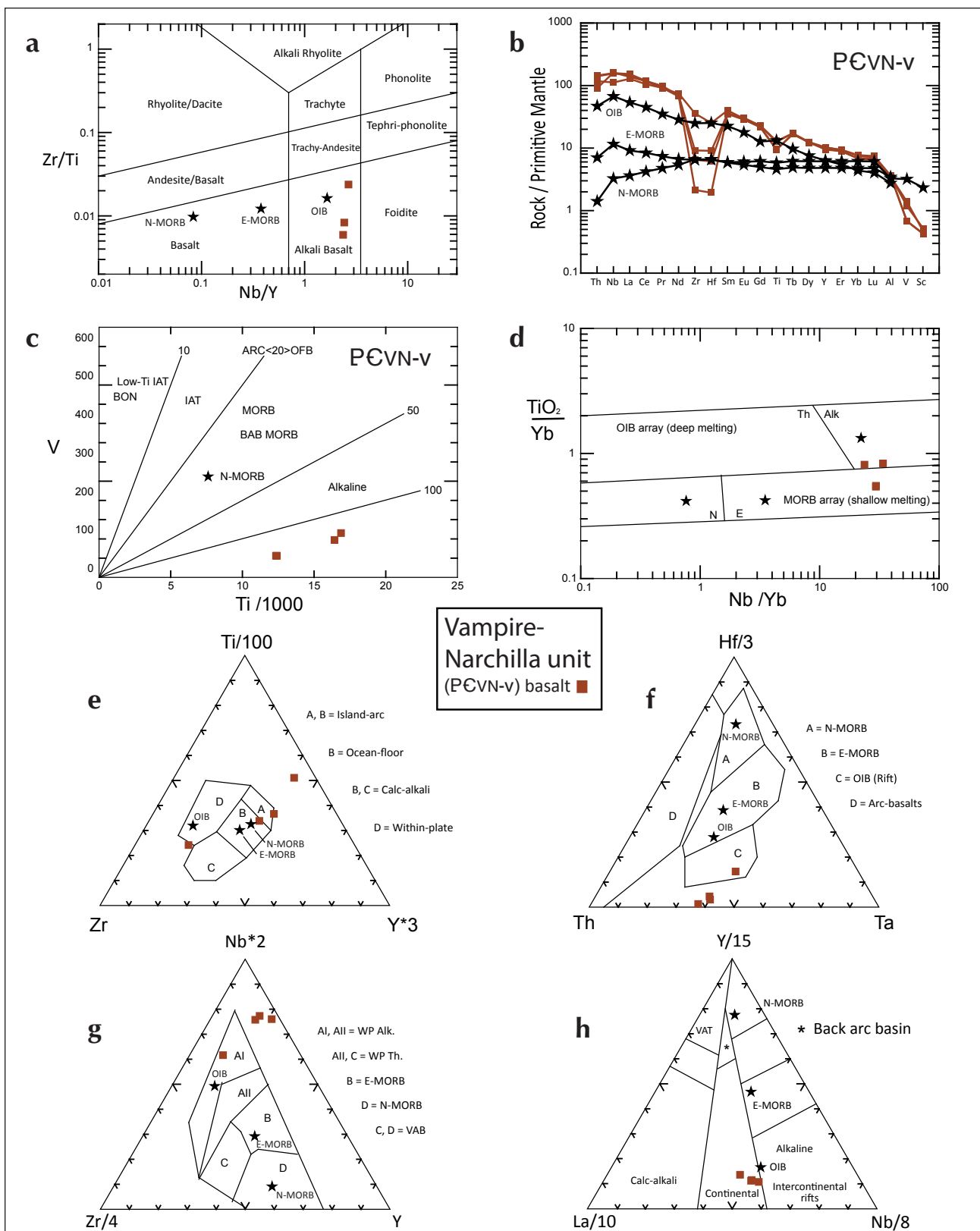


Figure 54. Geochemical and tectonic discriminant diagrams for volcanic rocks of the undivided Vampire Narchilla unit: **(a)** Zr/TiO₂-Nb/Y diagram of Winchester and Floyd (1977), as modified by Pearce (1996); **(b)** primitive mantle-normalized, multi-element diagram; **(c)** Ti/V diagram of Shervais (1982); **(d)** TiO₂/Yb-Nb/Y diagram of Pearce (2008); **(e)** Zr-Ti-Y diagram of Pearce and Cann (1973) for tholeiitic basalt; **(f)** Th-Hf-Ta diagram of Wood (1980); **(g)** Zr-Nb-Y diagram of Meschede (1986); and **(h)** La-Y-Nb diagram of Cabanis and Lecolle (1989) for basalt.

In general these rocks are poorly discriminated on ternary diagrams (Fig. 54e-h). They straddle multiple fields on the ternary Ti-Zr-Y plot designed for tholeiitic basalt (Fig. 54e; Pearce and Cann, 1973), and are so low in Hf and Zr that most plot outside the established fields on the other diagrams (Fig. 54f,g).

The alkali basalt designation is confirmed by Figure 54a,c,d. Figure 54b and d suggest an enriched mantle source with minimal to no crustal contamination; limited crustal contamination of the magma suggests rapid extrusion from the mantle source area.

Crow Formation volcanic rocks (€OC-v)

Volcanic rocks form narrow belts of exposure within the Crow Formation west of upper Toobally Lake and in the core of the Caribou anticline (Plate 1). The previous study of Pigage (2009) is augmented by additional analyses here. Analyses on eight samples returned a loss-on-ignition (LOI) greater than 10% [flows: 05LP008, 04LP018-1, 05LP060; altered dikes/sills: 03LP003, 03LP010, 03LP017; altered breccia: 03LP023, 04LP017]. The high volatile content likely reflects metamorphism and alteration. These samples also have anomalous CaO (indicative of secondary carbonate); they were not included in the diagrams. Two samples (09TOA141 and 10TOA024) have SiO₂ compositions indicative of andesite to rhyolite; these samples are included in the Appendix C tables but are also excluded from the discriminant and composition diagrams that are appropriate for basaltic rocks.

The total iron to magnesium ratio ranges from 1.5-4, with variable Cr (below 20 to 528 ppm), Ni (69-198 ppm) and uniform Nb (23-48 ppm). TiO₂ is low (1.4-3.3%) as is Zr (87-413 ppm), and P₂O₅ content is low to moderate (0.18-1.12%). K₂O is equal to or greater than Na₂O in half the samples; Ba is either low (<50 ppm) or relatively high (300-946 ppm). From the composition and discriminant plots these rocks are clearly alkaline basalt (Fig. 55a,b,c) in the 'within plate' and OIB fields (Fig. 55e,f,g) with a few samples near the boundary between continental and intercontinental rifts (Fig. 55h). Trace-element and rare earth element (REE) patterns normalized to primitive mantle range between OIB and enriched mid-ocean ridge basalt (E-MORB).

The tectonic discriminant diagrams indicate deep melting of enriched mantle with minimal contamination from crust during ascent (Pearce, 2008; and others listed in the caption for Fig. 54).

Rabbitkettle Formation volcanic rocks (€OR-v)

Five flows, one sill and two undefined samples (from drill core at Jeri-North prospect) represent the igneous component of the Rabbitkettle Formation. Volatile contents range from 3% to 8%; silica contents are typical of basalt. The total iron to magnesium ratio approaches 2, and all have low Nb (10-57 ppm), Cr (40-470 ppm, by ICP-MS) and Ni (below 20 to 240 ppm). TiO₂ ranges from 0.67 to 3.2%, and Zr from 131-272 ppm. The rocks are sodic (Na₂O: K₂O is 3-10), and some contain appreciable Ba (up to 1591 ppm).

On the Zr/Ti vs Nb/Y composition diagram the Rabbitkettle volcanic samples are andesitic basalt to alkali basalt (Fig. 56a), the samples plot in both the alkaline, OIB and MORB fields (Fig. 56c,d). On ternary discriminant diagrams, the samples occupy the 'within plate' and OIB fields (Fig. 56e,f,g), although the high La in the samples pulls them into the calc alkaline field (Fig. 56h). The composition normalized to primitive mantle indicates depletions in Nb and Ti for some of the samples (Fig. 56b), suggesting slight crustal contamination for the basalt; this indication of crustal contamination is also suggested by several of the samples plotting above the MORB array in Figure 56d. A continental, within-plate, extensional environment with slight crustal contamination of an enriched mantle source is suggested.

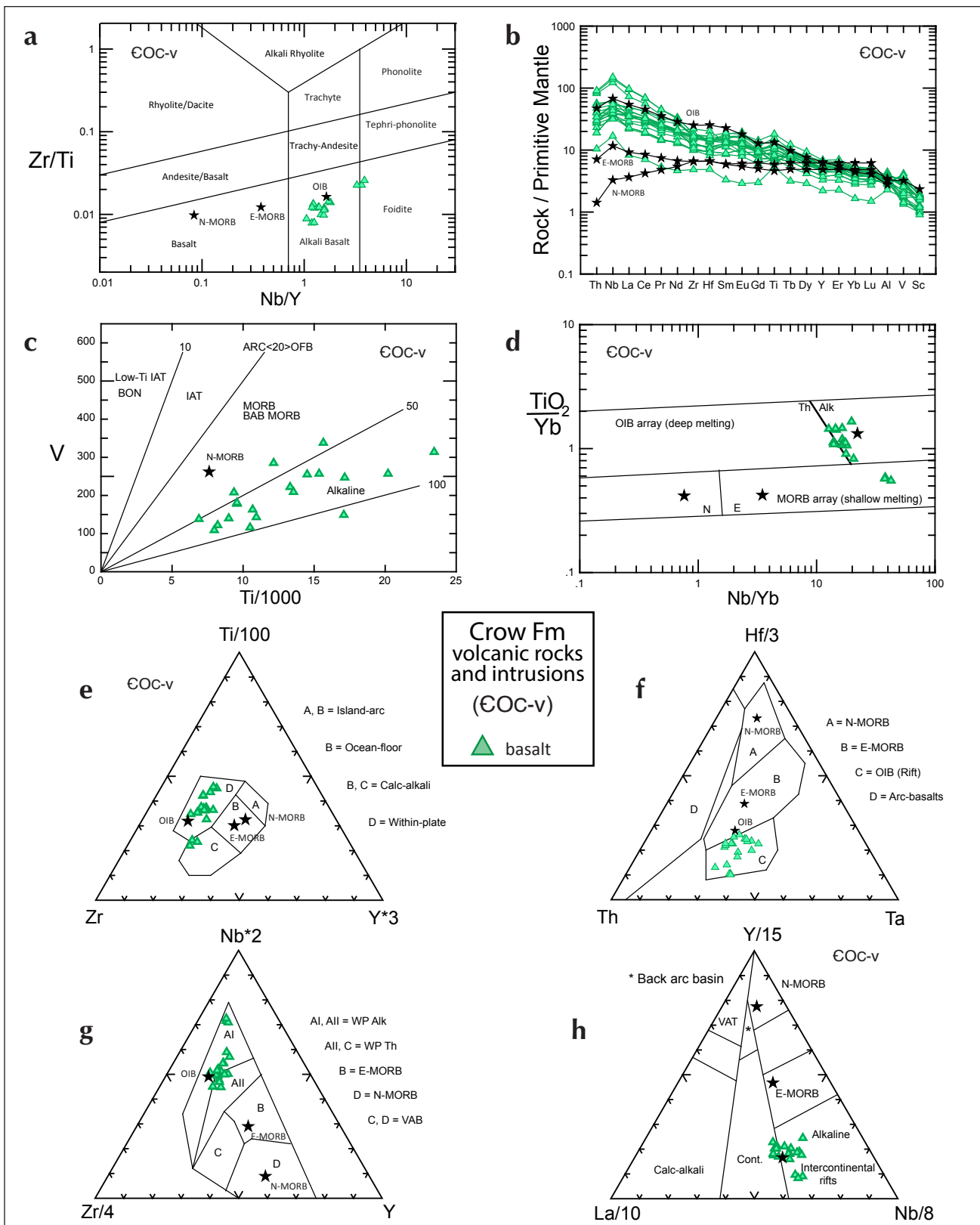


Figure 55. Geochemical and tectonic discriminant diagrams for volcanic rocks and intrusions of the Crow Formation: **(a)** Zr/TiO₂-Nb/Y diagram of Winchester and Floyd (1977), as modified by Pearce (1996); **(b)** primitive mantle-normalized, multi-element diagram; **(c)** Ti/V diagram of Shervais (1982); **(d)** TiO₂/Yb-Nb/Y diagram of Pearce (2008); **(e)** Zr-Ti-Y diagram of Pearce and Cann (1973) for tholeiitic basalt; **(f)** Th-Hf-Ta diagram of Wood (1980); **(g)** Zr-Nb-Y diagram of Meschede (1986); and **(h)** La-Y-Nb diagram of Cabanis and Lecolle (1989) for basalt.

