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Lower Paleozoic stratigraphy and geology, Richardson Mountains, Yukon (with stratigraphic and paleontological appendices)

M.P. Cecile, B.S. Norford, G.S. Nowlan, and T.T. Uyeno

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Cover illustration

Photo of the middle of the Cronin Formation, section 82-CJA-03 (top of Fig. A-5), taken by M.P. Cecile along the Rock River in NTS map area 116-I/16 (base of the section is at UTM 8W, 449099E, 7403767N, NAD 83). NRCan photo 2019-737

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Lower Paleozoic stratigraphy and geology, Richardson Mountains, Yukon (with stratigraphic and paleontological appendices)

Abstract: The Richardson Trough was a rift basin on the southern margin of an ancestral Iapetus Ocean. It was part of a complex paleogeography that included at least two major rift basins on western Franklinian and northern Cordilleran continental shelves. This paleogeography included the Ogilvie Arch, Porcupine Platform, Blackstone 'supra-basin', Babbage Basin, Husky Lakes Arch, Richardson Trough, Mackenzie Arch, Lac des Bois Platform, and the White Mountains and Campbell uplifts. The Richardson Trough was the failed arm of a triple rift system that formed when an early Paleozoic Iapetus Ocean developed north of the trough. The Richardson Trough displays a classic 'steer's head' profile with two rift fill cycles. The first features late early to middle late Cambrian rifting and late late Cambrian to late Early Ordovician post-rift subsidence; the second, late Early Ordovician to early Silurian rifting and late early Silurian to early Middle Devonian post-rift subsidence. Lower Paleozoic strata exposed in the Richardson Trough range in age from middle Cambrian to early Middle Devonian and are similar to strata in their sister rift, the Misty Creek Embayment. Before this study, the stratigraphic units defined for the Richardson Trough were the Slats Creek Formation and the Road River Formation. Here, the Slats Creek Formation and a new Road River Group are recognized. In order, this group consists of the middle and/or late Cambrian to Early Ordovician Cronin Formation; the early Early Ordovician to latest early Silurian Mount Hare Formation; the early Silurian to late Silurian Tetlit Formation; and the late Silurian to early Middle Devonian Vittrekwa Formation. These Road River Group strata are unconformably overlain by the late Middle to Late Devonian Canol Formation (outcrop) and by the Early Devonian Tatsieta Formation (subsurface).

Résumé : La cuvette de Richardson consistait en un bassin de rift sur la marge sud du proto-Océan Iapétus. Il constituait l'une des entités d'une paléogéographie complexe qui comprenait au moins deux importants bassins de rift dans la partie ouest de la plate-forme continentale franklinienne et la partie nord de la plate-forme continentale de la Cordillère. Cette paléographie se distinguait, entre autres, par les entités suivantes : l'arche d'Ogilvie, la plate-forme de Porcupine, le « supra-bassin » de Blackstone, le bassin de Babbage, l'arche de Husky Lakes, la cuvette de Richardson, l'arche de Mackenzie, la plate-forme de Lac des Bois ainsi que les soulèvements de White Mountains et de Campbell. La cuvette de Richardson constituait le bras avorté d'une jonction triple d'un système de rift qui s'est formé lorsque l'Océan Iapétus du Paléozoïque précoce s'est développé au nord de la cuvette. La cuvette de Richardson affiche un profil classique en « tête de bouvillon » comprenant deux cycles de remplissage de rift. Le premier correspond au rifting de la fin du Cambrien précoce au milieu du Cambrien tardif et à la subsidence post-rift de la fin du Cambrien tardif à la fin de l'Ordovicien précoce. Le second, au rifting de la fin de l'Ordovicien précoce au Silurien précoce et à la subsidence post-rift de la fin du Silurien précoce au début du Dévonien moyen. Les strates du Paléozoïque inférieur affleurant dans la cuvette de Richardson s'étendent en âge du Cambrien moyen au début du Dévonien moyen et sont très semblables à celles de son rift frère, le rentrant de Misty Creek. Avant cette étude, la Formation de Slats Creek et la Formation de Road River étaient les seules unités stratigraphiques qui avaient été définies dans la cuvette de Richardson. Dans le présent bulletin, nous reconnaissons la Formation de Slats Creek et un nouveau Groupe de Road River. Ce groupe se compose, dans l'ordre, des formations suivantes : la Formation de Cronin (du Cambrien moyen et/ou tardif à l'Ordovicien précoce); la Formation de Mount Hare (du début de l'Ordovicien précoce à la toute fin du Silurien précoce); la Formation de Tetlit (du Silurien précoce au Silurien tardif); et la Formation de Vittrekwa (du Silurien tardif au début du Dévonien moyen). Ces strates du Groupe de Road River sont surmontées en discordance par la Formation de Canol de la fin du Dévonien moyen et du Dévonien tardif (en affleurements) et par la Formation de Tatsieta du Dévonien précoce (dans le sous-sol).

SUMMARY

The Richardson Mountains trend north from the area where the Hart, Wind, and Bonnet Plume rivers join the Peel River. From there, this narrow range of mountains extends to the Arctic Coastal Plain and Beaufort Sea. The Richardson anticlinorium dominates the southern Richardson Mountains and is the result of structural inversion of lower Paleozoic basin strata that were deposited in a north-trending rift basin. The Richardson anticlinorium has been described as a broad, gently north-plunging anticlinal structure between the northern Interior Platform on the east and the Eagle Plains fold belt on the west. The Richardson Trough is a rift basin on the southern margin of an ancestral Iapetus Ocean, and it is filled with lower Paleozoic basin facies strata overlain by small outcrops of upper Paleozoic and Cretaceous clastic rocks. It is similar in geometry, size, and sedimentary fill to its sister rift, the Misty Creek Embayment. The trough forms part of a complex paleogeography that includes several rift-related features at the junction between the western Franklinian and northern Cordilleran ancestral continental shelves. The western Franklinian paleogeographic features include the Ogilvie Arch, Porcupine Platform, Blackstone 'suprabasin', Babbage Basin, Husky Lakes Arch, Richardson Trough, Mackenzie Arch, Lac des Bois Platform, and White Mountains and Campbell uplifts.

The southern Richardson Mountains were the site of one of the earliest detailed studies of lower Paleozoic basin facies rocks in the northern Canadian Cordillera. Several published measured sections in the area were assigned detailed graptolite zonations, and the basin facies were assigned to a single formation called 'Road River'. In our study area, the pre-Canol Formation strata consist of the Slats Creek Formation and the Road River Group. The Road River Formation was recently raised to group status; this group consists of four formations, which in order of age are the middle and/or late Cambrian to Early Ordovician Cronin Formation; the early Early Ordovician to latest early Silurian Mount Hare Formation; the early to late Silurian Tetlit Formation; and the late Silurian to early Middle Devonian Vittrekwa Formation. These Road River Group strata are unconformably overlain by the Late Devonian Canol Formation in outcrop and by the Early Devonian Tatsieta Formation (Pugh, 1983) in the adjacent subsurface. The geometry and scale of the Richardson Trough are similar to those of segments of the east African rift system. The Kenya Rift, for example, compares well in geometry and scale: it is a 68 km wide graben with a length of about 120 km flanked by fault escarpments as high as 1500 m on the west

SOMMAIRE

Les monts Richardson s'étirent vers le nord depuis la région où les rivières Hart, Wind et Bonnet Plume se jettent dans la rivière Peel. De là, cette étroite chaîne montagneuse se prolonge jusqu'à la plaine côtière de l'Arctique et la mer de Beaufort. L'anticlinorium de Richardson domine la partie sud des monts Richardson. Il est le résultat d'une inversion structurale des strates de bassin du Paléozoïque inférieur qui se sont déposées dans un bassin de rift s'allongeant vers le nord. L'anticlinorium de Richardson est décrit comme une large structure anticlinale plongeant faiblement vers le nord, située entre la partie nord de la Plate-forme de l'Intérieur, à l'est, et la zone de plissement d'Eagle Plains, à l'ouest. La cuvette de Richardson consiste en un bassin de rift situé sur la marge sud du proto-Océan Iapétus. Elle est remplie de strates de faciès de bassin du Paléozoïque inférieur qui sont surmontées, dans de petits affleurements, de roches clastiques du Paléozoïque supérieur et du Crétacé. Cette cuvette est très semblable, sur les plans de la géométrie, de la taille et du remplissage sédimentaire, à son rift frère, le rentrant de Misty Creek. Elle appartient à une paléogéographie complexe qui comprend plusieurs entités apparentées à un rift à la jonction de la partie ouest de la proto–plate-forme continentale franklinienne et de la partie nord de la proto–plate-forme continentale de la Cordillère. Les entités paléogéographiques de la partie ouest de la proto–plate-forme continentale franklinienne comprennent l'arche d'Ogilvie, la plate-forme de Porcupine, le « supra-bassin » de Blackstone, le bassin de Babbage, l'arche de Husky Lakes, la cuvette de Richardson, l'arche de Mackenzie, la plate-forme de Lac des Bois ainsi que les soulèvements de White Mountains et de Campbell.

L'une des premières études approfondies des roches de faciès de bassin du Paléozoïque inférieur dans la partie nord de la Cordillère canadienne a été réalisée dans le sud des monts Richardson. Plusieurs coupes mesurées de la région ayant fait l'objet de publications présentent des zonations de graptolites détaillées et leurs faciès de bassin ont été attribués à une seule formation, dénommée « Road River ». Dans notre région d'étude, les strates antérieures à la Formation de Canol appartiennent à la Formation de Slats Creek et au Groupe de Road River. La Formation de Road River a récemment été élevée au rang de groupe, lequel est composé, dans l'ordre, des quatre formations suivantes : la Formation de Cronin (du Cambrien moyen et/ou tardif à l'Ordovicien précoce); la Formation de Mount Hare (du début de l'Ordovicien précoce à la toute fin du Silurien précoce); la Formation de Tetlit (du Silurien précoce au Silurien tardif); et la Formation de Vittrekwa (du Silurien tardif au début du Dévonien moyen). Ces strates du Groupe de Road River sont surmontées en discordance par la Formation de Canol du Dévonien tardif, en affleurements, et par la Formation de Tatsieta du Dévonien précoce, dans le sous-sol adjacent (Pugh, 1983). La géométrie et la taille de la cuvette de Richardson sont comparables à certains segments du système de rift est-africain. À ce titre, le rift du Kenya est un bon exemple : il s'agit d'un graben large de 68 km, long d'environ 120 km et bordé d'escarpements de faille pouvant atteindre 1 500 m de haut, du côté ouest, et de 200 à 500 m de haut, du côté est, et son fond s'incline du nord vers le

and 200 to 500 m on the east; and the rift floor slopes from north to south (900 m change in elevation along the rift). By comparison, the Richardson Trough is 50 to 70 km wide and 150 to 160 km long. The late middle Cambrian to early Middle Devonian sedimentary basin centre fill is about 3 km thick, compared to 1 km for correlative strata on the edge of adjoining platforms. The presence of lower Paleozoic alkalic basalts in its sister rift, the Misty Creek Embayment, and throughout the Canadian Cordillera indicates widespread extensional tectonics. In addition, basin facies sedimentary strata in the Misty Creek Embayment show strong alkali volcanic content. Two occurrences of basic clastic volcanic rocks, along with tephra and bentonite, have also been found in the Mount Hare Formation, Richardson Trough.

A cross-section through the Richardson Trough, like one through the Misty Creek Embayment, shows classic rift 'steer's head' profiles illustrating at least two rift cycles. The first cycle consists of the Slats Creek Formation, representing an initial rift fill, followed by post-rift regional subsidence represented by Franklin Mountain–Cronin deposition. The second cycle is the lower-middle Mount Hare rift fill, followed by the upper Mount Hare Aitch Member, Mount Kindle, Tetlit, Delorme, Vittrekwa, and other Siluro-Devonian carbonates representing regional post-rift subsidence. Early Paleozoic strata in the North American Arctic include Franklinian Basin facies belts facing an ancestral Iapetus Ocean west of the Canadian Arctic Islands. And, in northern Yukon, Alaska, and Russian Chukotka, a basin facies belt faced an ancestral Iapetus Ocean to the north. Our data suggest a reconstruction where both the Siberian and North American lower Paleozoic strata faced an ancestral Iapetus Ocean on their (present day) northern margins. In this model the Richardson Trough represents a failed rift (aulacogen), and the other two rifts opened to form the Babbage Basin — a Franklinian shelf — opening to the Iapetus Ocean. The paleogeography surrounding the Richardson Trough was part of the western Franklinian ancestral shelf.

sud (dénivelé de 900 m sur la longueur du rift). En comparaison, la cuvette de Richardson est large de 50 à 70 km et longue de 150 à 160 km. Le matériel de remplissage de la partie centrale du bassin sédimentaire, déposé de la fin du Cambrien moyen au début du Dévonien moyen, a une épaisseur de 3 km, comparativement à 1 km pour les strates corrélatives sur les bordures des plates-formes adjacentes. La présence de basalte alcalin du Paléozoïque inférieur dans le rift frère du rentrant de Misty Creek, et dans l'ensemble de la Cordillère canadienne, témoigne d'une tectonique d'extension sur une vaste étendue. De plus, les strates sédimentaires de faciès de bassin dans le rentrant de Misty Creek présentent une forte composante de débris du volcanisme alcalin. Deux occurrences de roches volcanoclastiques basiques, accompagnées de téphra et de bentonite, ont également été relevées au sein de la Formation de Mount Hare, dans la cuvette de Richardson.

Une coupe transversale de la cuvette de Richardson révèle, comme pour le rentrant de Misty Creek, des profils classiques en « tête de bouvillon » qui rendent compte d'au moins deux cycles de remplissage de rift. Le premier cycle correspond au remplissage initial du rift, représenté par la Formation de Slats Creek, qui a été suivi d'une subsidence régionale post-rift ayant donné lieu au dépôt des formations de Franklin Mountain-Cronin. Le second cycle s'amorce par un remplissage du rift, représenté par les parties inférieure et intermédiaire de la Formation de Mount Hare, qui a été suivi d'une subsidence régionale post-rift se manifestant par le Membre d'Aitch de la partie supérieure de la Formation de Mount Hare et les formations de Mount Kindle, de Tetlit, de Delorme et de Vittrekwa ainsi que par d'autres successions de roches carbonatées du Silurien-Dévonien. Les strates du Paléozoïque précoce dans l'Arctique nord-américain comprennent les zones de faciès du bassin franklinien à regard dirigé vers sur un proto-Océan Iapétus, à l'ouest de l'archipel Arctique canadien. Dans le nord du Yukon, en Alaska et dans le Tchoukotka russe, on trouve également une zone de faciès de bassin faisant face à un proto-Océan Iapétus, au nord. Nos données favorisent une reconstitution dans laquelle les strates du Paléozoïque inférieur, tant en Amérique du Nord qu'en Sibérie, faisaient face à un proto-Océan Iapétus sur leurs marges continentales nord (actuelles). Suivant ce modèle, la cuvette de Richardson représente un rift avorté (aulacogène), et les deux autres rifts se sont ouverts pour former le bassin de Babbage – appartenant à une plate-forme continentale franklinienne – s'ouvrant sur l'Océan Iapétus. La paléogéographie entourant la cuvette de Richardson se rapportait à la partie ouest de la proto–plate-forme continentale franklinienne.

INTRODUCTION

The southern Richardson Mountains were the site of one of the earliest detailed studies of lower Paleozoic basin facies rocks in the northern Canadian Cordillera (Fig. 1). Jackson and Lenz (1962) measured several sections across the area, making detailed graptolite zonations and putting most of the basin facies into a single formation they called ‘Road River Formation’. Thereafter, the term ‘Road River’ was widely applied to graptolitic basin facies across the Yukon, into Alaska, and south into northeastern British Columbia (Cecile 1982). Norford (1964), following the suggestion of Jackson and Lenz (1962), divided the Road River into two distinct members: a lower member of limestone and argillaceous limestone; and an upper recessive member of shale, argillaceous limestone, shaly argillite, and chert. In subsequent mapping by Norris (1981b, c), however, Norford’s (1964) lower limestone member was lumped in with the lower part of Norford’s upper member, and both were mapped as Norris’s ЄDR1. Norris (1981b, c) defined additional mappable units within Norford’s upper member, the ЄDR2, 3, 4 map units, and mapped an additional unit, the ЄDR0, below Norford’s limestone member. In the early 1980s, basin facies rocks exposed in the Selwyn Basin and Misty Creek Embayment to the south were divided into a number of mappable units (*see* Cecile, 1982; Gordey and Anderson, 1993). Also, the Misty Creek Embayment was recognized as being similar in stratigraphy and geometry to the Richardson Trough (Cecile, 1982). As a result, we initiated remapping and stratigraphic study of the northern Richardson Trough to detail the characteristics of basin facies map units in the southern Richardson Mountains. This bulletin summarizes that information.

A note of caution about location data: in 1982, we used airphotos and base maps consisting of enlarged portions of a NAD 27 (North American Datum of 1927) 1:250 000 topographic map. There were no GPS devices. During the production of new NAD 83 1:50 000 topographic maps, significant errors were found in the NAD 27 1:250 000 topographic map. Although some of this problem is alleviated by referring to the original air photographs, the user may find some inaccuracies in the location data reported here.

PHYSIOGRAPHY

The Richardson Mountains trend north from where the Hart, Wind, and Bonnet Plume rivers join the Peel River. From there, this narrow range of mountains extends to the Arctic Coastal Plain and Beaufort Sea. These mountains are not high: some are just over 1000 m. They form a drainage divide between the Eagle and Porcupine rivers on the west and the northward-flowing Peel River on the east (Bostock, 2014). In the Quaternary, they also provided a divide between glaciation on the east and an unglaciated area to the west (Hughes, 1972). The range can be divided geologically into a northern half, characterized by faulted and folded upper Paleozoic and Mesozoic strata; and a southern half, featuring a large Richardson anticlinorium exposing Cambrian to Devonian basin facies in its core (*see* Norris, 1985). The divide between southern and northern halves is marked approximately by the east–west-trending Yukon–Northwest Territories border and the Dempster Highway that crosses the mountains at this point.

GENERAL GEOLOGICAL SETTING

The Richardson anticlinorium dominates the southern Richardson Mountains. It is the result of structural inversion of lower Paleozoic basin strata that filled a north-trending rift basin (Fig. 1, 2). Norris (1997b, p. 28) described the anticlinorium as follows:

> Richardson anticlinorium is the broad, gently north-plunging anticlinal structure between the autochthon of the northern Interior Platform on the east and Eagle Foldbelt on the west.... It is bounded for much of its length on the east by Trevor Fault [his Fig. 3.9, 3.10] and on the west by Deception Fault.... The anticlinorium is laced with north-trending, curviplanar, near-vertical faults comprising the Richardson Fault Array.... Southward, the array veers to the southeast and changes style from a zone of nearly vertical strike-slip faults to one of steeply-dipping, high-angle oblique-slip faults.... Various strands of the array have known right lateral separations up to 40 km and illustrate the cumulative effects of dextral shear.

Strata exposed in the core of the anticlinorium range in age from middle Cambrian to Early Devonian. These strata are flanked by mostly clastic strata of Devonian, Carboniferous, and Cretaceous age. The northern half of the anticlinorium was remapped by Cecile et al. (1982; *see* Fig. 1), and more recently the Mount Hare National Topographic Series (NTS) map area 116-I/9 was partially remapped and re-interpreted by Lane and Cecile (2021). In addition, Lane and Cecile are preparing a geology map for the Mount Cronin map area NTS 116-I/16 expected to be published in 2022.

Southern Richardson Trough: upper Peel Canyon studies and changes to our manuscript

In the final stages of preparing this bulletin, we were contacted by Jason Strauss and made aware that he and a large group of colleagues had submitted a detailed paper to the *Canadian Journal of Earth Sciences* on the lower Paleozoic stratigraphy in the Peel Canyon area, southern Richardson Trough, based on fieldwork in 2015 to 2017 (Strauss et al., 2020). The Peel Canyon area lies to the south

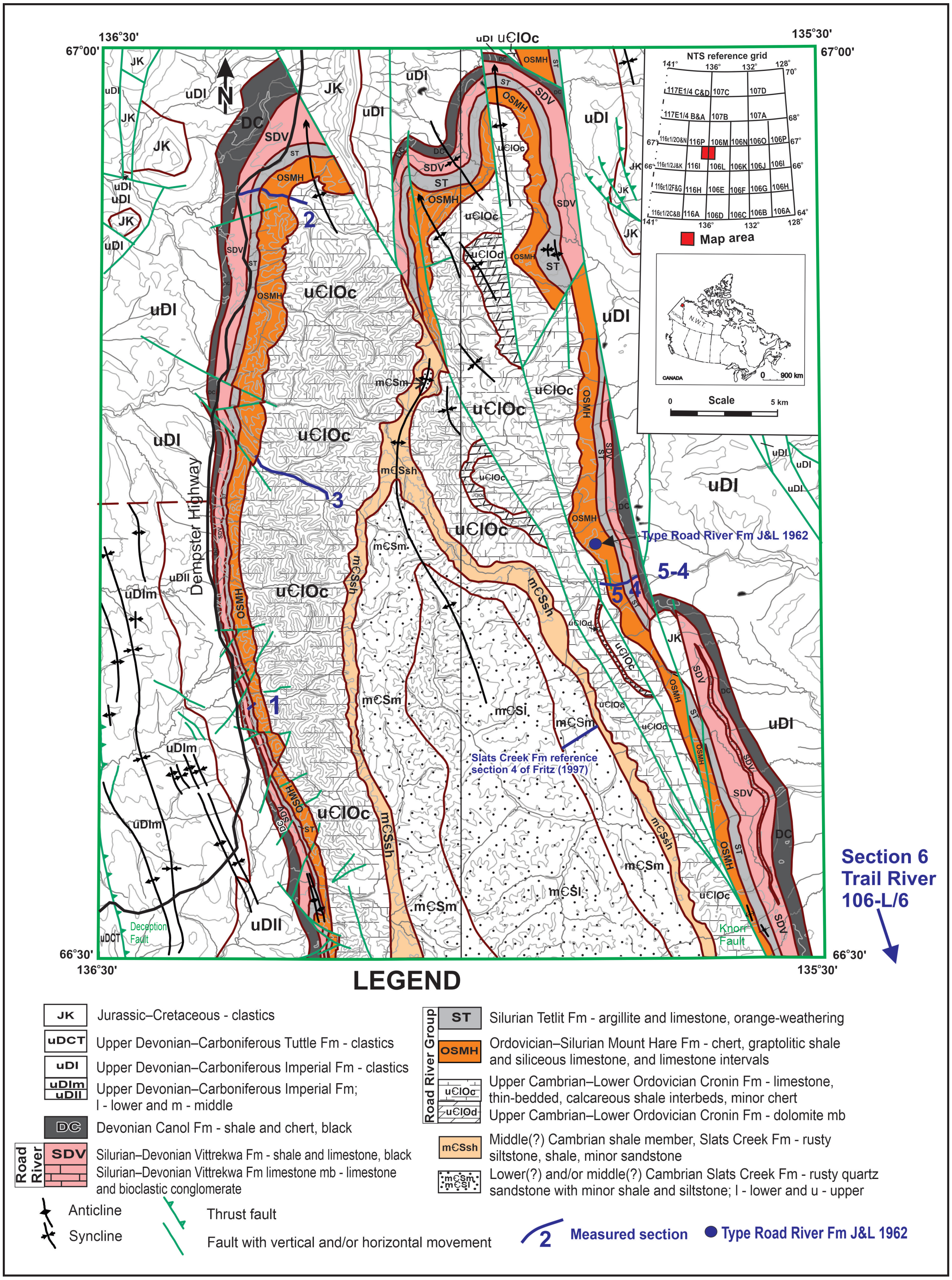

Figure 1. Geological map of the northern Richardson anticlinorium with section locations. *Based on* the geological map of Cecile et al. (1982) and data from L.S. Lane (pers. comm., 2018). Geographic base is from NTS digital maps based on a NAD 83 datum (North American Datum of 1983). The original type section of the Road River Formation and reference sections are outlined. J&L = Jackson and Lenz (1962).