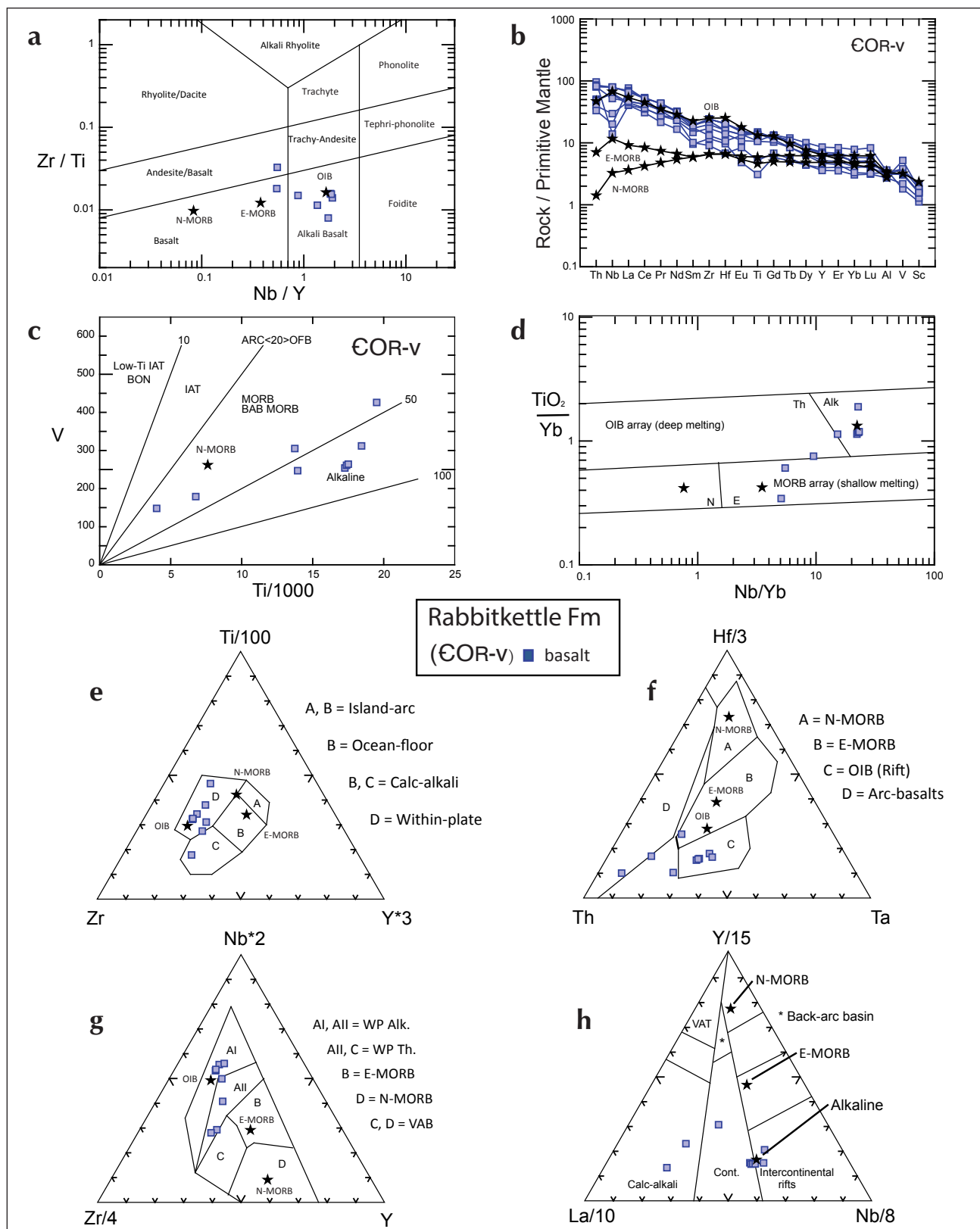


Figure 56. Geochemical and tectonic discriminant diagrams for volcanic rocks of the Rabbitkettle Formation: **(a)** Zr/TiO₂-Nb/Y diagram of Winchester and Floyd (1977), as modified by Pearce (1996); **(b)** primitive mantle-normalized, multi-element diagram; **(c)** Ti/V diagram of Shervais (1982); **(d)** TiO₂/Yb-Nb/Y diagram of Pearce (2008); **(e)** Zr-Ti-Y diagram of Pearce and Cann (1973) for tholeiitic basalt; **(f)** Th-Hf-Ta diagram of Wood (1980); **(g)** Zr-Nb-Y diagram of Meschede (1986); and **(h)** La-Y-Nb diagram of Cabanis and Lecolle (1989) for basalt.

Sunblood Formation volcanic rocks (OSu-v)

Two samples were selected from flows within the Sunblood Formation. The composition of one may be less reliable because its carbonate and hydrous mineral content amounted to 7.2% LOI. Both samples show roughly equal total iron to magnesium ratios, low Nb (~30 ppm), variable Cr (69-348 ppm) and Ni (40-160 ppm). One sample has high K₂O (5.2%) but lower Ba (517 ppm, in contrast to 875 ppm in the other) suggestive of alteration, given its high volatile content. On the Zr/Ti vs Nb/Y composition diagram the samples plot within the alkali basalt field (Fig. 57a). Trace element patterns normalized to primitive mantle match that of OIB (Fig. 57b), and the samples plot neatly within the OIB and 'within-plate' fields on various discriminant diagrams (Fig. 57c-h), similar to those for the Crow and Rabbitkettle formations.

Discussion

The volcanic rocks in the Coal River map area are part of a widespread assemblage of mafic volcanic rocks of similar ages and composition that are distributed throughout Selwyn basin and adjacent Mackenzie platform (Goodfellow *et al.*, 1995), as well as more sparsely along the eastern half of the southern Canadian Cordillera. The chemistry of the assemblage indicates an enriched mantle source, similar to OIB, but reflects intermittent extension within unstable, thinned continental crust of the outer continental margin.

Dominantly mafic, submarine volcanic rocks from lower Cambrian to Middle Devonian age form lenticular occurrences in east central Alaska, eastward and southeast to the Coal River map area (Goodfellow *et al.*, 1995). Significant exposures include the southern Ogilvie Mountains (Roots, 1988), the axis of the Misty Creek embayment (Marmot Formation; Cecile, 1982) and the Anvil Range north of Faro (Menzie Creek formation; Jennings and Jilson, 1986; Pigage, 2004b).

Locally quartz and feldspar-phyric flows and intrusions occur in the western Ogilvie mountains, near the Dempster Highway (Roots, 1988), near the Marg VMS deposit northeast of Mayo and in Crow and Rabbitkettle formations within the Coal River map area (this report). Their composition is rhyolite, with high K₂O and Ba, although these elements may be secondarily enriched.

The mafic localities have similar depositional environment and tectonic settings. They dominantly form subaqueous, low magma volume volcanic edifices (individual occurrences estimated to contain <20 km²; greatest thicknesses are in Misty Creek embayment (500 m in Porter Puddle Complex; Goodfellow *et al.*, 1995) and at Fossil Creek (610 m; Wheeler *et al.*, 1986)). They overlie and are intercalated with clastic sediments of the upper Hyland Group (typically Narchilla formation), Rabbitkettle Formation and Road River Group (e.g., Hess River, Rabbitkettle, Elmer Creek/Duo Lake and Steel formations). Many occurrences are overlapped by limestone patch reefs, although the Sunblood Formation of southeast Yukon is one of only two regionally widespread platform carbonate units to contain volcanic horizons (the other is the Haywire Formation). Typically, flows low in the volcanic successions are pillowed, while some upper sections contain conglomerate and maroon breccia that indicate emergence (Roots, 1988; Goodfellow *et al.*, 1995). The preservation of subaerial facies between flow units and relatively deep water sediments indicates rapid subsidence of parts of the volcanic edifice.

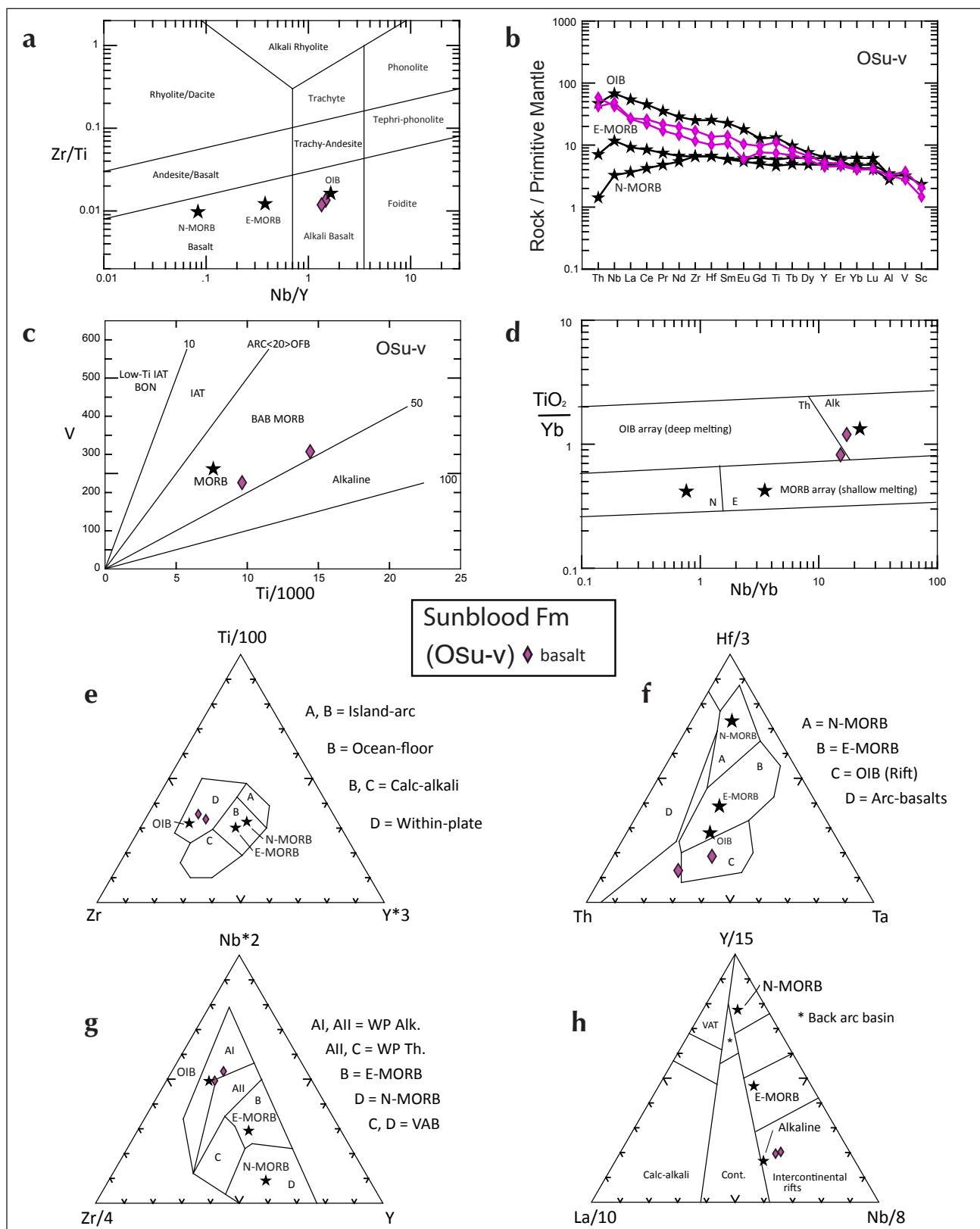


Figure 57. Geochemical and tectonic discriminant diagrams for volcanic rocks of the Sunblood Formation: **(a)** Zr/TiO₂-Nb/Y diagram of Winchester and Floyd (1977), as modified by Pearce (1996); **(b)** primitive mantle-normalized, multi-element diagram; **(c)** Ti/V diagram of Shervais (1982); **(d)** TiO₂/Yb-Nb/Y diagram of Pearce (2008); **(e)** Zr-Ti-Y diagram of Pearce and Cann (1973) for tholeiitic basalt; **(f)** Th-Hf-Ta diagram of Wood (1980); **(g)** Zr-Nb-Y diagram of Meschede (1986); and **(h)** La-Y-Nb diagram of Cabanis and Lecolle (1989) for basalt.

The discontinuous and interdigitating nature of the volcanic outcrops suggests that they issued from fissures; their primary geometry is masked by subsequent folding and faulting and poor exposure. The range in age suggests that Selwyn basin (*i.e.*, early Paleozoic continental margin) underwent episodic tensional stress that reactivated deep fractures in the continental margin. Their alkalic nature and within-plate chemistry are consistent with this extensional tectonic regime (Barberi *et al.*, 1982; Bailey, 1985). The volcanic magma was sourced from enriched mantle, and ascended with only minor crustal contamination. Slight differences in the chemistry of the Coal River volcanic rocks attest to heterogeneity in the source region, with no indication of progressive change over time.

Cretaceous Intrusions (mKg)

Fifteen plutons (Table 2) are scattered across the northern half of the map area where they generally occupy low lying, heavily forested areas. Nine were either discovered during this program or were previously only recorded on industry maps. The intrusions are typically subcircular and range from 335 m to about 8380 m across. Aeromagnetic anomalies aided detection and mapping of the intrusions (Fig. 58).