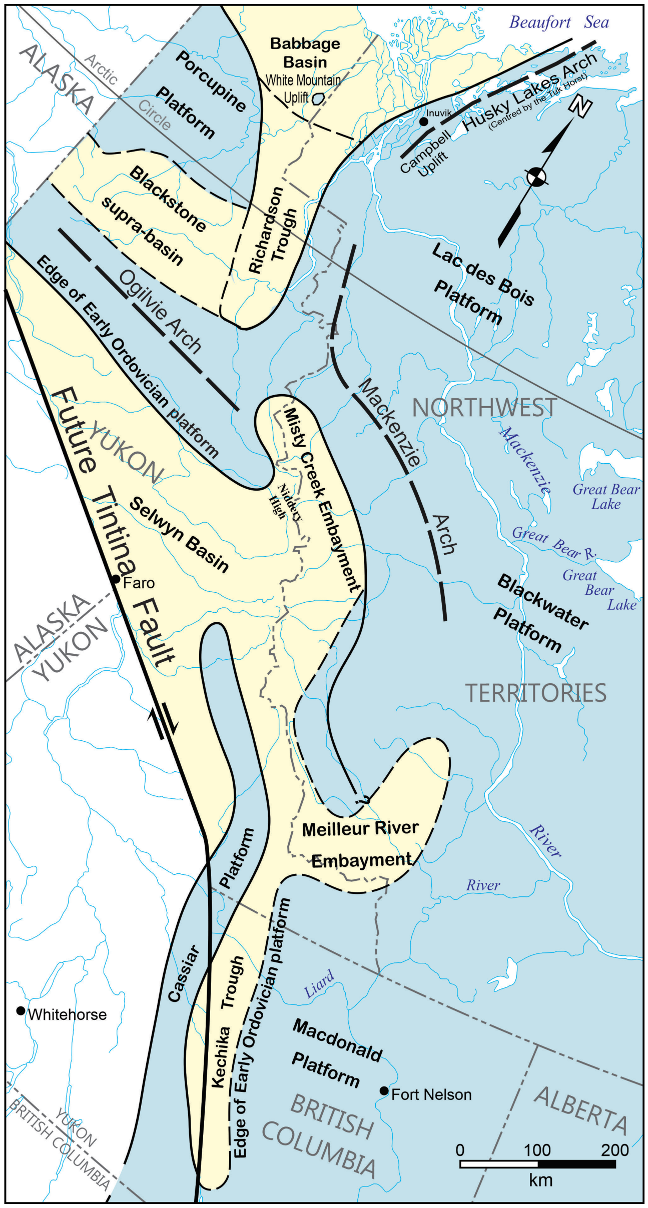

Figure 2. Lower Paleozoic paleogeography of the northern Canadian Cordillera.

of, and outside, our study area. We exchanged manuscripts in review to ensure that we benefited from each other's efforts, and we established a common stratigraphic nomenclature. Given that their paper was more advanced in the publication review process, we agreed that the upgraded type Road River Group would be in Peel Canyon. The advantage to this is that the units are all in one section. The disadvantage is that some of their sections are faulted. Our paper will provide detailed reference sections for all of the Road River Group in the northern Richardson Trough. Between the two manuscripts, the readers will get a much better understanding of the stratigraphy and biostratigraphy of the entire Richardson Trough.

The common nomenclature both manuscripts use in ascending order is as follows: the Cronin Formation, which was the Rabbitkettle Formation of Cecile et al. (1982) and Morrow (1999); the Mount Hare Formation, which replaces the Locheux Formation of Cecile et al. (1982) and Morrow (1999); and the Tetlit Formation, which Strauss et al. (2020) proposed to replace the Dempster Formation of Cecile et al. (1982). The Vittrekwa Formation of Cecile et al. (1982) will be preserved and used in both publications. The type sections for the Cronin, Mount Hare, Tetlit, and Vittrekwa formations will all be in the Peel Canyon as part of the new type Road River Group. All of our sections, described in this study, will serve as reference sections for the Road River Group. These northern reference sections have some real advantages for the reader/user: they are likely more easily accessed than the Peel Canyon sections; and flooding and flash flooding, which are a hazard in the Richardson Mountains, are probably less dangerous on the reference sections than in Peel Canyon. In addition, three of our sections, 82-CJA-01 (Tetlit reference section), 82-CJA-02 (Mount Hare and Vittrekwa reference sections), and 82-CJA-03 (Cronin Formation reference section), can all be reached on foot from the Dempster Highway (Fig. 1).

Strauss et al. (2020) also provide a detailed profile of $\delta^{13}C$ isotopes through their upper Peel Canyon sections, noting that their "data record multiple global carbon isotopic events,… 507 new carbonate carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopic measurements, and 674 organic carbon ($\delta^{18}C_{org}$) isotopic analyses and total organic carbon contents (TOC) from specified stratigraphic sections." We will refer the readers to their paper for that information and interpretation. Finally, we provide very detailed and extensive fossil and biostratigraphic descriptions in this manuscript, and Strauss et al. (2020) provide extensive additional biostratigraphic material. Extensive fossil and biostratigraphic data can also be found in Lenz (1966, 1972), McCracken (1991a, b), and Jackson and Lenz (1962, 2003).

PALEOGEOGRAPHIC FEATURES (NORTH OF OGILVIE ARCH)

Richardson Trough: definition

The Richardson Trough (Fig. 2; *see* Fig. 4) was first recognized by Lenz (1972). The Richardson Trough is filled with lower Paleozoic basin facies strata overlain by minor amounts of upper Paleozoic and Cretaceous clastic rocks. The trough was a rift basin similar in age, geometry, size, and sedimentary fill to its sister rift, the Misty Creek Embayment (Cecile, 1982), which lies to the southeast. The Richardson Trough in the lower Paleozoic strata merges northward into a large basin area known as the Babbage Basin (Cecile et al., 1997) and merges to the south into the Blackstone 'supra-basin' (Lenz, 1972; Cecile et al., 1997). To the east it is bordered by the Lac des Bois Platform carbonates, including the Campbell Uplift (Fig. 2; *see* Fig. 4, A-11, and Cecile et al. (1997, 2015, 2017)) and to the west by the Porcupine Platform (Fig. 2; *see* Fig. 4, A-12, and Cecile et al. (1997)). The Richardson Trough is exposed in the Richardson anticlinorium (Fig. 1), a broad anticlinal structure that is the central feature of a 1:500 000 scale map of Norris (1985) and 1:250 000 maps of Norris (1981b, c, 1982a). This structure shows outcrops of Cambrian to Lower/Middle Devonian strata (Norris's Road River Formation) east of the Dempster Highway, west of the Peel River, south of an east–west jog in the Yukon and Northwest Territories boundary line at 67°N, and north of the east–west-trending Ogilvie Mountains fold belt (Norris, 1985).

White Mountains Uplift

North of the Richardson anticlinorium is a small uplift, the White Mountains (Fig. 2). The uplift appears to represent a distinct isolated platform succession on a fault block within the Babbage Basin. Road River Group strata are exposed east, west, and south of the uplift, and to the north the uplift is bordered by younger clastic rocks (*see* Norris 1985). The uplift was described by Dyke (1972) as "a structural, as well as physiographic, entity" composed of an 8 km × 11 km uplifted and tilted block of Paleozoic carbonate rocks bounded on all sides by Permian to Jurassic clastic rocks. Dyke (1997) described strata on the uplift as ranging from Proterozoic to late Paleozoic age. The following description is from Dyke (1997, p. 346): The oldest Proterozoic strata consist of

> massively bedded dolomite, overlain by a 100 m thick unit of dark green mafic volcanic and volcaniclastic rock [followed by a] massively bedded dolomite and red to orange weathering quartzite.... The base of the Paleozoic succession is represented by light grey quartzites, calcareous quartzite, and an interval of interbedded red shale and siltstone, all of Early Cambrian age (Fritz, 1974; Morrow, 1989).... Above the Lower Cambrian clastics is a [Paleozoic] carbonate sequence [and] a nearly complete section of the strata exposed in the core [of the uplift].

The lower part of this succession consists of the Cambrian to late Silurian Vunta Formation, comprising "light grey pelletoidal to finely crystalline limestone" (Norford, 1964, section 23, 1967, section 116-P/7). Overlying the Vunta Formation are late Silurian to Middle Devonian dolomites and limestones (Norris, 1985), which are followed by Pennsylvanian limestone (Bamber et al., 1971) and end in Permian limestone. Cecile et al. (2015, 2017) found that on the Campbell Uplift, about 100 km to the northeast (Fig. 1), what was mapped as Vunta Formation was divisible into Franklin Mountain and Mount Kindle formations. Therefore, the Vunta Formation of the White Mountains is likely a direct equivalent of the Franklin Mountain and Mount Kindle formations. According to Morrow (1999), the late Silurian to Middle Devonian carbonates overlying the Vunta Formation are equivalent to the Delorme Group and Ogilvie Formation and overlie the Vunta Formation across a middle Silurian unconformity.

Babbage Basin

Lower Paleozoic rocks defining the Babbage Basin (Fig. 2) are exposed in the Barn Uplift (Cecile 1988; Cecile and Lane, 1991) and British Mountains (Lane and Cecile, 1989; Lane, 1991) and extend more than 80 km into northeastern Brooks Range, Alaska (Strauss et al., 2019). The Barn Uplift centres the Yukon portion of the Babbage Basin and consists of mappable basin facies Cambrian argillite (Ꞓa), Ordovician chert (Oac), and Silurian argillite (Sa). The Cambrian argillite has maroon and green argillites and a mappable limestone member. In the British Mountains to the northwest, the lower Paleozoic strata consist of Cambrian clastic rocks and carbonates including early to middle Cambrian argillite (Ꞓa), which in turn is overlain by a thin succession of Ordovician chert (Oc) and a thin succession of Silurian green argillite with some black shale (Sa) (Cecile, 1988; Lane and Cecile, 1989). In the British Mountains, these lower Paleozoic basin facies strata were mapped by Norris (1981e) as the Proterozoic Neruokpuk Formation. Lane and Cecile (1989), however, found that the Neruokpuk Formation is actually a succession of lower Paleozoic basin facies strata very similar to strata exposed in the Barn Uplift, but the Neruokpuk Formation includes some additional Cambrian units. Hofmann et al. (1994) found early to early middle Cambrian trace fossils in maroon and green argillite of the Cambrian units of both the Barn Uplift and the British Mountains. Lane and Cecile (1989) also found Early Ordovician and early Silurian graptolites in the Oc and Sa units of the British Mountains, and early Paleozoic graptolites are common in the Barn Uplift.

Structural panels in the Barn Uplift and British Mountains, which include parts of the Cambrian argillite, the Ordovician chert, and the Silurian argillite, are about 1 km thick and comparable to similar successions found in the Selwyn Basin (Cecile, 2000). These strata are approximate equivalents to the Cronin, Mount Hare, and Tetlit formations of the Richardson Trough, and the Vittrekwa Formation is equivalent to black argillites with turbiditic sandstones that surround the uplift (Lane, 2007).

Included in the Babbage Basin is the Whale Mountain allochthon, found in the northeast Brooks Range, Alaska. Johnson et al. (2019, p. 439) described the allochthon as

> a structural complex composed of lower Paleozoic mafic volcanic and marine sedimentary rocks that are exposed within three fault-bounded, east–west-trending belts…. Trace-element systematics from the volcanic rocks define distinctive suites that are geographically restricted to each belt. The volcanic rocks of the southern belt (the Marsh

> Fork volcanic rocks) have a tholeiitic character and rare earth element trends that resemble modern mid-ocean-ridge basalt. The volcanic rocks of the central belt (the Whale Mountain volcanic rocks) and northern belt (Ekaluakat formation; new name) both have an alkaline character, but the northern belt rocks are significantly more enriched in the incompatible trace elements.

Johnson et al. interpreted the volcanics and sedimentary strata in the Whale Mountain allochthon as relics of the Iapetus Ocean. Goodfellow et al. (1995, p. 1239) described the Whale Mountain volcanic rocks in the Yukon as alkalic and outcropping in "an east–west-trending belt in the British Mountains of the northern Yukon and northeastern Alaska. They consist of a mixture of tuffs, basalt flows, and volcaniclastic rocks. Dutro et al. (1971, 1972) recovered Late Cambrian trilobites from a limestone in the basal part of this succession."

Babbage Basin strata are clearly thrust on each other and would spread over a large area if palinspastically restored. In the Whale Mountain allochthon, the southern belt of volcanic rocks with a tholeiitic character (Johnson et al., 2019) may represent obducted ocean crust.

Blackstone supra-basin

The Blackstone supra-basin lies north of the Ogilvie Arch and south of the Porcupine Platform (Fig. 2). It was originally defined as the 'Blackstone Trough' (Cecile and Norford, 1993) based on surface outcrops that run through Ogilvie and Hart River map areas NTS 116-G, 116-F E½, 116-H, and 106-E. In those map areas, east–west-trending Road River (ЄDR) Blackstone basin facies strata overlie ЄDb platform facies rocks (Norris 1981g, 1982a, b, c, 1985). The ЄDb carbonates in this area were renamed the 'Bouvette Formation' by Morrow (1999). On the west end of this outcrop belt, Blackstone basinal strata turn northward about 70 km, extending into Porcupine map area NTS 116-J. In the subsurface Road River Group, basin facies rocks equivalent to those in outcrops have been shown to extend some distance to the northwest under Eagle Plain (Morrow 1999, his Fig. 34). Thus, the Blackstone supra-basin is a much broader feature than the outcrop area originally used to define 'Blackstone Trough'. The presence of Bouvette (ЄDb) carbonates under Road River strata suggests that initially, the Blackstone supra-basin area below Road River strata was part of a broader Porcupine Platform extending to, and bordered by, the Ogilvie Arch. Thus, Blackstone supra-basin developed as this platform area was submerged to basinal depths during latest Ordovician (?) to Early Devonian time. Because we consider the basin to have developed over carbonate strata of the southern Porcupine Platform, we use the term 'supra-basin'. Ages for unit 8 (now the Bouvette Formation) on the adjacent Ogilvie Arch are Early Ordovician to late Silurian (Green and Roddick, 1962; Green, 1972). The Bouvette Formation, outside the Blackstone supra-basin, may be as young as Early Devonian (Morrow, 1999). In the Ogilvie and Hart River map areas (NTS 116-G, 116-F E½, 116-H), the Road River Formation is overlain by Lower Devonian strata (Norris, 1982b, c). Thus, the Blackstone supra-basin would have existed from approximately the late Silurian to the Early Devonian.

Ogilvie Arch

The Ogilvie Arch (Fig. 2) is defined by the unconformable juxtaposition of Green's (1972) unit 8 platform carbonates on his Proterozoic units 1 and 2. Fossils collected from unit 8 range in age from Early Ordovician to late Silurian (Green, 1972). Morrow (1999) renamed unit 8 as the 'Bouvette Formation' and suggested these strata could be as young as Early Devonian. A tuffaceous unit (8a of Green, 1972) is believed to be Middle to Late Ordovician in age. Road River strata correlative with the upper part of unit 8 define the transition northward from the Ogilvie Arch into the Blackstone supra-basin. On the south side of the arch, carbonates transition southward into basinal strata of the Selwyn Basin in the Ogilvie and Hart River map areas of Green (1972) (NTS 116-G, 116-F E½, 116-H), which run east to west along the axis of the arch. Thus, Ogilvie Arch is considered a positive linear feature like the Mackenzie Arch.

Porcupine Platform

The Porcupine Platform (Fig. 2) was originally defined by Cecile and Norford (1993). In this study, the southern Porcupine Platform consists of the Bouvette Formation carbonates (Morrow, 1999) (the ЄDb unit of Norris, 1985), which extend from the surface and run under the Blackstone supra-basin (*see* Fig. 4). In the south, the platform merges with the Ogilvie Arch. In the north, it covers a wide area of the western and northwestern Yukon, both at the surface as the ЄDb unit of Norris (1985) and in the subsurface as the Franklin Mountain and Mount Kindle formations (Pugh, 1983).

The ЄDb carbonates also extend to the Yukon border with Alaska and into Alaska. In east-central Alaska, bordering the central Yukon, equivalent carbonates are found across much of the southern Colleen quadrangle as the SOCl unit (dolomite and limestone (Brosgé and Reiser, 1969)) and across the northern part of the northeast Black River quadrangle (Cl limestone and Sl limestone units of Brabb (1967, 1970) and Brabb and Churkin (1969)).

The Porcupine Platform extends as far north as 67°30′N along the Alaska border (Norris, 1985). On the surface in the northwest, the ЄDb unit may be divisible into mappable Franklin Mountain and Mount Kindle formations. Several fossil collections typical of the Mount Kindle Formation were collected from the ЄDb in the Old Crow map area, NTS 116-O (Norris, 1981f). In the subsurface below the central Eagle Plain (the central and northeastern part of the

Porcupine Platform, Fig. 2), ЄDb carbonates are represented as the Franklin Mountain and lower Mount Kindle formations (Pugh, 1983, his Fig. 26a), which, combined, are 1 to 2 km thick (*see* Fig. 4, A-12). The upper Mount Kindle is, in some wells, a transitional to basin facies limestone succession overlain by parts of the Mount Hare Formation (Road River Group). These strata are overlain unconformably by what Pugh (1983) described as Devonian Peel and Tatsieta formations. To the west, near Alaska, and in the northwest, Pugh (1983, his Fig. 26b) found an 800+ m thick succession of dolostone and crystalline dolostone that he correlated only with the Franklin Mountain Formation. However, the same interval is equivalent to the ЄDb unit at the surface nearby (Old Crow map area, Norris, 1981f), and here, there have been age determinations of late Cambrian to Devonian; Early, Middle, and Late Ordovician; early and late Silurian; and Early Devonian (Norris, 1981f, g). Thus, Pugh's Franklin Mountain carbonate interval is, in fact, an age equivalent of the interval Franklin Mountain+Mount Kindle+Vittrekwa formations. This dates the Porcupine Platform in the northwest as Late Cambrian (?), Ordovician, Silurian, and Early Devonian.

Tuk Horst, Husky Lakes Arch, and Campbell Uplift

The Husky Lakes Arch (Fig. 2) is a positive pre-Mesozoic feature that runs northeastward from Inuvik across the Tuktoyaktuk Peninsula and into the Beaufort Sea (Wielens, 1992). (Note: That paper used the name 'Eskimo Lakes Arch' for this feature; however, in alignment with the recommendation in Hadlari et al. (2020) to rename the Eskimo Lakes fault and Eskimo Lakes fault zone to 'Husky Lakes fault' and 'Husky Lakes fault zone', we have used the name 'Husky Lakes Arch' instead in this bulletin.) The Husky Lakes Arch parallels the Tuk Horst, which centres the arch. The Tuk Horst features a variety of late Precambrian, early Cambrian, and Middle Ordovician (dolomite) strata intersected in about 50 wells. The Husky Lakes Arch runs directly into the Campbell Uplift, where Cecile et al. (2015, 2017) mapped Franklin Mountain and Mount Kindle formations overlying Proterozoic to Cambrian dolostones, argillites, and quartzites, which are overlain by the Lower to Middle Devonian Arnica Formation. Cecile et al. were unable to measure thicknesses in the uplift, but they noted that in the Inuvik D54 well there were 750 m of Paleozoic carbonates above the Proterozoic–Cambrian clastic rocks. Cecile et al. noted that the Franklin Mountain and the Mount Kindle formations strongly resemble their equivalents exposed on the Mackenzie Arch. The Franklin Mountain Formation on the Campbell Uplift is massive, crystalline, and indivisible, and it is cherty toward its top, as on the Mackenzie Arch.

Lac des Bois Platform

The Lac des Bois Platform (Fig. 2) is a large area of mainly Cambrian clastic and Cambrian to Devonian shallow-water carbonate deposition that thickens to the west and northwest. It is considered part of the Franklinian ancestral continental shelf (formerly miogeocline). Formerly, it was considered to be the northern portion of the Mackenzie Platform of Cecile and Norford (1993), but given that the Richardson Trough and Babbage Basin demonstrate the presence of a northern continental shelf bordering a northern (Iapetus) ocean, Cecile et al. (1997) decided to split the Mackenzie into a northern platform (Lac des Bois), associated with the Franklinian continental margin; and a southern platform (Blackwater), associated with the Paleo-Pacific (Cordilleran) continental margin. The northernmost exposure of the Lac des Bois Platform is found on the Campbell Uplift near Inuvik (Cecile et al., 2015, 2017) and east of there adjacent to the Brock Inlier.

STRATIGRAPHY AND BIOSTRATIGRAPHY OF RICHARDSON TROUGH; AND ROAD RIVER FORMATION ELEVATION TO GROUP

Strata defining the Richardson Trough range in age from middle Cambrian to Early Devonian. In ascending succession they are the middle Cambrian Slats Creek Formation and the Road River Group. The Road River Formation of Jackson and Lenz (1962) was elevated to group status by Fritz (1985).

Slats Creek Formation

The Slats Creek Formation was adopted from maps of Norris (1981b, c) and described in some detail by Fritz (1997). It is poorly exposed in the study area, but it can be divided into three map units, mainly on the basis of weathering and topography (Fig. 1).

Type and reference sections

The type section is section 7 of Fritz (1997), in the Wind River map area, NTS 106-E. The base of Fritz's section 7a is at Universal Transverse Mercator (UTM) 8W, 497072E, 7227960N, NAD 83 (North American Datum of 1983).

In the Richardson Trough, Fritz's (1997) section 4 (*see* Fig. 1) will serve as a reference section for the middle Slats Creek Formation (mЄSu), given that it is located in the central part of the Richardson Trough. The base of the section is at UTM 8W, 461815E, 7389841N, NAD 83 in the Tetlit Creek map area (NTS 106-L/12).

Lithology, thickness, and contacts

On our traverses in 1982, we noted that the Slats Creek Formation is a rusty-brown-weathering lithic quartz sandstone with shale and siltstone. There are three informal members: a poorly exposed lower member with scattered outcrops of shale and siltstone; a middle member with 50% sandstone and 50% shale and siltstone; and an upper middle Cambrian shale member (m∈Ssh). The lower contact with the Illtyd Formation is not exposed in the study area, but elsewhere in the Richardson Trough, the Slats Creek Formation sits conformably on the Illtyd Formation (Fritz, 1997). Fritz (p. 84) described a photo as "Cambrian Slats Creek Formation resting with right-angular unconformity upon vertically dipping, Helikian Quartet Group along upper Hart River, Y.T. View is to the northeast. GSC photo 3-11-70." The upper contact between the upper member (m∈Ssh) and the Cronin Formation is poorly exposed.