Since the intrusive bodies are poorly exposed, their full size, contact relationships and metamorphic effects such as hornfelsing, skarn development and alteration remain unclear and poorly documented. The Kostiuk, Spork and Ivo-Salivo plutons consist of the southern portions of large plutons primarily located in adjacent Frances Lake (NTS 105H) and Flat River (NTS 95E) map areas.

The plutons of the Coal River map area consist predominantly of biotite $\pm$ hornblende, metaluminous granodiorite to quartz monzodiorite. Textures range between porphyritic and equigranular. Porphyritic variants are typically crowded with plagioclase phenocrysts up to 5 mm across in a fine-grained, grey matrix; hornblende, biotite, and minor quartz also occur as phenocrysts. The Main pluton is the only body which contains primary muscovite. Many of the intrusions are incipiently to extensively altered, with chlorite replacing hornblende and biotite, and sericite dust occurring within feldspar.

Geochronology and geochemistry of the plutons are described in Pigage *et al.* (2014). All sampled intrusions (except for the Main pluton; see discussion below) belong to the Tay River suite as outlined by Rasmussen (2013; see also Heffernan, 2004; Hart *et al.*, 2004; Mortensen *et al.*, 2000). They are the southernmost exposures of the Tay River suite, a belt of contemporaneous and compositionally coherent intrusions extending 450 km northwest.

Crystallization ages for nine of the plutons were determined using CA-TIMS geochronology on single zircon grains. These ages are tightly clustered, ranging from 97.70 ± 0.03 Ma to 99.80 ± 0.03 Ma. Pigage *et al.* (2014) described their compositions, suggesting that the intrusions are partial melts from a reasonably homogenous, igneous, infracrustal source rock. They further suggested that partial melting was related to subduction with flattening of the subducting slab resulting in the Tay River plutonic suite being 400 km inboard of the postulated subduction trench.

The Gabe, Main and Spork plutons occur within the north to northeast-trending belt defined by a positive aeromagnetic anomaly (Fig. 58) and rocks of higher metamorphic grade. The aeromagnetic anomaly may be caused by the presence of metamorphic pyrrhotite or magnetite in the thermal aureole of a large intrusion, or a magnetic phase of a buried pluton.

Table 2. Intrusions in Coal River map area. Coordinates are UTM zone 9N, NAD83 datum.

Name	UTM East (m)	UTM North (m)	Age Ma $\pm$ 2 sigma*	Reference
Powers	658 872	6 743 596	98.2 $\pm$ 1.3	Rasmussen <i>et al.</i> , 2007
Jorgensen	645 250	6 751 550	98.35 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Last 1	621 360	6 751 642	-	
Last 2	620 192	6 745 800	98.52 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Gabe	570 761	6 722 414	97.83 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Kostiuk	555 895	6 762 820	99.39 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Oudder	625 672	6 723 074	97.70 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Lookout	655 673	6 752 196	98.20 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Spork	597 672	6 764 282	98.09 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Main	586 791	6 754 152	-	
Gusty	626 261	6 704 777	99.79 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Balsam	655 415	6 737 047	-	
Caribou	652 311	6 752 434	98.27 $\pm$ 0.13	Pigage <i>et al.</i> , 2014
Patterson	631 695	6 751 436	97.5 $\pm$ 0.5	Heffernan, 2004
Ivo-Salivo	606 595	6 764 260	-	

* For a discussion of error, see Pigage *et al.* (2014).

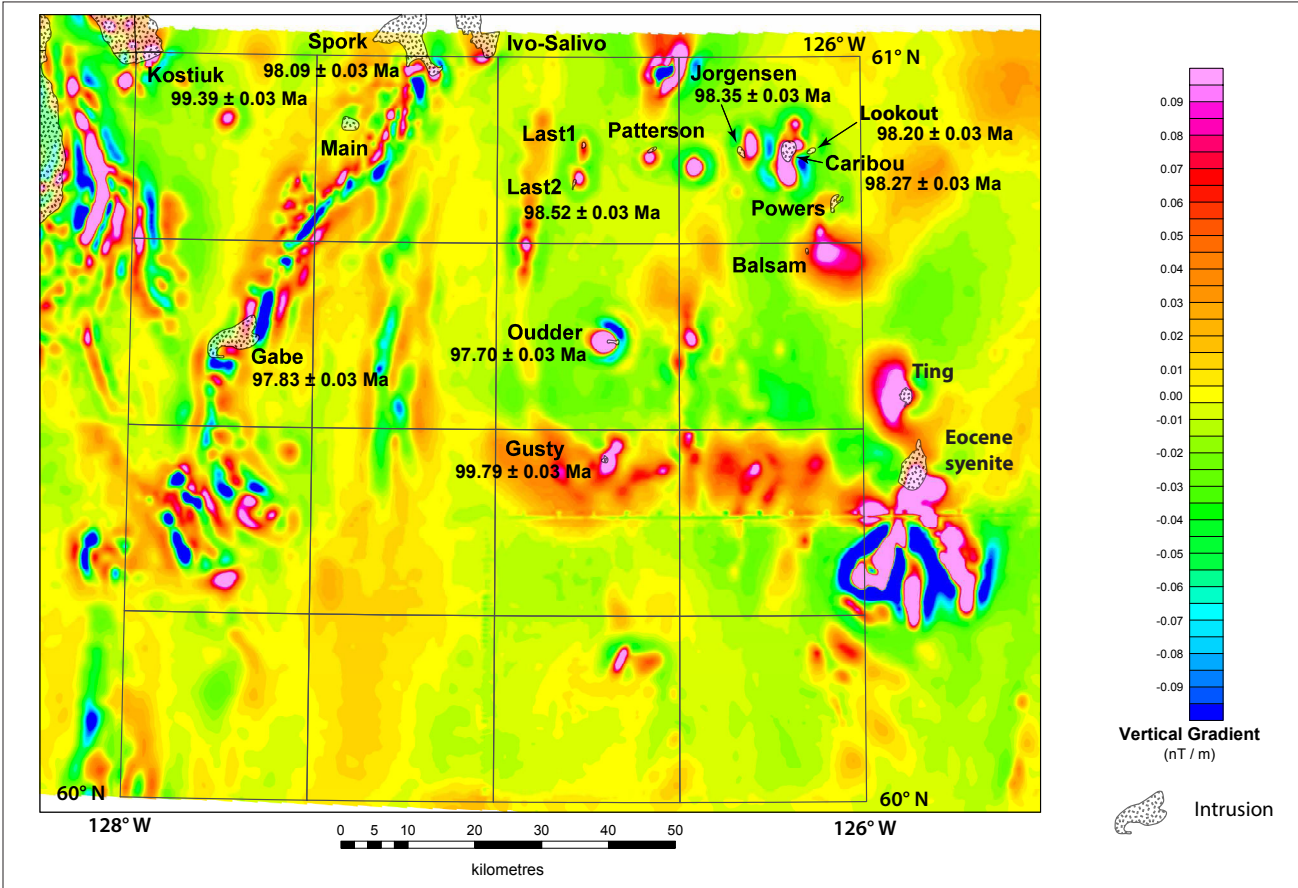


Figure 58. First vertical derivative of regional aeromagnetic survey with Cretaceous and Cenozoic granitic intrusions superimposed. Eocene syenite from Pigage (2009). Ting intrusions from Harrison (1982).

The sample from the Main pluton is a medium-grained, equigranular, foliated, medium grey, muscovite-tourmaline-garnet granite. The feldspar is exclusively plagioclase. Subhedral plagioclase and interstitial quartz constitute approximately 90% of the mode. Staining reveals very minor, fine-grained, interstitial K-feldspar. The chemistry is also significantly different from the other plutonic samples (Pigage *et al.*, 2014). The Main sample (sample10TOA019) yielded such poor quality zircon that isotopic dating was not attempted (Pigage *et al.*, 2014).

Another linear positive magnetic anomaly extends westerly from the eastern boundary of the map area to very near the Rock River (Fig. 58). It may also represent a series of buried plutons. The eastern end of this anomaly, in the Pool Creek map area (NTS 95C/5), contains exposures of a magnetite-bearing, Eocene biotite syenite (Pigage, 2009). Boulders of granite (Gusty pluton) were found over the most magnetic part of the anomaly. Elsewhere along this trend the surface exposures are siliciclastic and carbonate rocks with little to no magnetic expression.

STRUCTURE

Introduction

The Coal River map area is characterized by steeply dipping, northwest to northeast-trending faults and folds. It has been divided into four domains (domains A-D, Fig. 59), and structural measurements are plotted on equal area stereonet (Figs. 60-63). The domains, described here from west to east, reflect decreasing intensity of deformation and waning penetrative structural fabrics.

In domains A and B and the western part of domain C folds are associated with a penetrative axial planar slaty cleavage in argillaceous units. Second-phase refolding of earlier contractional structures by north-trending, open cross-folds (domains A, B and C) resulted in the local development of an axial planar crenulation cleavage in argillaceous units. A penetrative slaty cleavage fabric is not readily visible in domain D.

Domain A

The westernmost structural domain A is bounded to the east by the interpreted east-verging Acland thrust fault. Stratigraphic units in the domain are the Yusezyu Formation, undivided Vampire-Narchilla unit, Rabbitkettle Formation, and Road River Group. The domain is characterized by northwest-trending, southwest-verging, asymmetric folds with an associated pervasive, axial planar, slaty cleavage. Poles to bedding form a broad girdle with a best-fit trend/plunge of 330/11 (Fig. 60a). The axial planar slaty cleavage is dominantly steep (Fig. 60b); lineations plunge both to the northwest and southeast with a mean trend/plunge of 328/11. Locally these early folds are refolded with the development of later, small, north-trending, east-verging, open folds with an associated axial planar crenulation cleavage.

Lack of stratigraphic markers in the Yusezyu Formation hinder recognition of structures larger than outcrop scale. Consistent bedding and structural orientations over fairly large areas hint at the existence of large-scale folds. Northwest-trending anticlines cored by Yusezyu Formation have been interpreted in domain A on the basis of these structural relations between bedding and the pervasive slaty cleavage.

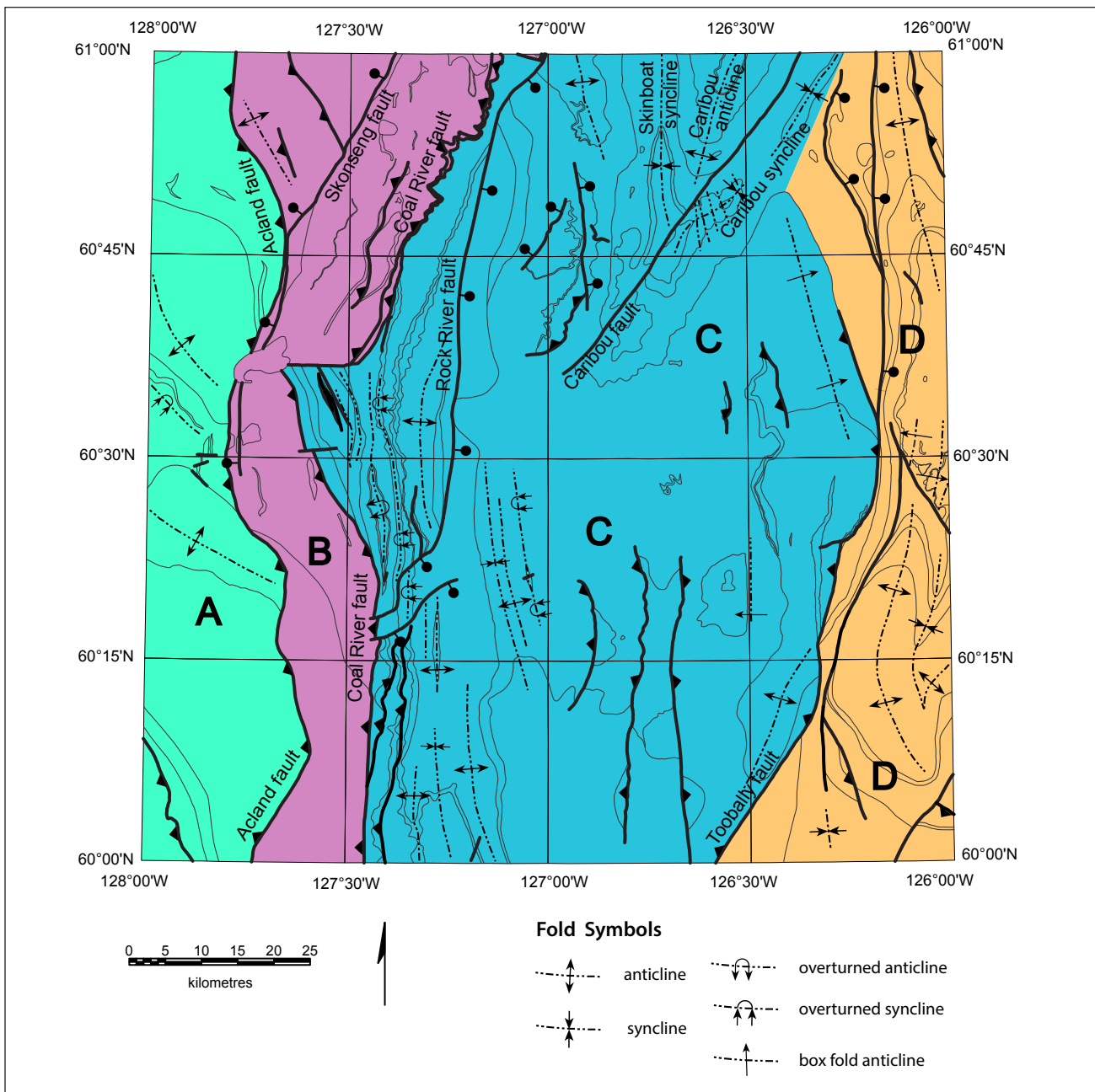


Figure 59. Structural domains in Coal River map area.