At the type section, outside the trough and to the southeast, the Slats Creek Formation comprises a lower siltstone member (unit A-4, 799 m) and an upper conglomerate and sandstone member (772.5 m, total thickness 1572 m (Fritz, 1997)).

In the study area where reference section 4 (Fig. 1) is located, only the middle member of the Slats Creek Formation is represented. Fritz (1997, p. 94) described section 4 as a "monotonous succession of rusty to medium brown weathering sandstone that exceeds 747 m in thickness (base not exposed). The sandstone is in medium to thin beds that are medium to medium dark grey on fresh surfaces." He noted that the sands were very fine to fine grained and that current-generated features were rare and transport direction could not be determined. The lower Slats Creek Formation was not exposed near the base of the reference section.

Sedimentary features

The Slats Creek Formation is laminated to massive and can show graded bedding.

Age

The Slats Creek Formation is dated as late early to middle Cambrian. Fritz (1997, p. 98) noted the following:

> *Olenellus* sp. is present 77 m above the base of the Slats Creek Formation (GSC loc. 90620) in Section 7, and therefore the formation, up to at least that level, belongs in the Lower Cambrian *Bonnia–Olenellus* Zone. The boundary between the Lower and Middle Cambrian is tentatively placed 4.5 m higher, at the base of a 7 m sandstone succession [his Fig. 5.4b]. Other fossils found in the formation belong to the *Plagiura–Poliella* and/or *Albertella* Zone (GSC locs. 90621–90626), questionably to the *Glossopleura* Zone (GSC locs. 90627–90629), and definitely to the *Glossopleura* Zone (GSC locs. 90630–90636). The base of the Slats Creek Formation is considered diachronous between Sections 7 and 8, because at Section 8 the basal Slats Creek belongs to the Middle Cambrian *Plagiura–Poliella* Zone (GSC locs. 90675–90678). The presence of *Glossopleura* within the Slats Creek Formation and of cf. *Polypleuraspis* sp. (GSC loc. 90682) in the overlying Taiga Formation at Section 8 indicates that here the Slats Creek–Taiga boundary is within the *Glossopleura* Zone.

Fritz (1997, p. 94) also described "sponge spicules belonging to the genus *Protospongia* [as being] present 33.5 m above the base of the Slats Creek Formation succession" at his section 5, south of the Richardson Trough.

Distribution

The Slats Creek Formation is found throughout the Richardson anticlinorium, Ogilvie and Wernecke mountains.

Correlation

The Slats Creek Formation correlates with the Saline River Formation and possibly the Mount Cap Formation on the Lac des Bois Platform (Yukon Geological Survey correlation chart (Pigage, 2009)). It also correlates with the Hess River Formation in the Misty Creek Embayment; that formation consists of black shale, calcareous shale, and argillaceous limestone (Fig. 3). Northwest of the Misty Creek Embayment, a thick succession of sandstones, the Hess River flysch, divides typical Hess River Formation shale–argillaceous limestone units (Cecile, 1982). The Hess River flysch is interpreted as a submarine fan complex consisting of 1580 m of quartz sandstone and shale flysch.

Upper Slats Creek Formation (m∈Ssh) — middle Cambrian shale member

Reference area

Central part of the Richardson anticlinorium (Fig. 1). No specific location.

Lithology, thickness, and contacts

At eight field stations, this unit consists of dominantly siltstone/mudstone and shale, with some rusty brown sandstone and quartzite. Shales are black and fissile; muscovite flakes were seen at one locality, and the shale doesn't react to HCl. The lower contact is gradational with the middle Slats Creek m∈Sm unit. The upper contact with Cronin Formation

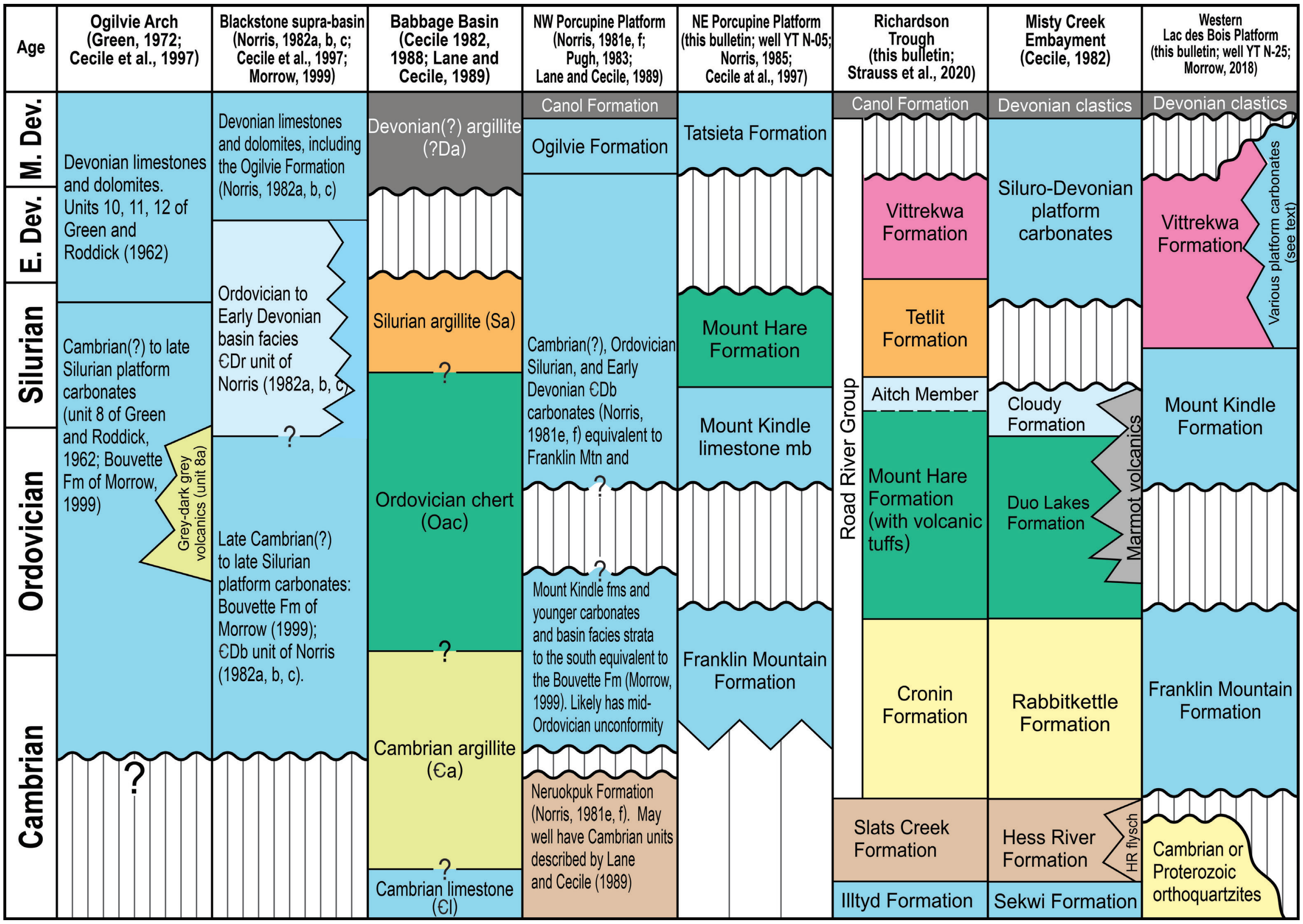

Figure 3. Correlation chart showing relationships of Richardson Trough stratigraphic units to strata in paleogeographic features across the northern Yukon. E. Dev. = Early Devonian; M. Dev. = Middle Devonian.

is not exposed, but it is marked at the point where these clastic rocks change into wafery limestone, shaly limestone, and shales of the lower Cronin Formation.

Sedimentary features

Sandstones are laminated to massive and can show turbiditic features.

Age

The upper Slats Creek Formation is dated as middle Cambrian by its stratigraphic position above the Slats Creek Formation and below the Cronin Formation.

Distribution

The upper Slats Creek Formation is found in the Richardson anticlinorium, Ogilvie Mountains. It may also be present in the Wernecke Mountains, but Norris (1982a) did not map Slats Creek Formation units in this area.

Correlation

The upper Slats Creek Formation is not shown as a separate unit on the Yukon Geological Survey correlation chart (Pigage, 2009), where it is included in either the Slats Creek Formation or the 'Rabbitkettle equivalent'.

Road River Formation and Road River Group

The Road River Formation was first described by Jackson and Lenz (1962) as consisting of close to 1000 m of graptolitic shale, argillaceous limestone and minor chert, dolostone, siltstone, and sandstone from a section on a tributary to the Road River, Richardson Mountains, Yukon. Road River Formation strata are dominated by fine-grained carbonate and siliciclastic strata that we in this bulletin and Strauss et al. (2020) broadly interpret as representing slope to basin-floor deposits. Norford (1964) divided the Road River Formation into two distinct members within the type area: a lower member of limestone and argillaceous limestone; and an upper recessive member composed of shale, argillaceous limestone, shaly argillite, and chert. The lower member is late Cambrian and Early Ordovician in age (Norford, 1964), and the upper member has faunal zones ranging through the Ordovician, Silurian, and Early Devonian (Jackson and Lenz, 1962; Lenz, 1966, 1972).

Road River Formation and equivalent facies strata are reported from the Arctic coast of the Yukon, southward through the Richardson and Ogilvie mountains (Norris, 1985), into east-central Alaska (Brabb, 1967, 1970; Brabb and Churkin, 1969; Brosgé and Reiser, 1969), and south through the Selwyn Basin into the northern Peace River area of British Columbia. South of the Misty Creek Embayment, across the southeastern Yukon, and into northeastern British Columbia, current usage follows Gabrielse et al. (1973a, b), who restricted the Road River Formation to basin facies strata that overlie Rabbitkettle Formation. This then restricts use of 'Road River Formation' to only the upper half of the type Road River Formation. The Rabbitkettle Formation is a direct equivalent of the lower half of the type Road River Formation (Cronin Formation in this report). A similar restricted usage occurs farther south, where 'Road River' is only applied to strata above the Kechika Formation, another equivalent of the lower type Road River Formation (*see* Cecile and Norford, 1979; Pyle and Barnes 2000, 2003, 2017). Because of this, Cecile (2000) recommended that the term 'Road River' not be used in the Selwyn Basin, nor in the Misty Creek Embayment, noting that basin strata in these areas are now divided into numerous new map units (*see* Gordey and Anderson, 1993; Cecile 2000), making the term 'Road River' redundant.

Fritz (1985), in a Geological Survey *Current Research* article, and using mainly published literature and some original research, elevated the Road River Formation to group status. His group in the Richardson Mountains included all the original type Road River Formation units spanning Norford's (1964) lower and upper parts. In the Richardson Trough, he placed the lower boundary at the contact with the Slats Creek Formation. But then he went on to extend the Road River Group to the Misty Creek Embayment of Cecile (1982), where he not only included equivalents of the type Road River Formation but extended it down to include Hess River Formation, and by default, the Hess River flysch. This created a problem, given that the Hess River flysch and other Hess River lithological units are compositionally similar to the Slats Creek Formation, which Fritz (1985) didn't include in the Road River Group.