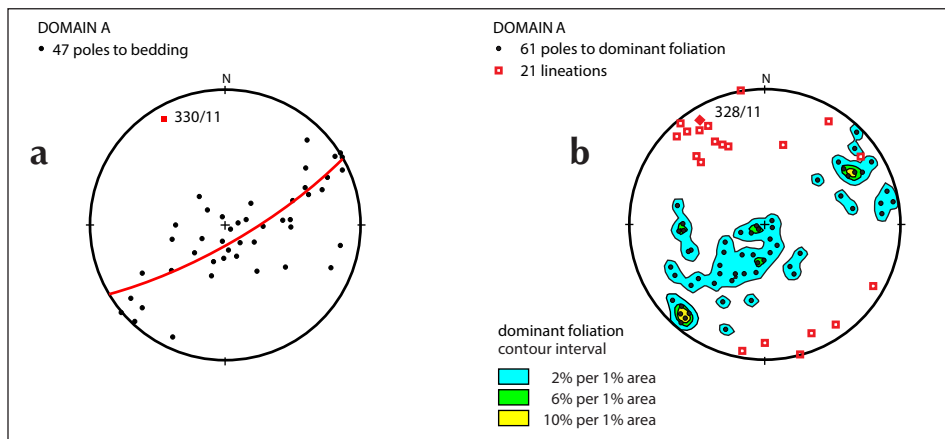


Figure 60. Structural domain A structural fabrics; (a) poles to bedding; (b) poles to dominant foliation, lineations associated with dominant foliation.

Domain B

The next structural panel to the east is cored by the undivided Vampire-Narchilla unit and bounded to the east by the Coal River thrust fault array. Bedding and foliation measurements are dispersed (Fig. 61), but generally correspond with trends of the aeromagnetic anomalies. Documented early folding consists of north-trending, east-verging, large-scale, tight, asymmetric folds with steep to vertical limbs and gently west-dipping limbs (Fig. 61a); poles to bedding form a broad girdle with a best fit pole of 188/11. Rocks in these folds have an associated pervasive, axial planar, slaty cleavage dipping moderately to the west (Fig. 61b); associated lineations plunge gently to the north-northeast and south-southwest with an average trend/plunge of 196/14. Structural domain B also contains locally extensive development of later, small-scale, north-trending, east-verging folds with an associated axial planar crenulation cleavage which refolds the earlier folds (Fig. 61c); the crenulation cleavage dips gently to moderately to the west. Associated lineations plunge gently to the north-northeast and southwest.

The Skonseng fault in the northwest corner of the map area separates rocks containing muscovite-chlorite (west) from rocks containing biotite-staurolite-garnet (east). The change in metamorphic grade is abrupt and is interpreted as a post-peak metamorphism normal fault.

The Coal River fault array consists of two or more closely spaced east-verging reverse faults. Rock units between the faults in the northern part of the map area are strongly foliated, suggesting that the reverse faults developed in hinge zones of tight folds. The faults are locally well exposed towards their north end, and dip moderately west. Displacement is estimated to be 2000-3000 m.

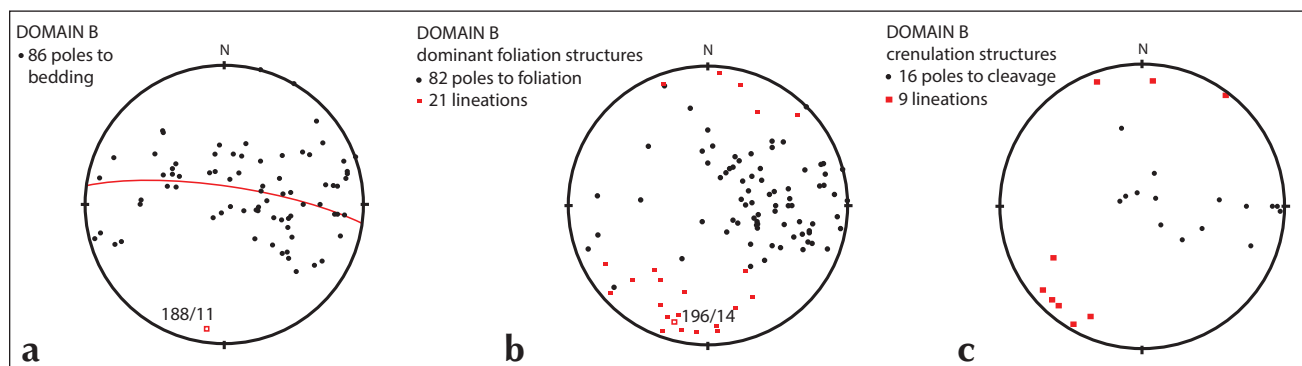


Figure 61. Structural domain B structural fabrics, (a) poles to bedding; (b) poles to dominant foliation, lineations associated with dominant foliation; (c) poles to crenulation cleavage, lineations associated with crenulation cleavage.

Domain C

Domain C underlies the central part of the map area and is bounded by the Coal River reverse fault to the west and the Toobally reverse fault to the east. It is characterized by asymmetric to overturned, east-verging folds with associated pervasive, west-dipping, axial planar, slaty cleavage in the west-central part of the map area. These folds are particularly well developed in the immediate Otter Creek area (Mel mineral occurrence - Yukon MINFILE 95D 005). To the south, the folds decrease in intensity and become more open and symmetrical; to the north the folds are replaced by east-verging reverse faults separated by west-dipping sedimentary strata. To the east, folding becomes less intense and transitions to a generally west-dipping, homoclinal stratigraphic succession with locally developed, macro-scale, east-verging reverse faults and box-style folds. Some small-scale, west-verging reverse faults and/or normal extensional faults are also present; these structures generally trend northerly.

Poles to bedding indicate a predominant, moderate west dip (Fig. 62a). The pervasive axial planar cleavage dips steeply to the west (Fig. 62b); associated lineations plunge gently to north and south (Fig. 62b).

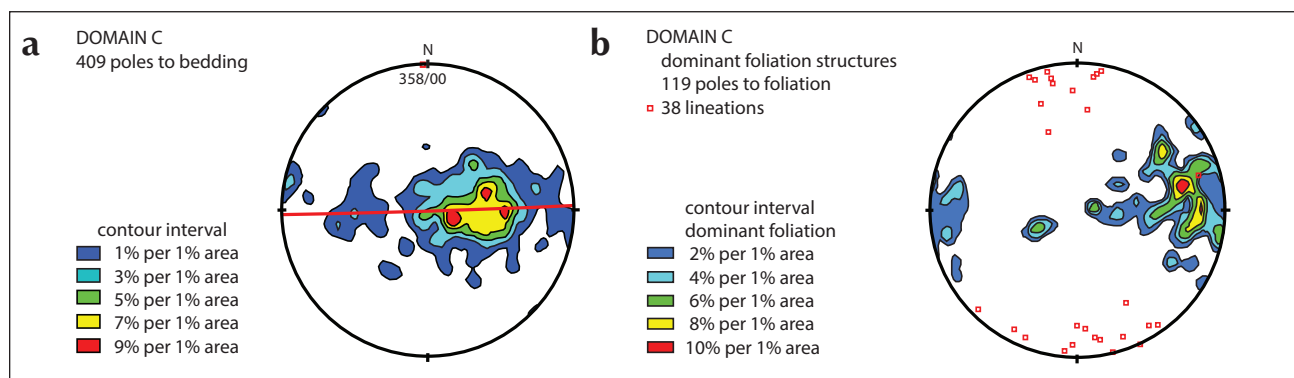


Figure 62. Structural domain C structural fabrics; (a) poles to bedding; (b) poles to dominant foliation, lineations associated with dominant foliation.

The northern part of domain C is dominated by the Caribou anticline (Gabrielse and Blusson, 1969) and its associated adjacent synclines. The Caribou anticline is a south-plunging, symmetrical structure. The herein named Skinboat syncline immediately west of the Caribou anticline is a tight, symmetrical, south-plunging syncline cored by the Permian Fantasque Formation.

In contrast, the Caribou syncline (Gabrielse and Blusson, 1969), located southeast of the Caribou anticline, is open and northeast-trending with very gently dipping limbs. The Caribou syncline is refolded by open, north-trending cross folds.

In the upper Toobally Lake area the east-verging Toobally fault (Gabrielse and Blusson, 1969) places the Proterozoic(?) Toobally Formation and the Cambrian-Ordovician Crow Formation in the hanging wall structurally on top of the undivided Triassic Grayling-Toad formations in the footwall. Structural displacement across this fault is difficult to determine because of differences in the thicknesses of the formations between structural panels C and D. Displacement across the Toobally fault decreases both to the north and south away from upper Toobally Lake.

The Rock River fault (Gabrielse and Blusson, 1969) forms the west margin of the Eocene Rock River basin sediments. Gabrielse and Blusson (1969) interpret it as an east-verging thrust fault. In contrast we propose that an east-dipping normal fault would permit deposition of Eocene sediments in a north-trending, extensional half-graben.

Domain D

The easternmost domain D is bounded on the west by the Toobally fault in the south and central parts of the map area, and the Caribou syncline in the northern part of the map area. In the north it is dominated by a north-plunging anticline cored by Mattson Formation and Sunblood Formation in the centre. Immediately north of the Toobally-Crow fault it has a box-fold style with a wide flat hinge zone and straight, moderately dipping limbs. South of the Toobally-Crow fault a similar, doubly plunging anticline is cored by Crow Formation. Slaty cleavage is not generally developed in argillaceous units in this domain.

Poles to bedding outline a girdle with trend/plunge of 189/07 (Fig. 63). The predominant bedding dip is moderately to the west.

Domain D also contains several north-trending faults with small displacements. In the north, the faults have been interpreted as normal; one fault in the central area has been interpreted as a west-verging, small-scale, back-thrust.

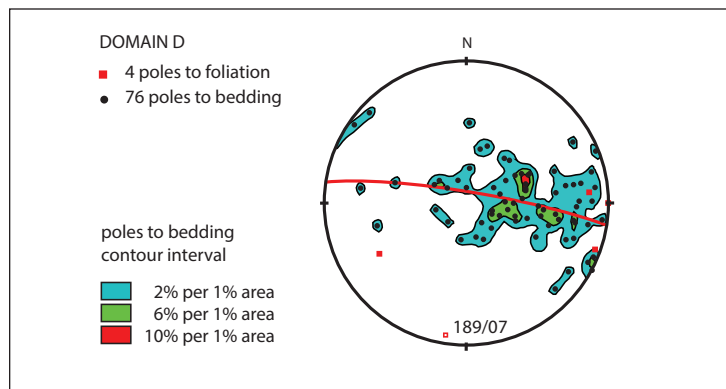


Figure 63. Structural domain C structural fabrics; poles to bedding, poles to dominant foliation.

Late Extensional Deformation

Extensional deformation is manifested by normal faults documented in the Coal River area. These structures are late-stage because they displace and offset earlier contractional fold and fault structures. The largest of these extensional features is the Rock River fault which forms the western margin of the upper Eocene sedimentary rocks. Because the upper Eocene sedimentary rocks east of the Rock River fault dip gently west, movement on the fault is inferred to be syn-late Eocene with faulting being concurrent with deposition of the late Eocene Rock River basin strata. The Rock River fault juxtaposes undivided Vampire-Narchilla unit against Road River Group and Eocene strata. A minimum displacement across the fault is at least 450 m (the known thickness of Eocene strata); a possible thickness of 1100 m for the Eocene strata (Wright and Miller, 1986) suggests a significantly greater minimum displacement across the fault.

Discussion

Fold structures and associated slaty cleavage in domain A trend northwest and are truncated by the north-trending Acland reverse fault, suggesting the contractional deformation associated with the folding in this domain predates the predominant north to northeast-trending folds occurring in the other domains. We infer that the locally developed, north-trending, east-verging minor folds and associated axial planar crenulation cleavage in domain A are correlated with the predominant fold and fault structures occurring in the other domains. The timing of the earlier deformation is poorly constrained to being post-lower Cambrian strata and pre-middle Cretaceous thrust faults.

The predominant contractional deformation (in domains B, C, D) at this structural level (now at surface) is constrained to post-Early Triassic time because Triassic and older argillaceous strata are folded and contain the pervasive slaty cleavage. It is further constrained to pre-middle Cretaceous time as the mid-Cretaceous plutons that crosscut fold and fault structures regionally are undeformed (Gordey and Anderson, 1993). Contractional structures are inferred to flatten into a shallow, west-dipping detachment located in pre-Hyland Group strata (cross section on Plate 1). Displacement at depth on this detachment may well have continued after emplacement of the Cretaceous intrusions.

Deformation in the Coal River area is considered to be part of the Cordilleran orogen (Gabrielse *et al.*, 1991; Nelson and Colpron, 2007; Nelson *et al.*, 2013), a manifestation of the amalgamation of Laurentia with allochthonous terranes.

The Rock River fault and associated half-graben occurred when east-directed compressional deformation ceased in Paleocene or Eocene, and dextral motion was initiated on the northwest-trending Tintina fault (Nelson *et al.*, 2013).

METAMORPHISM

Metamorphic mineral assemblages in the pelitic rocks regionally range from muscovite-chlorite zone in lower greenschist facies to biotite-garnet-staurolite-chloritoid zone in lower amphibolite facies (Table 3). All mineral assemblages in the basaltic volcanic rocks contain epidote, calcite and chlorite. The biotite-garnet-staurolite grade rocks occur in a northeast-trending belt extending from near the Hyland Gold MINFILE occurrence (Roy Lake) to north of the Coal River map area. The aluminosilicate minerals (andalusite, kyanite, sillimanite) were not observed in the pelitic rocks.

The dominant foliation (S1) and the later crenulation cleavage (S2) are delineated by matrix muscovite, chlorite and biotite. The porphyroblastic minerals garnet, staurolite, biotite and chloritoid contain planar inclusion trails which pass into the external, dominant foliation; the S2 crenulation cleavage wraps around the porphyroblasts. These different textures indicate maximum metamorphic conditions occurred during, or after, the formation of the S1 foliation, and before the formation of the S2 cleavage.

Table 3. Metamorphic assemblages in Vampire-Narchilla unit, Coal River map area. Coordinates are UTM zone 9N, NAD83 datum.

Station	UTM East (m)	UTM North (m)	Mineral Assemblage
09LP001	570 845	6 706 095	quartz-muscovite
09LP050	583 278	6 742 306	quartz-muscovite-chlorite-biotite
09LP051	582 745	6 742 319	quartz-muscovite-biotite
09LP055	580 956	6 743 751	quartz-muscovite-biotite
09RAS048	591 454	6 758 267	quartz-muscovite-biotite-garnet-staurolite
09RAS085	591 270	6 762 014	quartz-muscovite-biotite
09RAS086	590 101	6 762 277	quartz-muscovite-biotite-staurolite
09TOA009	595 171	6 714 622	quartz-plagioclase-muscovite
09TOA084	577 859	6 738 819	quartz-muscovite-chlorite-biotite-garnet-staurolite
09TOA090	580 872	6 738 795	quartz-muscovite-chlorite-biotite
09TOA098	582 139	6 742 420	quartz-feldspar-muscovite-biotite
09TOA109	577 140	6 733 039	quartz-muscovite-biotite-garnet-staurolite
09TOA110	576 299	6 733 094	quartz-chlorite-biotite-garnet-chloritoid
09TOA111	576 053	6 733 332	quartz-muscovite-chlorite-garnet-staurolite

MINERAL OCCURRENCES AND METALLOGENY

The Coal River map area offers potential for sediment-hosted base metal and intrusion-related base and precious metal mineralization. Sediment-hosted mineralization may include both sedimentary exhalative Zn-Pb±Ba in black shale (SEDEX) and Irish-type or MVT Zn-Pb replacements in carbonate rock. Intrusion-related mineralization may include massive sulphide mantos, tungsten and base metal skarns, precious metal veins, sheeted veins, and replacement deposits.

The basinal facies within both Selwyn basin and Kechika trough are characterized by stratiform mineral deposits. In the latter, 200 km south of Coal River map area, stratiform barite-lead-zinc deposits are hosted in sub-basins along the platform margin within Middle Ordovician, Lower Silurian and Upper Devonian strata (MacIntyre, 1992), including the Cirque, Fluke, and Elf deposits in the Gataga district (MacIntyre, 1992). In the former, stratiform barite-lead-zinc and barite deposits are hosted within Cambrian, Silurian, Devonian, and Mississippian carbonaceous shale (Abbott *et al.*, 1986).

The lower Paleozoic platform-to-basin transition of the Macdonald platform also hosts Mississippi Valley type (MVT) deposits, the most important is at Robb Lake (Macqueen and Thompson, 1978; Paradis *et al.*, 1999).

The recognition of nine additional plutons in the Coal River map area results in more exploration target areas for intrusion-related, base and precious metal mineralization.

The following mineral occurrence descriptions are summarized from government-maintained databases (Yukon MINFILE and NWT NORMIN; Fig. 64) with interpretation and clarification in light of recent fieldwork. MINFILE occurrences with no apparent economic significance are excluded from the following discussion. The 2009 mapping refined the geological setting of some of these occurrences and identified four new potential exploration targets.

Sedimentary exhalative (SEDEX) mineralization

Although the Road River Group has previously been considered a favourable host for SEDEX mineralization in the Coal River map area, no SEDEX occurrences have yet been found. A few MINFILE occurrences record elevated zinc concentrations, but these are considered to be typical values for much of the Road River Group and not related to SEDEX mineralization. In the eastern part of the map area the black shale is limited in extent and overlies thick sequences of Rabbitkettle and Sunblood carbonate rocks. Possibly, the carbonate prevented the formation of SEDEX deposits by reacting with expelled basinal fluids to form replacement deposits such as the MEL before they could reach the surface. More favourable environments may exist farther west along the Coal River, where the Road River Group is more extensive than previously thought and older strata are primarily siliciclastic.

Black shale of the Besa River Formation, although equivalent to the well-mineralized Devonian-Mississippian Earn Group, contains no known sedimentary exhalative sulphide deposits. This may be for the same reasons cited above for the Road River Group. Alternatively it may be because of an apparent lack of syndepositional tectonism as indicated by the absence of Devonian-Mississippian coarse siliciclastic facies and volcanism in this area.

Bedded barite is known in one locality in the Northwest Territories at the Last Mountain (NORMIN 095DNE0003) occurrence. There, finely laminated, but thick-bedded to massive barite between 3 and 10 m thick occurs in a structurally complex zone on the eastern limb of the Skinboat syncline. It has not been traced along strike due to lack of outcrop. The barite occurs close to the contact with basal quartzite of the Mattson Formation but whether it lies above or below the quartzite could not be determined due to poor exposure and cryptic structures. The Mattson Formation is Middle and

Late Mississippian in age; therefore the barite is likely to be Mississippian as well. The Tea deposit near Macmillan Pass (Dawson and Orchard, 1982) is another barite deposit of roughly equivalent age.

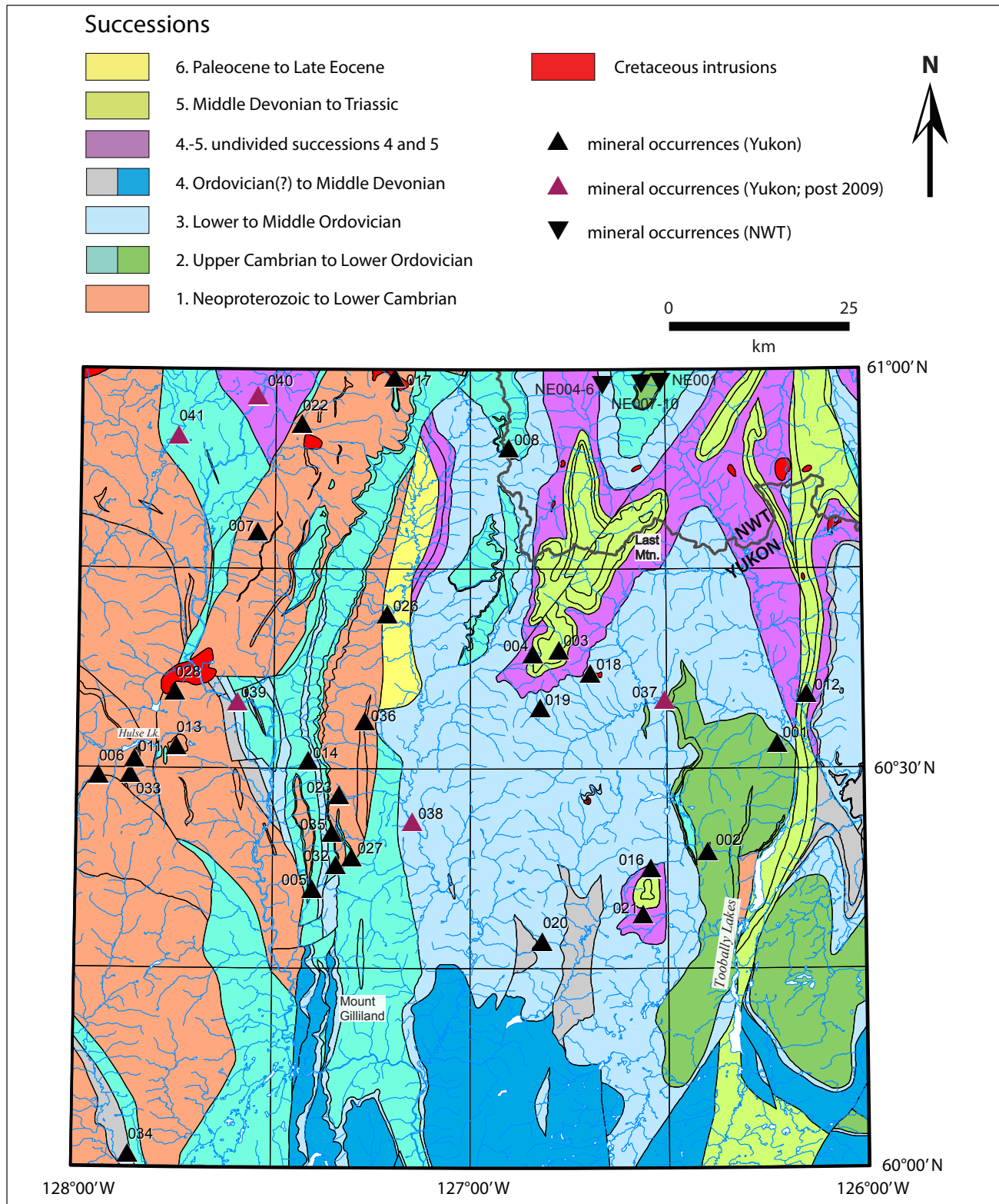


Figure 64. Mineral occurrences in Coal River map area. Numbers refer to Yukon MINFILE for 95D and NORMIN database (2010), and are referred to in the text.

Carbonate replacement (MVT, Irish type) mineralization

Four epigenetic, stratabound zinc±lead±barite deposits and showings (Yukon MINFILE 095D005, 095D027, 095D032 and 095D035) are located in NTS 95D/6. Each of these mineral occurrences is now considered to be hosted in massive, fine-grained limestone of the Otter Creek Formation at the contact with the overlying argillaceous limestone of the Rabbitkettle Formation. The following summary is condensed from a comprehensive description and discussion of the origin of these deposits by Pigage (2008).

The Mel (Yukon MINFILE 095D005) is the largest of these deposits with a published, pre-NI43-101, drill-indicated reserve of 6.78 MT (million tonnes) grading 54.69% barite, 7.10% Zn, and 2.03% Pb (King, 1995). It is a stratabound lens about 800 m long and up to 22 m thick near its centre, and it remains open at depth. It consists of very coarse grained, white barite and reddish-brown, coarse-grained sphalerite with late, interstitial galena occurring along fractures and as selvages.

The Mel-East showing (Yukon MINFILE 095D027) is poorly exposed for a strike length of 170 m. True width is unknown but may exceed 3 m. Mineralization consists of disseminated smithsonite blebs ranging from less than 1 mm to 20 mm in size that are associated with dolomitization and silicification of the massive limestone over a width of 10 m.

The Jeri occurrence (Yukon MINFILE 095D032), consists of smithsonite in silicified dolostone at three localities. The smithsonite forms veins and discontinuous masses up to 1 m thick with the total width of mineralization exceeding 11 m.

The Jeri North occurrence (Yukon MINFILE 095D035) is located north of the Jeri zone along strike. Mineralization consists of coarse brown sphalerite and quartz infilling fractures in strongly silicified limestone.