Strauss et al. (2020, p. 1215) recently established a new type section for the Road River Group and noted the following:

> Here, we mostly follow the original suggestion of Fritz (1985) in elevating the Road River unit to "Group" status and Cecile et al. (1982) and Morrow (1999) for more specific definitions of the base and top of the succession in the type area of the Richardson Mountains. Our main departure from Fritz (1985) is to redefine the base of the Road River Group in the Richardson trough to the first appearance of carbonate strata (Cronin Formation).

Strauss et al. (2020, p. 1213) go on to write that

> we highlight three options regarding Road River Group terminology in the northern Cordillera: (1) retain Road River Group within the various paleogeographic elements of the northern Cordillera but restrict its usage to reflect deep-water strata spanning from the sub-Jiangshanian unconformity to the base of the Devonian–Carboniferous Earn Group; (2) restrict the Road River Group to the Richardson trough type area and define new Group-level units in the Selwyn basin, Yukon block, Mackenzie/Peel platform, Kechika trough, and Cassiar terrane; or (3) retain the Road River Group nomenclature only in the Richardson trough and Selwyn basin and define new Group- and Formation-level units in the Yukon block, Kechika trough, Mackenzie/Peel platform, and Cassiar terrane. Our preference is option 1, as it has clear regional chrono- and tectono-stratigraphic significance. Future investigators should consider these choices when making new stratigraphic calls on deep-water Cambrian–Devonian strata throughout the northern Cordillera.

In this bulletin, we prefer that the term 'Road River Group' *not be used south of the Ogilvie Mountains* and that use of 'Road River Group' be restricted to the Richardson Mountains. This is simply because south of the Ogilvies, 'Road River' has mainly been used for only the upper type Road River. And then when Fritz (1985) re-included the lower type Road River in the areas south of the Ogilvies, he went further by pushing the group down to include the Hess River Formation in the Misty Creek Embayment (Cecile, 1982), further confusing the nomenclature, given that this is an equivalent of the Slats Creek Formation in the Richardson Mountains, which he didn't include in the Road River Group.

The Road River Group in the Richardson Mountains consists, in ascending order, of the Cronin Formation, the Mount Hare Formation (including the Aitch Member (new) at its top), the Tetlit Formation, and the Vittrekwa Formation. The authors of this bulletin and of Strauss et al. (2020) came to an agreement, during the critical review of their manuscripts, to use these four names to avoid creating a duplicate nomenclature for the Road River Group. Cecile et al. (1982) had informally described the Road River Formation interval in the Richardson Trough as consisting of Rabbitkettle, Locheux, Dempster, and Vittrekwa formations. Of these only the name 'Vittrekwa Formation' survives.

The type sections for the Road River Group formations are found in Strauss et al. (2020), and in this bulletin we present additional reference sections. The Road River Group is overlain unconformably by the Late Devonian Canol Formation. Morrow (1999), however, postulated that this might not be an unconformity but a condensed section instead.

Note the following information on five Road River map units of Norris (1981b, c). Norris's ЄDR0 unit is the lower Cronin Formation, and his ЄDR1 lumps most of the Cronin Formation in with the Mount Hare Formation. His ЄDR3 unit is the Tetlit Formation, and his ЄDR4 unit is the Vittrekwa Formation. His ЄDR2 consists of large debris flows and intraclast conglomerates that are found within the Mount Hare Formation.

Cronin Formation (new, Road River Group)

Reference section

The reference section of the Cronin Formation in the study area is section 82-CJA-03 (Fig. 1; *see* Appendix A, Fig. A-5, A-6), located on Rock River in Mount Cronin map areas NTS 116-I/16, 9. The base of the section is located at UTM 449099E, 7403767N, and the top is at UTM 443349E, 7406667N, NAD 83. Note that there is an approximately 200 m covered interval mapped as lower Mount Cronin Formation below the base of the reference section (*see* Appendix A, Fig. A-5). The formation is named after Mount Cronin in the southeast Mount Cronin map area, NTS 116-I/16, in our study area. The mountain is entirely composed of Cronin Formation.

Type section

The following description is from Strauss et al. (2020, p. 1200):

> Type area: Exposures along the Peel River, southwestern Richardson Mountains, Yukon Territory, Canada
>
> Unit type section: Section J1728–T1701 [their Fig. 3]
>
> Located on north side of Peel River about 4–5 km downstream from Aberdeen Canyon
>
> Lower boundary: [G]radational contact with interbedded shale, siltstone, and sandstone of Slats Creek Formation (65.882946, 135.586117) [UTM 8W, 473276.6E, 7306987.73N, NAD 83]
>
> Upper boundary: [F]aulted contact with Mount Hare Formation (65.874512, 135.614517) [UTM 8W, 471972.56E, 7306060.09N, NAD 83]

Lithology, thickness, and contacts

The Cronin Formation in the study area consists predominantly of intervals of thin-bedded, yellow-weathering, dark grey to black limestone and very thin-bedded shaly or very shaly black limestone beds. Interstratified with these lithological units are successions of beds dominated by yellow-weathering limestone (*see* Fig. 5). The upper 400+ m at the reference section consists of grey-weathering, thin-bedded calcisiltite alternating with yellowish weathering calcilutite. Chert nodules and rare discontinuous chert beds are found in most of the upper two thirds of the reference section. Slope breccias are found in the Cronin Formation across the basin, and there is a thick slope breccia in the reference section. Graptolites and small inarticulate brachiopods (identified with conodont residues) occur at numerous intervals. Phosphate rods, annulated phosphate tubes, and phosphate plates are also found in conodont residues. Sponge spicules can be seen in residues in the middle of the reference Cronin Formation (Fig. 4, 5; *see* Fig. A-5, A-6).

On traverses on the east side of the Richardson Trough, we found a mappable succession of grey to yellow, thin- to thick-bedded dolostone within the Cronin Formation ('dolostone mb', Fig. 1). This is likely a tongue of Franklin Mountain Formation dolostone connecting the Cronin Formation to dolostone on the Lac des Bois Platform (Fig. 1; *see* Fig. A-11). Thin units of shaly dolostone and dolostone breccia are found in the eastern Richardson Trough at section 82-CJA-05–04 (combined sections 82-CJA-05 and 82-CJA-04; *see* Fig. A-7).

The lower approximately 200 m of the Cronin Formation are generally poorly exposed, and there are rare outcrops of shaly, wafery limestone, limestone, and calcareous shale. The lower 200 m are likely the ЄDR0 unit of Norris (1981b, c), which he described as "shale, black, calcareous; limestone black; marine." L.S. Lane (pers. comm., 2019) mapped a similar but discontinuous unit, which he considered basal Cronin Formation, in Mount Raymond map area NTS 116-I/8.

The Cronin Formation is 1955 m thick in reference section 82-CJA-03. The section includes a 200 m covered interval at the base. This thickness appears to be typical across the study area.

The lower contact with middle Cambrian rusty shales, siltstones, and minor quartzite is not exposed but is marked at the point where these clastic rocks change into wafery limestone, shaly limestone, and shales of the lower Cronin Formation. The upper contact at the reference section is relatively sharp, passing from yellowish weathering limestone into black chert of the Mount Hare Formation (*see* Fig. A6). The upper contact on the east limb of the Richardson anticlinorium is also abrupt: Cronin Formation shaly dolostone is in direct contact with black chert and shale of the Mount Hare Formation (*see* Fig. A-7).

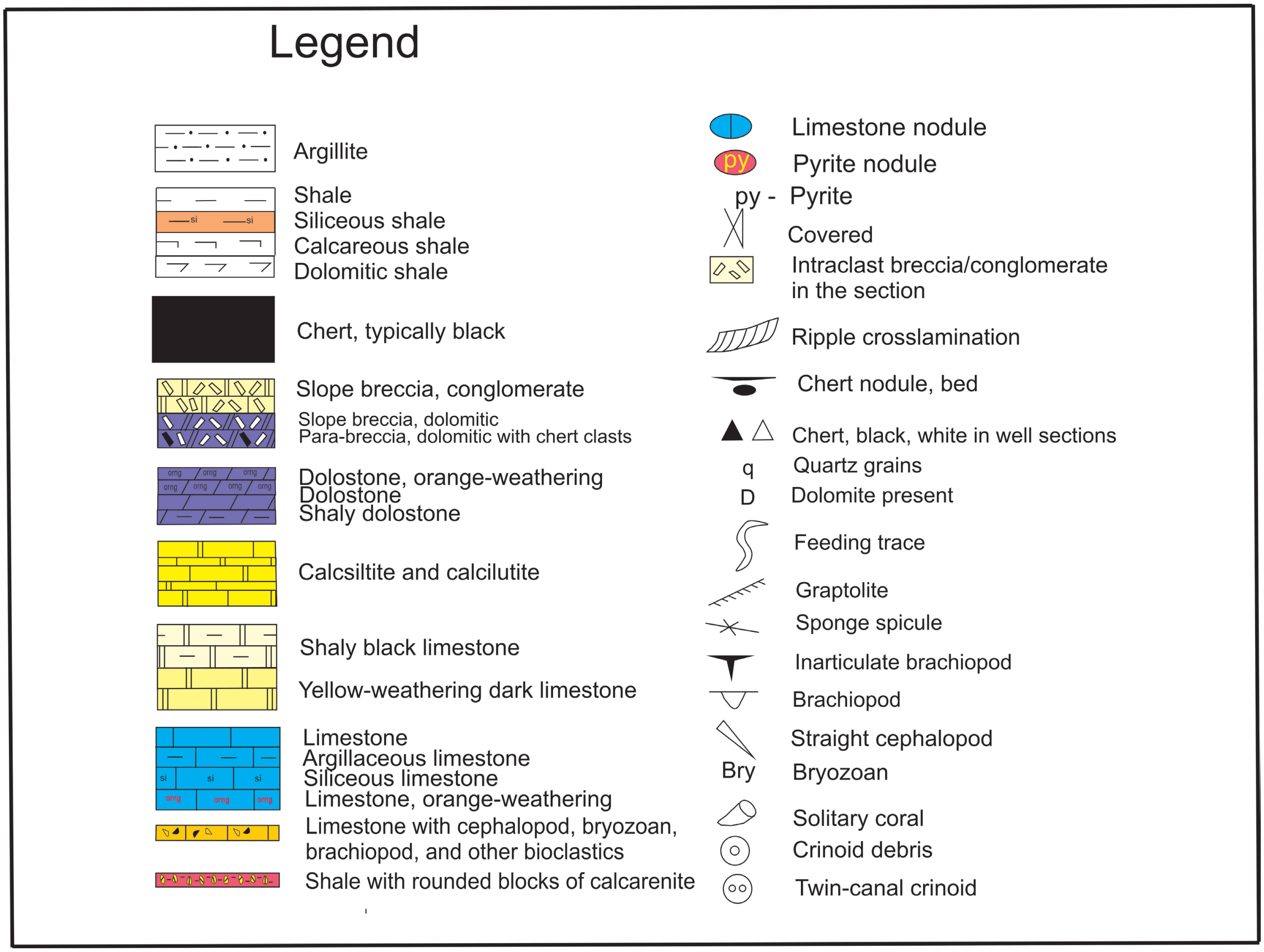

Figure 4. a) Legend for b) composite section.