The Mel and nearby deposits are probably Devonian-Mississippian in age on the basis of lead isotope data (Godwin and Sinclair, 1982; Godwin *et al.*, 1988), and best classified as epigenetic Irish-type replacement or MVT deposits (Pigage, 2008). Similar deposits may occur elsewhere in the Otter Creek Formation or other carbonate units. Limestone of unit SDc is commonly replaced by hydrothermal dolomite. Modern sinkholes and karst features demonstrate the susceptibility of unit SDc to dissolution and cavity formation, making it a possible candidate for MVT or Irish type mineralization. One possible target for Mel-type mineralization is the Watsit (Yukon MINFILE 095D014) occurrence, located on strike to the north of the Mel. There, a zinc soil geochemical anomaly up to 4500 ppm is located above limestone of the Rabbitkettle Formation near the contact with dolostone of the Sunblood Formation (Yukon MINFILE).

Volcanic-related mineralization

The Grant (Normin 095DNE0001), Chuck (Normin 095DNE0009), Gabe (Yukon MINFILE 095D008), and Gusty (Yukon MINFILE 095D002) copper occurrences are in Cambrian and Ordovician mafic volcanic rocks. All consist of scattered disseminations of chalcopyrite±bornite and malachite. None of these are known to have significant size or potential.

Intrusion-related mineralization

The McMillan massive sulphide replacement deposit (Yukon MINFILE 095D006) consists of two zones. The Main Zone contains pre-NI 43-101 reserves of 1.1 MT grading 8.3% Zn, 4.1%Pb, and 62g/t Ag, and the South Zone contains 0.4 MT grading 9.3%Pb, 1.7% Zn, and 214g/t Ag (Vaillancourt, 1983). The Main Zone forms a gently east dipping tabular body in quartzite and massive grey limestone.

Nearby maroon and green phyllite are associated with the quartzite and limestone, and the assemblage has herein been assigned to the Vampire-Narchilla unit. Textural relationships clearly show that mineralization is discordant to bedding. Lead isotopes (Godwin, *et al.*, 1988) indicate a Cretaceous age for mineralization.

The Hyland Gold mineralization (Yukon MINFILE 095D011) is a low-grade, oxidized, fault-controlled Au deposit. Quartzite, phyllite and limestone host rocks resemble the host rocks to the McMillan deposit 5 km to the west and are assigned to the Vampire-Narchilla unit. A NI43-101 inferred resource of 12.5 MT grading 0.9 g/t Au and 5.6 g/t Ag (using a 0.6 g/t Au equivalent cutoff; Armitage and Gray, 2012) has been identified in the Main Zone. Mineralization is controlled primarily by north-trending faults, but occurs in four settings: 1) breccia zones mainly in quartzite; 2) north-trending fault zones; 3) limestone replacement bodies up to 40 m thick containing pyrite, pyrrhotite, arsenopyrite and siderite; and 4) narrow quartz veins containing erratic pods of massive jamesonite.

The Cuz gold occurrence (Yukon MINFILE 095D033) is about 4 km south of the Hyland Gold deposit in a quartzite and granular sandstone-dominated assemblage that is herein assigned to the Yusezyu Formation of the Hyland Group. The mineralized zone is not well defined and consists primarily of float. Two types of mineralization have been recognized: 1) grey chalcedonic quartz veins containing fine-grained arsenopyrite in brecciated and altered host rock and 2) silicified and leached quartzite and conglomerate. Results from assays of specimens of Type 1 are as high as 9.0 g/t while Type 2 are as high as 3.7 g/t (Carne, 1996).

Six kilometres east of the Hyland Gold deposit, stratabound disseminations and veinlets of sphalerite replace coarse-grained marble and staurolite-chlorite schist in the Hulse (Yukon MINFILE 095D013) occurrence. Channel sampling results returned up to 0.85% Zn, 0.15% Pb and 2.7 g/t Ag over 0.9 to 5.5 m widths (Stockwell, 1975).

The McMillan, Hyland Gold, Cuz and Hulse occurrences represent different styles of epigenetic mineralization typically associated with granitic intrusions, suggesting that they are related to one or more intrusions occurring at depth. Alteration is widespread between the McMillan and Hyland deposits; high temperature metamorphism is only seen at the Hulse. There is no pronounced magnetic anomaly in the area; therefore the hypothetical pluton would have a low magnetic susceptibility, like the Gabe pluton located 10 km to the north-northeast. Alternatively, the Hyland and Cuz occurrences might be considered 'orogenic' and related to a large, deep-seated fault system (Hart and Lewis, 2006).

The Chuck (Normin Occurrences 095NE0007, 8 and 9) gold occurrence consists of east-trending quartz veins 4-10 cm wide in volcanic and carbonate rocks with low grades of gold and arsenic. Silt samples from a creek draining the area returned values greater than 500 ppb gold. Float in the creek included skarn fragments and subangular vein quartz up to 50 cm across which returned values up to 50 ppb Au and 212 ppb As (Vulimiri, 1986). A strong aeromagnetic anomaly coincides with the occurrence. The SITE 1,2,3 placer gold occurrence (Normin 095DNE0004, 5 and 6) is probably derived from it. The style of mineralization and association with a positive aeromagnetic anomaly suggests the Chuck occurrences are associated with a buried intrusion. Placer and lode gold occurrences are associated with the Macleod and Big Charlie plutons located 8 and 25 km respectively to the north (Rasmussen *et al.*, 2007).

The Herpes (Yukon MINFILE 095D022) and Oudder (Yukon MINFILE 095D018) exploration targets record anomalous values of scheelite in stream sediment and soil respectively near poorly exposed intrusions. No associated bedrock occurrences are known.

The Toobally (Yukon MINFILE 095D001) occurrence is a large alteration zone exposed along a north-trending creek. Sandstone of the Crow Formation is pervasively altered to white clay. A rusty, vertical,

east-trending limonite zone is located near the centre of the alteration zone. Early work reported anomalous lead values from the limonite. An assay from a sample of limonite taken in 2009 returned anomalous values for Pb (38 ppm), Zn (218 ppm), Ni (95 ppm), Co (90 ppm), Mn (>10000 ppm), Fe (33.2%) and As (185 ppm). An RGS sample and a silt sample taken in 1999 from the mouth of the creek contained no anomalous values, but they may not have been representative of the creek drainage because they were located well into the valley of the Beaver River. No aeromagnetic anomaly is associated with the alteration, but the most likely explanation for it is a buried intrusion.

New exploration targets

The localities described below arose from field work in 2007, 2009 and 2010.

Gusty occurrence (Yukon MINFILE 095D037)

An extensive alteration zone and colour anomaly in the Sunblood Formation is located in a small creek draining into the Beaver River. Dolostone is completely decalcified and disaggregated to sand. No anomalous values were obtained from geochemical analysis of the material or from a silt sample from the creek. The alteration zone coincides with a small aeromagnetic anomaly.

Blood occurrence (Yukon MINFILE 095D038)

Highly fractured dolostone of the Sunblood Formation exposed on the banks of the Rock River contains veins and replacement lenses of fine-grained nodular pyrite.

Ferricrete occurrence (Yukon MINFILE 095D039)

On the banks of the Coal River, ferricrete is draped over highly fractured dolostone of the Sunblood Formation along an inferred small fault zone.

Argil occurrence (Yukon MINFILE 095D040)

On the banks of the upper Coal River, a small outcrop of shattered cherty olive green argillite tentatively assigned to the Road River Group contains breccia zones cemented by fine-grained pyrite and manganese stained fractures. An assay of pyrite breccia returned anomalous values for Mo (8.57 ppm), Cu (110.6 ppm), Ni (198.4 ppm), Mn (>10000 ppm) and Fe (24.35%).

Toe-in occurrence (Yukon MINFILE 095D041)

A small outcrop on the banks of the West Coal River consists of fine grained, altered biotite granodiorite (Cretaceous?) intruding rusty-weathering pyritic, cherty hornfelsed sediment assigned to the Rabbitkettle Formation. Skarn and granodiorite coincide with a regional magnetic high.

HYDROCARBON POTENTIAL

Oil and Gas potential

The Kotaneelee gas field in southeast Yukon is the only producing gas field in Yukon. Gas in the Kotaneelee field is located in stratigraphic traps related to karsting, diagenetic dolomitization and subsequent burial of Devonian carbonate rocks (Morrow *et al.*, 1990). Similar stratigraphy exists at

surface in the southern part of the Coal River map area. Carbonaceous shale and limestone in the Road River Group and Besa River Formation are possible hydrocarbon source rocks for conventional gas or oil reservoirs.

Carbonaceous silty shale and limestone from surface outcrops were collected and tested at the Geological Survey of Canada Organic Geochemistry Laboratory in Calgary for potential as hydrocarbon source rocks using Rock-Eval/TOC pyrolysis. The Rock-Eval 6 instrument provides information on type, maturity and quantity of organic matter present in the sample (Espitalié *et al.*, 1977). Appendix D presents results for the analyses; operating conditions during analysis are described in Pigage (2009).

All analyzed samples are from the Road River Group and/or Besa River Formation. Kirk Osadetz (GSC Calgary, personal communication 2009) kindly provided the following summary. Samples 09LP039, 09LP074, and 09LP062 have insufficient TOC to infer anything other than a lack of source rock potential. Samples 09CYA010, 09RAS106, 09LP093 and 09LP077 are overmature source rocks with S1 and S2 values below 0.2 mg/gm. The low S2 values mean the results may not be meaningful (Peters, 1986). Sample 09LP058 was flagged as being anomalous with an unusual low Tmax value. It was suggested that this sample was possibly contaminated by an organic fluid. Sample 10TOA035 is from the formation in the same general geographic area. Analytical results for 10TOA035 indicate an overmature source rock with low S1 and S2 values.

Organic-rich rocks in the Coal River map area have been subjected to temperatures which have essentially destroyed their capability of generating oil or gas locally. Any conventional hydrocarbon reservoir in the Coal River area would have to form through extensive lateral migration into the map area from a source area which has not been subjected to these higher temperatures. It is inferred that conventional reservoir potential in the map area is very limited.

Several of the samples analysed with rock-eval contain several percent total organic carbon. Although overmature, the samples could potentially have generated gas which could still be present if the formation was impermeable to gas migration. The possibility of a tight shale unconventional gas resource has not been tested in the Coal River area.

Coal potential

The Eocene Rock River basin in the north-central Coal River area contains a 5 m-thick outcrop of lignite coal along a tributary of the Rock River. Five diamond drill holes were completed in 1981 by Sulpetro Minerals Ltd. to test the regional extent of the coal seams (Wright and Miller, 1986). Significant near-surface coal was intersected in two of the holes. The coal ranges from lignite A to sub-bituminous C rank. Thermal content was reported as 6645 Btu/lb with 17.6% ash and 1.09% sulphur at equilibrium moisture of 26.3%. Maximum depth penetrated by drilling was 162 m. In contrast, the depth of Tertiary sediment based on gravity data was interpreted as being up to 1100 m (Wright and Miller, 1986), thus indicating the potential for coal seams at greater depth.

SUMMARY

Bedrock geological mapping in 2009-2010 succeeded in redefining the understanding of the geologic history and mineral potential of southeastern Yukon. The area contains six successions of sedimentary rocks, ranging from Proterozoic to Eocene in age with a composite thickness exceeding 14 000 m. These strata record the evolution of the Laurentia passive continental margin, lateral facies changes associated with the development of Selwyn basin, and subsequent deformation and plutonism. Figure 65 schematically portrays the stratigraphic history, igneous history, tectonic evolution and setting of mineral occurrences in the region.

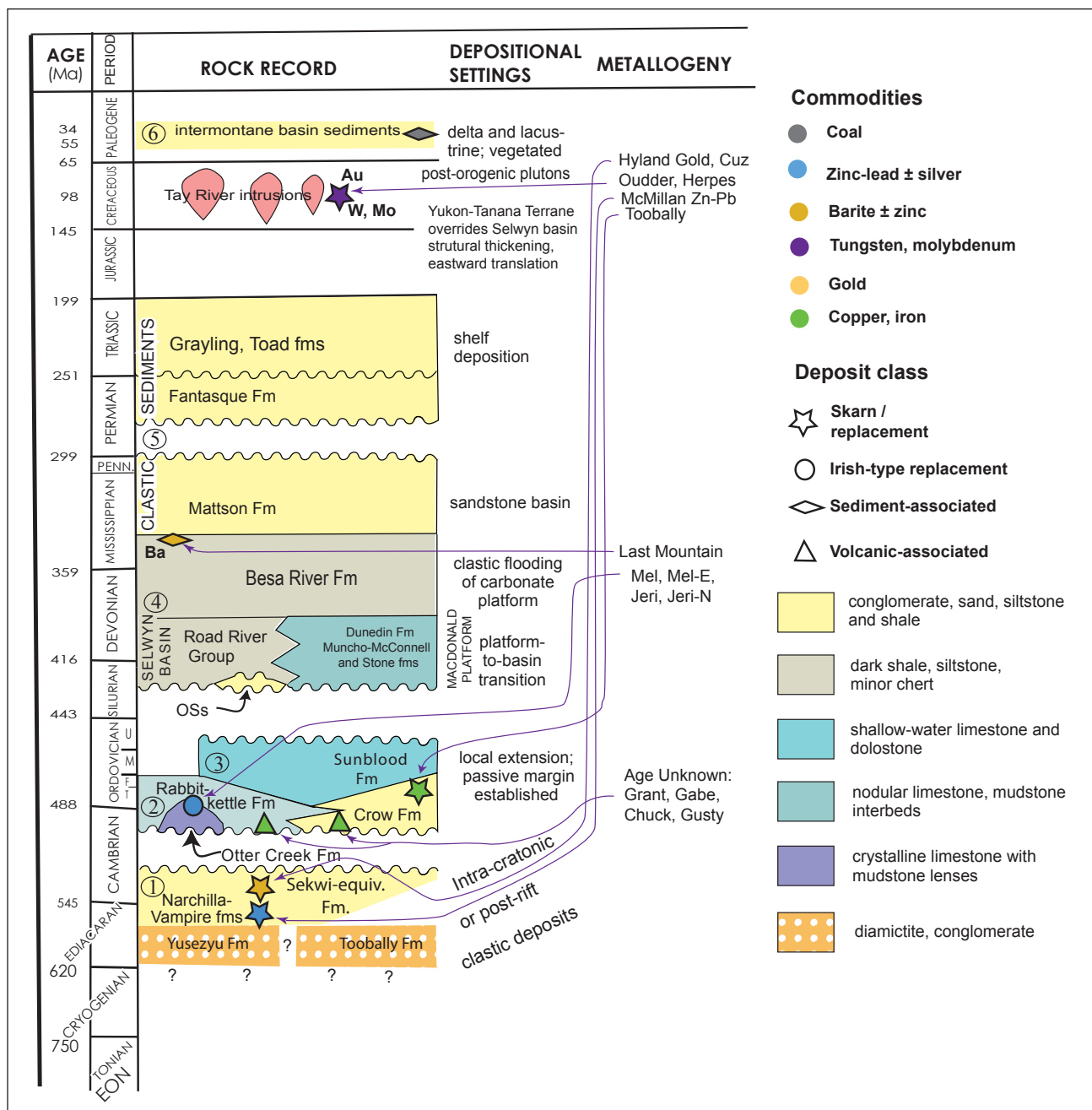


Figure 65. Summary of stratigraphic history and tectonic evolution in Coal River map area, and the geological relationship to mineral occurrences.

The earliest exposed deposition consists of Neoproterozoic to early Cambrian, dominantly siliciclastic sedimentary units documenting the initiation of rifting of Rodinia to form the western passive continental margin of Laurentia.

Deposition in late Cambrian to Middle Ordovician chronicles the initiation of an extensive continental carbonate platform along the western margin of Laurentia. The Sunblood Formation first developed near upper Toobally Lake in earliest Ordovician time and expanded laterally. Rabbitkettle Formation, coeval with both Crow and lower Sunblood formations, represents the gentle ramp-slope deposition of carbonate debris away from the Sunblood carbonate platform. The thick but aerially restricted siliciclastic Crow Formation defines a delta complex fed by a large river draining the east and northeast.

The Silurian through Middle Devonian carbonate platform lacks a ramp facies; it is an abrupt northward change to carbonaceous, fine-grained sediment of the locally anoxic deeper water of Selwyn basin. In Middle Devonian through Mississippian time the platform was flooded and deposition of carbonaceous sediment extended eastward. A mid-Mississippian regression then led to sandstone (Mattson Formation) as a westward-prograding delta.

Thin Permian and Triassic successions record marine deposition in a shallow water, shelf setting. These successions are separated from other units by hiatuses.

Jurassic and Early Cretaceous strata are absent from the Coal River map area. This time interval coincides with the Cordilleran orogeny (Nelson *et al.*, 2013), manifested by deformation and thickening of the sedimentary succession through folding and thrust faulting. Cretaceous silt and sand depositional basins located immediately east of the map area record development of foreland basins associated with deformation and uplift in the hinterland (including Coal River map area). Deformation was accompanied by low-grade to medium-grade regional metamorphism, as well as exhumation and erosion of earlier sedimentary formations. At the presently exposed structural level, deformation had essentially ceased before the intrusion of only slightly deformed mid-Cretaceous granitic stocks.

Farther east in Northwest Territories and Alberta, thrust faulting continued into the Paleocene. The entire exposed Coal River stratigraphy is presumed to have passively moved eastward along a basal detachment located at an unknown deeper structural level. Consequently the exposed early Paleozoic alkali basalt and the Cretaceous intrusions are structurally separated from their deep sources of partial melting.

Extension along south-trending, post-orogenic, normal faults locally preserved Eocene fluvial sediment with coal horizons (Rock River basin sediment). Intermontane basins in the Cordillera formed between major thrust sheets and along dextral strike-slip faults. These latter may be a response to re-orientation of relative movement between the Pacific and North American tectonic plates.

Mineral occurrences include Irish-type or MVT Zn-Pb replacements in carbonate rocks, massive sulphide mantos, tungsten and base metal skarns, and precious metal, intrusion-related veins and replacement deposits. Potential exists for sedimentary exhalative Zn-Pb $\pm$ Ba deposits, although none have been noted to date.

Carbonaceous sedimentary successions are overmature for source hydrocarbon potential. Conventional oil or gas reservoirs are probably not present. Potential does exist for unconventional tight shale gas resource. Coal resources have been identified in the late Eocene Rock River basin sediments.

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APPENDIX A - PALEONTOLOGY

Table A1. Fossil collections, arranged by formation.

Paleontology - NTS 95D				
Map ID	GSC ID	Fossil Type	Age Range	Reference
Unit Cs				
1	73840, 68958, 68957, 68956, 68955	trilobite; archeocyathid	Early Cambrian (Series 2; Stage 3)	Handfield (1971)
2		trilobite	Early Cambrian (Series 2; Stage 4)	Bohach, L. (2009 pers comm)
Unit COoc				
3	C-092627	trilobite; brachiopod	Cambrian (Furongian) - Early Ordovician (Tremadocian)	Miller and Wright (1986); Norford (1984)
4	C-061554	trilobite; brachiopod	Cambrian (Furongian) - Early Ordovician (Tremadocian)	Miller and Wright (1986); Norford (1984)
5	C-535898	conodont	late Early Ordovician (Floian) - Late Ordovician (Sandbian)	Nowlan (2010c)
Unit COc				
6	C-417157	conodont	Early Ordovician (Tremadocian)	Pigage (2009); Pyle (2004)
7	C-535867	conodont	Middle Ordovician (Dapingian)	Orchard (2010); Nowlan (2010a)
Unit COR				
8	O-081023	brachiopod; trilobite	Early Ordovician (Tremadocian - Floian)	Norford (1968a)
9	O-081025	brachiopod; trilobite	Early Ordovician (late Tremadocian - early Floian)	Gabrielse and Blusson (1969)
10	O-081026	trilobite	Early Ordovician (late Tremadocian - early Floian)	Norford (1968a)
11	V-000005	conodont	Early Ordovician (early Tremadocian)	Nowlan (2010b)
12	C-535864	conodont	Early Ordovician (late Floian)	Nowlan (2010a)
13	V-000386	conodont	Early Ordovician	Orchard (2009b)
14	C-535939	conodont	Early Ordovician (early Tremadocian)	Nowlan (2010c)
15	C-535940	conodont	Early Ordovician (early to middle Floian)	Nowlan (2010c)
16	C-535951	conodont	Early Ordovician (Tremadocian)	Nowlan (2010c)
17	C-535953	conodont	Early Ordovician (late Tremadocian - Floian)	Nowlan (2010c)
18	C-535881	conodont	Early Ordovician (late Tremadocian - Floian)	Orchard (2010); Nowlan (2010a)
19	C-535963	conodont	Early Ordovician (late Tremadocian - early Floian)	Nowlan (2010c)
20	C-535964	conodont	Early Ordovician (late Floian)	Orchard (2010); Nowlan (2010c)
21	C-535966	conodont	Early Ordovician (late Tremadocian - early Floian)	Nowlan (2010c)

APPENDIX A - PALEONTOLOGY, continued

Table A1, continued. Fossil collections, arranged by formation.

Paleontology - NTS 95D				
Map ID	GSC ID	Fossil Type	Age Range	Reference
Unit OSu				
22	O-079251	gastropod	Late Ordovician (late Sandbian - late Katian)	Gabrielse and Blusson (1969)
23	O-079252	gastropod	Middle Ordovician (Dapingian) - Late Ordovician (Sandbian)	Gabrielse and Blusson (1969)
24	O-079253	brachiopod; gastropod	Early Ordovician (Floian) - Late Ordovician (early Katian)	Gabrielse and Blusson (1969)
25	O-079254	gastropod; brachiopod	Late Ordovician (late Sandbian - early Katian)	Gabrielse and Blusson (1969)
26	O-079153	trilobite; brachiopod	Middle Ordovician (Dapingian) - Late Ordovician (Sandbian)	Gabrielse and Blusson (1969)
27	O-079246	brachiopod	Cambrian (Furongian) - Devonian	Norford (1968b)
28	O-079247	brachiopod	Ordovician - Present	Norford (1968b)
29	C-417165	conodont	Early Ordovician (middle Tremadocian)	Pigage (2009); Pyle (2004)
30	C-417159	conodont	Middle Ordovician (Darriwilian)	Pigage (2009); Pyle (2004)
31	C-417166	conodont	Early Ordovician (Floian) - Middle Ordovician (Darriwilian)	Pigage (2009); Pyle (2004)
32	C-417167	conodont	Early Ordovician (Floian) - Middle Ordovician (Dapingian)	Pigage (2009); Pyle (2004)
33	C-417163	conodont	Late Ordovician (Sandbian)	Pigage (2009); Pyle (2004)
34	C-307428	conodont	Middle Ordovician (Dapingian)	Nowlan (2008)
35	C-307626	conodont	Ordovician	Nowlan (2008)
36	C-307629	conodont	Middle Ordovician (Dapingian)	Nowlan (2008)
37	C-307630	conodont	Early Ordovician - Middle Ordovician (Dapingian)	Nowlan (2008)
38	C-307631	conodont	Middle Ordovician (Darriwilian)	Nowlan (2008)
39	C-307632	conodont	Middle Ordovician (Dapingian)	Nowlan (2008)
40	V-000007	conodont	Middle Ordovician - Middle Devonian	Nowlan (2010b)
41	V-000387	conodont	Early Ordovician	Orchard (2009b)
42	C-535932	conodont	earliest Middle Ordovician (early Dapingian)	Nowlan (2010c)
43	C-535866	conodont	Middle Ordovician (Dapingian)	Orchard (2010); Nowlan (2010a)
44	C-535934	conodont	late Early Ordovician (Floian)	Nowlan (2010c)
45	C-535869	conodont	Middle Ordovician (Dapingian)	Orchard (2010); Nowlan (2010a)
46	C-535870	conodont	Middle Ordovician (Dapingian - Darriwilian)	Orchard (2010); Nowlan (2010a)

APPENDIX A - PALEONTOLOGY, continued

Table A1, continued. Fossil collections, arranged by formation.

Paleontology - NTS 95D				
Map ID	GSC ID	Fossil Type	Age Range	Reference
Unit OSu (continued)				
47	C-535878	conodont	Early Ordovician (Tremadocian - Floian)	Orchard (2010); Nowlan (2010a)
48	C-535942	conodont	Early Ordovician (Tremadocian - Floian)	Nowlan (2010c)
49	C-535943	conodont	Early Ordovician (late Tremadocian - Floian)	Nowlan (2010c)
50	C-535945	conodont	Early Ordovician (late Tremadocian - early Floian)	Nowlan (2010c)
51	C-535949	conodont	late Early Ordovician (Floian)	Nowlan (2010c)
52	C-535872	conodont	Early Ordovician - Middle Ordovician	Orchard (2010); Nowlan (2010a)
53	C-535874	conodont	Middle Ordovician (Dapingian)	Orchard (2010); Nowlan (2010a)
54	C-535959	conodont	late Early Ordovician (late Floian)	Nowlan (2010c)
55	C-535883	conodont	Early Ordovician - early Middle Ordovician	Orchard (2010); Nowlan (2010a)
56	C-535888	conodont	latest Early Ordovician (latest Floian)	Nowlan (2010c)
57	C-535960	conodont	Early Ordovician (late Tremadocian - early Floian)	Nowlan (2010c)
58	C-535890	conodont	latest Early Ordovician (latest Floian)	Nowlan (2010c)
59	C-535961	conodont	earliest Early Ordovician (Tremadocian)	Nowlan (2010c)
60	C-535892	conodont	latest Early Ordovician (late Floian)	Nowlan (2010c)
61	C-535893	conodont	late Early Ordovician (middle - latest Floian)	Nowlan (2010c)
62	C-535894	conodont	Early Ordovician (Floian)	Nowlan (2010c)
63	C-535901	conodont	late Middle Ordovician (middle Darriwilian) - early Late Ordovician (early Sandbian)	Nowlan (2010c)
64	C-535904	conodont	earliest Middle Ordovician (early Dapingian)	Nowlan (2010c)
65	C-535908	conodont	Early Ordovician (Tremadocian)	Nowlan (2010c)
66	C-535909	conodont	Early Ordovician (middle to late Floian)	Nowlan (2010c)
67	C-535910	conodont	Early Ordovician (Floian) - Late Ordovician (Sandbian)	Nowlan (2010c)
Unit SDc				
68	O-079240	coral	Silurian	Gabrielse and Blusson (1969)
69	O-079241	coral	Middle Ordovician - Permian	Norford (1968b)
70	V-000008	conodont	Early Devonian?	Orchard (2009a)

APPENDIX A - PALEONTOLOGY, continued

Table A1, continued. Fossil collections, arranged by formation.