At the type section, Strauss et al. (2020, p. 1200) gave the following description of the Cronin Formation:

> Generally monotonous succession of bioturbated resistant argillaceous limestone exposed throughout the Richardson Mountains. Basal contact with underlying strata of the Slats Creek Formation (previously called map unit ЄDr0 of Norris (1981*a*, 1981*b*, and 1981*c*) or Єsh of Cecile et al. (1982)) is gradational with contact defined as first appearance of interbedded limestone. The basal 20.6 m is dominated by interbedded black calcareous shale, chert, and dark grey and variably silicified lime mudstone with rare fine-grained fossiliferous wackestone and pyritic bentonite horizons. Overlying 123 m composed of thin- to medium-bedded lime mudstone, calcisiltite, wackestone, and grainstone with large variety of Bouma subdivisions, variable silicification, concretionary intervals, slump folds, barite nodules, nodular chert, and rare fossiliferous intervals with benthic graptolites and disarticulated phosphatic and calcareous brachiopods and trilobites. These strata are overlain by 16 m of thin- to medium-bedded calcareous turbidites with Bouma $T_{A–E}$ subdivisions and fossiliferous basal grainstone lags. The overlying 790 m of the Cronin Formation is dominated by a monotonous succession of medium-bedded lime mudstone, wackestone, and minor grainstone with rare intervals of thin or thick bedding and basal fossiliferous lags comprised of disarticulated brachiopod valves. These strata contain numerous intervals with slump folds, silicification, and stratiform concretionary zones.

Sedimentary features

Typically found in Cronin Formation limestone and shaly limestone are lenses of ripple crosslaminae, climbing ripples, and graded bedding. Also common are slope breccias composed of elongate clasts of thin slabs of Cronin Formation limestone and shaly limestone (in various orientations with

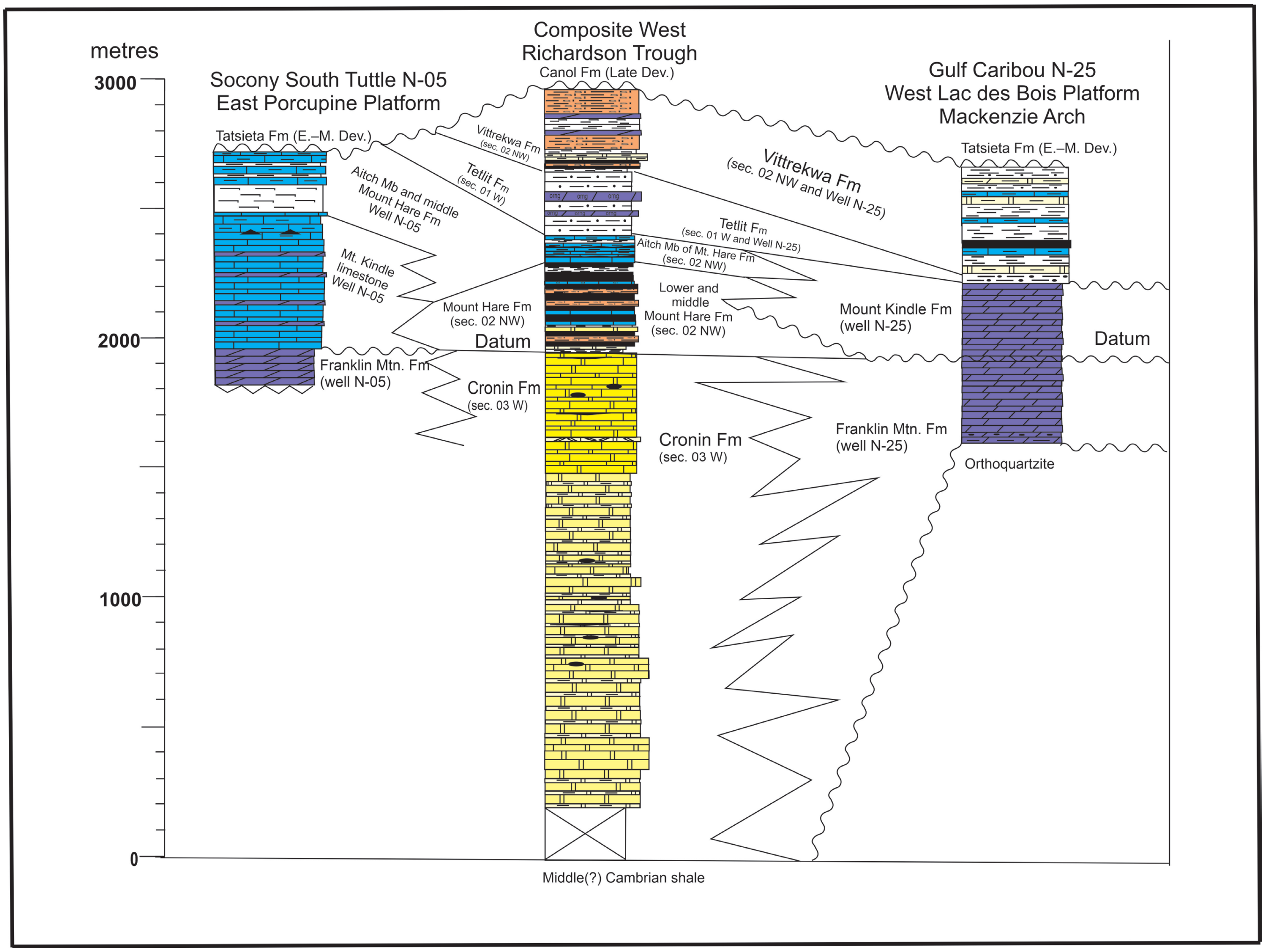

Figure 4. (cont.) b) Composite section (in the centre) from Richardson Trough correlated with subsurface wells. On the east is the well Mobil Gulf Caribou YT N25, which is located on the western Lac des Bois Platform. On the west is the well Socony Mobil Western Minerals South Tuttle YT N-05, which is located on the eastern edge of the Porcupine Platform. Age abbreviations: E.–M. Dev. = Early to Middle Devonian.

respect to bedding) and intraclast breccias. There are also chert nodules and discontinuous chert beds, many shaped like pancakes. Bedding-parallel feeding trace fossils are also common and are found around 700, 900, 1600, and 1700 m in the reference section (*see* Fig. A-5, A-6). Perpendicular-to-bedding common irregular laminae suggest that feeding traces are much more abundant than can be observed on bedding planes.

Age and fauna

The oldest age constraint for the reference section of the Cronin Formation is middle Cambrian to earliest Ordovician, determined from protoconodonts collected from the 200 to 300 m interval (*see* Fig. A-5). Several intervals above that level, and up to 1000 m, yielded conodonts and paraconodonts of middle to late Cambrian age. Therefore, the lower 200 to 1000 m of the section are middle to late Cambrian in age. The intervals from 1000 to 1800 m were dated as late Cambrian. The interval 1800 to 1955 m, the top of the section, yielded Early Ordovician (late Skullrockian [late Tremadocian]) conodonts (*see* Appendix B).

Graptolites were collected in the reference section at three places: below 490 m, in the interval 490 to 492 m, and at 510 m. The ages of the fossils ranged from late Cambrian to Carboniferous (*see* Appendix B). In combined section 82-CJA-05–04 (*see* Fig. A-7), graptolites collected from the Cronin Formation 45 to 48 m below the Mount Hare Formation are from the early Early Ordovician *Isograptus tenuis* Zone.

In summary, at the reference section the lower 200 m are undated; the 200 to 1000 m interval is middle to late Cambrian; the interval from 1000 to 1800 m is late Cambrian; and the topmost interval is Early Ordovician in age. At combined section 82-CJA-05–04, the youngest fossil age is early Early Ordovician.

Figure 5. Cliff exposure of a limestone-dominated unit in the Cronin Formation, Rock River. Note light-yellow weathering and thin and medium-thick bedding. Photograph by M.P. Cecile, Geological Survey of Canada, along section 82-CJA-03. NRCan photo 2019-737

Protoconodonts were found from the base of the reference section up to 1600 m; paraconodonts appear at the 800 m level and continue up to the 1700 m level; and euconodonts appear at the 1500 m level and continue to the top of the section (*see* Appendix B).

In addition to conodonts, the dissolution residues commonly contain small phosphatic inarticulate brachiopod shells and rare occurrences of phosphatic rods (600–800 m), annulated phosphatic tubes (800–900 m), sponge spicules (900–1100 m), and tubular plates (1500–1600 m).

As previously noted, bedding-parallel feeding traces are found around 700, 900, 1600, and 1700 m in the reference section and are common elsewhere.

Strauss et al. (2020) showed the Cronin Formation as being only late Cambrian (mainly Furongian) in age. Their supplemental Figure S3, however, is a succession of strata that we would mostly assign to the Cronin Formation. They assigned this section to the Mount Hare Formation.

Distribution

The Cronin Formation is found throughout the Richardson anticlinorium, northern Yukon (Fig. 1).

Correlation

The Cronin Formation is correlative with similar basin facies strata throughout the Canadian Cordillera (Fig. 3). It is similar in facies, lithology, and thickness to the Rabbitkettle Formation in the Misty Creek Embayment to the southeast (Cecile, 1982); the Kechika Formation in northern British Columbia (Cecile and Norford, 1979); and the McKay Group in the southern Cordillera (Belyea, 1990). The Cronin Formation is also time equivalent to platform facies Franklin Mountain Formation in the flanking Lac des Bois and Porcupine platforms (Cecile et al., 1997; and Fig. 3, 4). It is partially equivalent to the Bouvette Formation of Morrow (1999), also known as unit 8 of Green (1972), and is partially equivalent to the ЄDb unit of Norris (1981b, c, d).

The Cronin Formation is also what Norford (1964) identified as the lower member of the type Road River Formation. Norris (1981b, c) mapped a ЄDR1 unit, but it is a combination of the Cronin and Mount Hare formations. Norris may have had difficulty in distinguishing the two formations: the scree of the Mount Hare Formation consists of abundant slabs of argillaceous limestone that cover and parallel the mountain slope, giving the impression of more limestone than is actually there; and most of his observations were by helicopter. The ЄDR0 map unit of Norris (1981b, c) is likely the lower recessive unit of the Cronin Formation identified at the base of the reference section as a 200 m covered interval.

Interpretation

The Cronin Formation is an accumulation of mainly mud- to silt- and some sand-sized carbonate clastic sediments washed in from the adjacent carbonate platforms. Terrigenous shales probably came from rivers cutting through the platforms. The abundance of ripple crosslaminae and graded bedding indicates frequent deposition in the form of carbonate turbidites or storm currents. The presence of slope breccia, with clasts of typical Cronin Formation, indicates some slope failure due to gravity loading and/or tectonic activity.

Mount Hare Formation and Aitch Member (new, Road River Group)

Reference section

The reference section of the Mount Hare Formation (*see* Fig. A-3) is the lower part of section 82-CJA-02, M.P. Cecile. This section is on White Fox Creek in Mount Cronin map area NTS 116-I/16. The base of this section is in uppermost Cronin Formation, at UTM 8W, 446890E, 7422216N, NAD 83 (*see* Fig. A-3), and the top of the section is the top of the Vittrekwa Formation at the contact with the Canol Formation (*see* Fig. A-4), at UTM 8W, 442266E, 7422866N, NAD 83. The Aitch Member is a distinct unit in the interval 466 to 570 m at the top of the reference section (*see* Fig. A-3) and is also found in combined section 82-CJA-05–04 (*see* Fig. A-7). The formation is named after Mount Hare, which is in the centre of the Mount Hare map area, NTS 116-I/9, Richardson Mountains, in our study area.