Paleontology - NTS 95D				
Map ID	GSC ID	Fossil Type	Age Range	Reference
Unit SDc (continued)				
71	C-537288	conodont	Middle Ordovician - Middle Devonian	Orchard (2010); McCracken (2010a)
72	C-535948	conodont	Middle Ordovician - Middle Devonian	McCracken (2010b)
73	C-535891	conodont	Early Devonian (Lochkovian - Emsian)	McCracken (2010b)
74	C-535906	conodont	Early Devonian (early to late Emsian)	McCracken (2010b)
75	C-535907	conodont	Silurian	Nowlan (2010c)
76		2-hole crinoid	Early Devonian (Emsian) - Middle Devonian (Eifelian)	visual identification
77		2-hole crinoid	Early Devonian (Emsian) - Middle Devonian (Eifelian)	visual identification
Unit SDRR				
78	O-079161	graptolite	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
79	O-081024	tentaculitid; graptolite	Early Devonian	Gabrielse and Blusson (1969)
80	O-081032	coral	Late Ordovician - Silurian (Pridoli)	Gabrielse and Blusson (1969)
81	O-079154	graptolite	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
82	O-081028	graptolite; tentaculitid	Early Devonian	Gabrielse and Blusson (1969)
83	O-081027	graptolite; tentaculitid	Early Devonian (early Emsian)	Gabrielse and Blusson (1969)
84	O-079155	graptolite	Early Devonian (Emsian)	Gabrielse and Blusson (1969); Norford (1967)
85	O-079243	graptolite	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
86	O-079244	graptolite; brachiopod	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
87	O-079245	graptolite; brachiopod	Silurian	Gabrielse and Blusson (1969); Norford (1967)
88	O-079242	graptolite	Early Devonian	Gabrielse and Blusson (1969); Norford (1967)
89	O-079249	graptolite	Early Devonian	Gabrielse and Blusson (1969); Norford (1967)
90	C-535933	conodont	Early Devonian (late Emsian) - latest Middle Devonian	McCracken (2010b)
91	C-535861	conodont	Silurian (late Pridoli) - Early Devonian (early Lockhovian)	Orchard (2010); McCracken (2010a)
92		graptolite		visual identification
93		graptolite		visual identification

APPENDIX A - PALEONTOLOGY, continued

Table A1, continued. Fossil collections, arranged by formation.

Paleontology - NTS 95D				
Map ID	GSC ID	Fossil Type	Age Range	Reference
94		graptolite		visual identification
Unit SMRB				
95	O-079151	graptolite	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
96	O-079152	graptolite	Silurian (late Llandovery - Telychian)	Gabrielse and Blusson (1969); Norford (1967)
97	C-535902	conodont	Middle Devonian	McCracken (2010b)
98	C-535903	conodont	Middle Devonian	McCracken (2010b)
99	C-535876	conodont	Middle Devonian (Eifelian - Givetian)	McCracken (2010a)
100	C-535956	conodont	Middle Devonian (latest Eifelian - Givetian)	McCracken (2010b)
101		2-hole crinoid	Early Devonian (Emsian) - Middle Devonian (Eifelian)	visual identification
Unit PF				
102	C-417156	conodont	Permian	Pigage (2009); Pyle (2004)
103	C-535965	conodont	Pennsylvanian - Early Permian, possibly Late Permian	McCracken (2010b)
Unit TRGT				
104	C-404735	palynology	Early Triassic	Pigage (2009); Utting (2006)
Unit ERRS (all samples taken from diamond drill holes)				
105	C-082595	palynology	Late Eocene (Priabonian)	Long and Sweet (1994)
106	C-082596	palynology	Late Eocene (Priabonian)	Long and Sweet (1994)
107	C-082597	palynology	Late Eocene (Priabonian)	Long and Sweet (1994); Sweet, 1983

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APPENDIX B - DETRITAL ZIRCON ANALYSES

Table B1. Detrital zircon sample locations.

Sample ID	Field Station	Unit	UTM East	UTM North	Longitude	Latitude	Analytical Laboratory
09LP014-1	09LP014	PY	569 497	6 695 908	-127.7390	60.3936	Isotope Geology Laboratory, Boise State University
09TOA098	09TOA098	PEVN	582 139	6 742 420	-127.4903	60.8087	Isotope Geology Laboratory, Boise State University
09TOA094	09TOA094	PEVN	593 057	6 724 637	-127.2982	60.6467	TERRA, Memorial University
09TOA095	09TOA095	CS	590 771	6 723 883	-127.3403	60.6404	Isotope Geology Laboratory, Boise State University
09TOA096	09TOA096	CS	590 449	6 724 166	-127.3461	60.6430	TERRA, Memorial University
09LP093-1	09LP093	OSs	658 912	6 734 865	-126.0870	60.7114	Isotope Geology Laboratory, Boise State University
09LP090-2	09LP090	MM	634 909	6 692 950	-126.5550	60.3505	Isotope Geology Laboratory, Boise State University

All coordinates are NAD83 datum, zone 9.

LA-ICPMS Methods, Isotope Geology Laboratory, Boise State University

Zircon grains were separated from rocks using standard techniques and mounted in epoxy and polished until the centres of the grains were exposed. Cathodoluminescence (CL) images were obtained with a JEOL JSM-1300 scanning electron microscope and Gatan MiniCL. Zircon was analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) using a ThermoElectron X-Series II quadrupole ICPMS and New Wave Research UP-213 Nd:YAG UV (213 nm) laser ablation system. In-house analytical protocols, standard materials, and data reduction software were used for acquisition and calibration of U-Pb dates and a suite of high field strength elements (HFSE) and rare earth elements (REE). Zircon was ablated with a laser spot width of 25 μm using fluence and pulse rates of 5 J/cm² and 10 Hz, respectively, during a 45 second analysis (15 sec gas blank, 30 sec ablation) that excavated a pit ~25 μm deep. Ablated material was carried by a 1.2 L/min He gas stream to the nebulizer flow of the plasma. Dwell times were 5 ms for Si and Zr; 100 ms for ⁴⁹Ti and ²⁰⁷Pb, 40 ms for ²³⁸U, ²³²Th, ²⁰²Hg, ²⁰⁴Pb, ²⁰⁶Pb and ²⁰⁸Pb isotopes; and 10 ms for all other HFSE and REE. Background count rates for each analyte were obtained prior to each spot analysis and subtracted from the raw count rate for each analyte. Ablation pits that appear to have intersected glass or mineral inclusions were identified by time-resolved data that show large fluctuations in Ti or P, and were rejected. Similarly, pits that appear contaminated by common Pb were rejected based on an intensity of mass 204 above baseline. For concentration calculations, background-subtracted count rates for each analyte were internally normalized to ²⁹Si and calibrated with respect to NIST SRM-610 and -612 glasses as the primary standards. Temperature was calculated from the Ti-in-zircon thermometer (Watson et al., 2006). Because there are no constraints on the activity of TiO₂ in the source rocks, an average value in crustal rocks of 0.6 was used.

For U-Pb and ²⁰⁷Pb/²⁰⁶Pb dates, instrumental fractionation of the background-subtracted ratios was corrected and dates were calibrated with respect to interspersed measurements of the Plesovice zircon

standard (Sláma et al., 2008). Two analyses of Plesovice were done for every 10 analyses of unknown zircon; a polynomial fit to the standard analyses yields each sample-specific fractionation factor. Signals at mass 204 were indistinguishable from zero following subtraction of mercury backgrounds measured during the gas blank (<1000 cps ^{202}Hg), and thus dates are reported without common Pb correction. Radiogenic isotope ratio and age error propagation for all analyses includes uncertainty contributions from counting statistics and background subtraction. For spot analyses that are individually interpreted (e.g., detrital zircon analyses), the uncertainty from the standard calibration is propagated into the error on each date. This uncertainty is the standard deviation of the time-varying U/Pb fractionation factor and the standard error of the mean of the time-invariant, smaller $^{207}\text{Pb}/^{206}\text{Pb}$ fractionation factor. For groups of analyses that are collectively interpreted from a weighted mean date, a weighted mean date is first calculated using Isoplot 3.0 (Ludwig, 2003) using errors on individual dates that do not include the standard calibration uncertainties, and then the standard calibration uncertainty is propagated into the error on the weighted mean date. Data were collected from samples 09LP014 and 09TOA098 in one experiment in May 2011 (experiment 1), and from samples 09LP090, 09LP093, and 09TOA095 in three experiments (experiments 2-4) in one session in July 2012. Standard calibration uncertainties for $^{207}\text{Pb}/^{206}\text{Pb}$ dates are 0.9, 0.9, 0.7, and 0.8% (2σ) for experiments 1-4, respectively. Standard calibration uncertainty for $^{206}\text{Pb}/^{238}\text{U}$ dates are 3.3, 3.3, 4.8, and 1.8% (2σ) for experiments 1-4, respectively. Age interpretations are based on $^{207}\text{Pb}/^{206}\text{Pb}$ dates for >1000 Ma zircon. These analyses are $<17\%$ discordant. The $^{206}\text{Pb}/^{238}\text{U}$ dates are used for <1000 Ma zircon. Errors on the $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{206}\text{Pb}/^{238}\text{U}$ dates from individual LA-ICPMS analyses are given at 2σ , as are the errors on the weighted mean dates.

Two zircon secondary reference materials were treated as unknowns to assess accuracy, interspersed as groups of two analyses for every 20 unknown analyses. Weighted mean dates are calculated using Isoplot 3.0 (Ludwig, 2003) from errors on individual dates that do not include the standard calibration uncertainties. However, errors on weighted mean dates include the standard calibration uncertainties within each experiment (propagated in quadrature) and are given at 2σ . FC1 zircon (1098 Ma from unpublished chemical abrasion thermal ionization mass spectrometry (CA-TIMS) data, Boise State University) yielded weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ dates of 1105 ± 15 (MSWD=1.5, $n=24$), 1098 ± 20 (MSWD=0.4, $n=4$), 1117 ± 38 (MSWD=1.2, $n=4$), and 1087 ± 21 (MSWD=1.0, $n=4$) from experiments 1-4, respectively. Weighted mean $^{206}\text{Pb}/^{238}\text{U}$ dates are 1131 ± 34 (MSWD=1.0, $n=24$), 1121 ± 37 (MSWD=0.9, $n=4$), 1124 ± 52 (MSWD=0.3, $n=4$) and 1122 ± 24 (MSWD=0.3, $n=4$) from experiments 1-4, respectively. Seiland zircon (530 Ma from unpublished CA-TIMS data, Boise State University) yielded weighted mean $^{206}\text{Pb}/^{238}\text{U}$ dates of 540 ± 19 (MSWD=1.4, $n=10$), 537 ± 25 (MSWD=1.2, $n=10$), and 534 ± 10 (MSWD=0.5, $n=10$) from experiments 2-4, respectively. These results show that accurate $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{206}\text{Pb}/^{238}\text{U}$ dates were obtained.

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LAM-ICP-MS Methods, INCO Innovation Centre, Memorial University

Analyses were completed at the INCO Innovation Centre at Memorial University, St. John's, Newfoundland. The data set was acquired through Laser Ablation Microprobe Inductively Coupled Plasma Mass Spectrometry (LAM ICP-MS). Bennett and Tubrett (2010) present a detailed description of the methodology; this section summarizes from that more complete description.

Zircon grains were extracted using standard crushing techniques, a Wilfley™ table, heavy liquids, a Frantz™ isodynamic separator, and hand-picking in ethanol under a binocular microscope. The grains were mounted in epoxy with standard reference materials and polished to expose grain cores to a 0.25 µm finish using an automated Struers Tegrasytem™ polisher.

U/Pb and Pb/Pb isotopic ratios were measured using a Finnigan ELEMENT XR double focusing magnetic sector field ICP-MS coupled to a Geolas 193 nm excimer laser. A 10 µm laser beam was rastered over the sample surface at a velocity of 10 µm/second to create a 20 µm x 20 µm to 40 µm x 40 µm square. Laser energy was set at 5J/cm² with a laser repetition rate of 10 Hz.

An internal standard tracer solution introduced during laser ablation of the solid sample was used to correct for instrumental mass bias. Data were collected on the unknown zircon grains and several reference standards. Typically 10 unknown grains were measured for every 6-8 analyses of the reference materials. During ablation U and Pb isotopes and tracer solution signals were acquired in time-resolved, peak-jumping, pulse-counting mode with one point measured per peak. Raw data were corrected for dead time of the electron multiplier and processed off line in the Excel spreadsheet program LAMdate (Košler et al., 2002). No common Pb correction was applied to the data.

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