Type section

The following description of the Mount Hare Formation type section is from Strauss et al. (2020, p. 1201):

> Type area: Exposures along the Peel River, southwestern Richardson Mountains, Yukon Territory, Canada
>
> Unit type section: Sections 17-TF-03–J1727-J1611-J1729-J1518 [their Fig. 3]
>
> Located on north side of Peel River spanning 2–3 km upstream and downstream of Aberdeen Canyon, Yukon Territory, Canada
>
> Lower boundary: [F]aulted contact with upper Cronin Formation in prominent north-trending drainage (65.874512, 135.614517) [UTM 8W, 471972.51E, 7306060.09N, NAD 83]
>
> Upper boundary: Sharp contact with basal fine-grained orange-weathering dolosiltites of the Tetlit Formation (65.877133, 135.74485) [UTM 8W, 466031.89E, 7306416.57N, NAD 83]

Lithology, thickness, and contacts

The Mount Hare Formation in the study area is a succession of thin-bedded graptolitic black chert, calcareous and siliceous shale, limestone, and shaly and cherty limestone (Fig. 4, 6). At its reference section (*see* Fig. A-3), it is 455 m thick (including the Aitch Member). The upper interval is the Aitch Member, which is a 104 m succession dominated by limestone with chert, limestone, and shaly limestone (*see* Fig. A-3). Below that interval, the succession is dominated by chert and siliceous shale. On traverses we found two occurrences of basic volcanic rocks: a lapilli tuff at the base of the Mount Hare Formation and a tuffaceous siltstone within the Mount Hare Formation. Strauss et al. (2020) also mentioned "rare tephra horizons" and "bentonite"; see their text below.

The lower contact at the reference section is relatively sharp, passing from yellowish weathering limestone of the Cronin Formation into calcareous shale of the Mount Hare Formation (*see* Fig. A-3). On the east side of the Richardson anticlinorium, the lower contact is also abrupt: shaly Cronin Formation dolomite is in direct contact with black chert and shale of the Mount Hare Formation (*see* Fig. A-7).

At the reference section, the upper contact with the Tetlit Formation is abrupt and is located where the Aitch Member shaly limestone changes to grey, pale-brown-green-weathering argillite of the Tetlit Formation (*see* Fig. A-3, A-4) and at section 82-CJA-01 (*see* Fig. A-2). At combined section 82-CJA-05–04 (*see* Fig. A-7, A-8), the upper Aitch Member of the Mount Hare Formation is a calcareous black shale with thin beds of limestone and is in abrupt contact with grey, orange-weathering argillites interbedded with calcareous shale and shaly limestone of the Tetlit Formation.

Figure 6. Cliff exposure of the Mount Hare Formation on Rock River. Exposure is mainly shale, siliceous shale, and chert; resistant limestone beds can be seen high in the exposure. Photograph by M.P. Cecile, Geological Survey of Canada, along section 82-CJA-02. ISPG photo 1862-22

The following description is from Strauss et al. (2020, p. 1201):

> Variable succession of black shale, siliceous shale/siltstone, chert, and argillaceous limestone exposed throughout the Richardson Mountains. Basal contact with underlying strata of the Cronin Formation is faulted at type section but regionally is gradational and marked by an increase in shale content. Basal 62 m is dominated by interbedded dark grey to black pyritic calcareous black shale, argillaceous to silicified limestone, chert, and minor grainstone, wackestone, and matrix-supported rudstone. Strata are locally bioturbated and/or graptolitic and contain rare tephra horizons, fossiliferous grainstone or wackestone lenses, soft-sediment deformation, slump folds, and concretionary intervals. These strata are overlain by 100 m of recessive black calcareous and pyritic shale with abundant nodular pyrite concretions and rare graptolites, which are capped by two prominent ~2 m thick carbonate rudstone horizons. These marker beds enable tracing of these strata across a small strike-slip fault and through a broad fold, where they transition into 270 m of interbedded graptolitic black shale, calcareous shale, and dark to light grey lime mudstone, calcisiltite, and fine-grained grainstone. These strata are fine- to medium-bedded and contain remarkably consistent Bouma $T_{ABE–ABCE}$ subdivisions, as well as local slump folds, synsedimentary truncation surfaces, concretionary intervals, chert nodules, and fossiliferous grainstone horizons with shelf-derived corals, gastropods, crinoids, and brachiopod debris. These strata are overlain by 24 m of interbedded graptolitic silicified black

shale and chert with rare bentonite horizons, fossiliferous wackestone or packstone lenses, and carbonate rudstone horizons with planar basal contacts. This highly silicified interval is overlain by the Aberdeen Member, which consists of two >6 m thick amalgamated carbonate rudstone to megabreccia horizons with abundant shelf- and slope-derived clasts and rafts, planar to erosional bases, and discontinuous intervals of black graptolitic shale and calcareous shale. The Aberdeen Member is overlain by 270 m of interbedded black graptolitic calcareous and silicified shale, chert, and minor silicified lime mudstone, wackestone, and grainstone with local bioturbation, slump folds, synsedimentary truncation surfaces, tephra horizons, and silicified carbonate rudstone with shelf- and slope-derived clasts. Locally, these strata contain prominent concretionary intervals that appear to nucleate on porous carbonate rudstone horizons or chaotic slump-folded intervals. In the upper 75 m, these strata host abundant pyritized and silicified fossiliferous rudstone, grainstone, and wackestone horizons with tabulate and rugose corals, nautiloids, gastropods, brachiopods, and crinoids. The upper 20 m of this unit is poorly exposed and consists of recessive black graptolitic and pyritic calcareous shale that is abruptly overlain by resistant strata of the Tetlit Formation.

Sedimentary features

Typically, Mount Hare Formation is thin bedded and laminated and has some massive chert. Some limestone intervals are medium to thick bedded. Evidence of silicification is found in patches and nodules of limestone in chert and of chert in limestone. There is also some calcarenite with ripple crosslaminae and rare intraclast debris flows. In combined section 82-CJA-05–04, a 9 m thick dolomite-cemented parabreccia can be seen at 250 m. Intraclasts are rectangular to spherical. And in the Aitch Member at the reference section, there is a 5 to 10 cm bed of a pebble-sized intraclast orthoconglomerate (*see* Fig. A-7).

Age and fauna

The top 155 m of the underlying Cronin Formation yielded early Early Ordovician (late Skullrockian [late Tremadocian]) conodonts and graptolites collected in an interval 45 to 48 m below the Mount Hare Formation in combined section 82-CJA-05–04 (*see* Fig. A-7, Appendix B). This early Early Ordovician age means that the base of the Mount Hare Formation is as young as or younger than late Skullrockian (late Tremadocian).

Ages in the reference section (*see *Fig. A-3)

In the following description, 'metre' values indicate the distance from the base of the Mount Hare Formation at its reference section. All the faunal data can be found in Appendix B. Graptolites from 7 to 13 m are from the Early Ordovician *Tetragraptus fruticosus* and *Isograptus victoriae* zones (latest Tremadocian to early Floian) (Carter and Churkin, 1977). From 27 to 105 m, graptolites are from the early Middle Ordovician *Paraglossograptus tentaculatus* Zone; and from 205 to 269 m, graptolites are from the late Middle or Late Ordovician *Nemagraptus gracilis–Climacograptus bicornis* to *Dicellograptus complanatus–Dicellograptus ornatus* zones. Graptolites from 306 to 336 m are from the early Silurian (late Llandovery) *Monograptus turriculatus* Zone; and finally, from 424 to 434 m, graptolites are from the latest early Silurian *Cyrtograptus sakmaricus–Cyrtograptus laqueus* Zone. Thus, the Mount Hare Formation, at its reference section, ranges in age from early Early Ordovician (latest Tremadocian to Floian) to latest early Silurian.

Ages in combined section 82-CJA-05–04 (see Fig. A-7) parallel to the original Road River Formation type section and below the* Monograptus spiralis *Zone

In the following description, 'metre' values indicate the distance from the base of Mount Hare Formation at combined section 82-CJA-05–04 (*see* Fig. A-7). All the faunal data can be found in Appendix B. Graptolites from the Cronin Formation 45 to 48 m below the Mount Hare Formation are from the early Early Ordovician *Isograptus tenuis* Zone. Graptolites at 52, 83, 84, 118, and 125 m above the base of (and in) the Mount Hare Formation are from the early Middle Ordovician *Paraglossograptus tentaculatus* Zone. Graptolites at 193 and 198 m above the base of the Mount Hare Formation are from the late Middle Ordovician *Nemagraptus gracilis–Climacograptus bicornis* Zone. Graptolites from 260 m above the base of the Mount Hare Formation are from the early Silurian (late Llandovery) *Monograptus turriculatus* Zone, and graptolites from 281, 304, and 318 m above the base of the Mount Hare Formation are also late Llandovery, but from the *Monograptus spiralis* Zone. Conodonts from chip samples mainly in the Aitch Member are late Llandovery–early Wenlock (early to middle Silurian). Additional data on Mount Hare Formation conodont biostratigraphy can be found in McCracken (1991a).

Strauss et al. (2020) showed the Mount Hare Formation as being as old as late Cambrian (Furongian) and ranging through the Early Ordovician (Tremadocian). Their supplemental Figure S3, with these age data, shows a succession of strata that we would mostly assign to Cronin Formation. But they have assigned these strata to the Mount Hare Formation?

Distribution

The Mount Hare Formation is found throughout the Richardson anticlinorium in northern Yukon (Fig. 1).

Correlation

The Mount Hare Formation is correlative with similar basin facies strata throughout the Canadian Cordillera (Fig. 3). It is similar in facies, lithology, and thickness to the Duo Lake Formation and the Cloudy Formation in the Misty Creek Embayment to the southeast (Cecile, 1982). The Cloudy Formation is correlative with the limestone-dominated Aitch Member at the top of the Mount Hare Formation. The Mount Hare Formation is also similar to the Ospika Formation in Kechika Trough, northern British Columbia (units OR1-5 and SL of Cecile and Norford (1979, 1993); and the Ospika Formation of Pyle and Barnes (2003)). The Ospika Formation has three limestone members at its top (Findlay, Chesterfield, and Finbow members of Pyle and Barnes (2003)), all of which may correlate with the Aitch Member of the Mount Hare Formation. Finally, the lower to middle Mount Hare Formation is equivalent to the Glenogle Formation in White River Embayment, southern Cordillera (Cecile and Norford, 1993). An equivalent to the Aitch Member is likely missing, due to erosion, in the White River Embayment. The upper Mount Hare Formation, including the Aitch Member, is also equivalent to the platform facies Mount Kindle Formation and a limestone equivalent of the Mount Kindle Formation in the flanking Lac des Bois and Porcupine platforms (Cecile et al., 1997) (Fig. 4; *see* Fig. A-1, A-11, A-12). The Middle Ordovician is apparently missing from platform strata immediately adjacent to the Richardson Trough, but biostratigraphic control in the adjacent wells is sparse, particularly in the limestone unit shown in Figure A-12 (*see* Appendix A).

In the Richardson Trough, the Mount Hare Formation is the upper part of Norris's (1981b, c) ЄDR1 map unit, which is a combination of the Cronin and Mount Hare formations of this report.

Interpretation

The Mount Hare Formation represents both deep-water basinal and transitional (carbonate) to platform facies. Water depths would have ranged from below to above the carbonate compensation depth.

Tetlit Formation (new, Road River Group)

Reference section

The reference section (*see* Fig. A-2) for the Tetlit Formation (section 82-CJA-01, M.P. Cecile) is on a ridge east of Milepost 412, Dempster Highway, in Mount Hare map area NTS 116-I/9. The base of this section is in uppermost Mount Hare Formation at UTM 8W, 443016E, 7391532N, NAD 83, and the top is in lowermost Vittrekwa Formation at UTM 8W, 442759E, 7391400N, NAD 83. Tetlit Formation is named after Tetlit Creek, which is located across the northern Tetlit Creek map area, NTS 106-L/12, in our study area. In the Gwich′in language, the community of Fort McPherson is known as Tetlit zheh (Gwich′in Council International, 2020).

Type section

The following description of the Tetlit Formation type section is from Strauss et al. (2020, p. 1202):

> Type area: Exposures along the Peel River, southwestern Richardson Mountains, Yukon Territory, Canada
>
> Unit type section: Sections 15-TF-05 and 15-TF-07 [their Fig. 3]
>
> Located on north side of Peel River ~1–2 km upstream of Aberdeen Canyon, Yukon Territory, Canada
>
> Lower boundary: [A]brupt contact with calcareous shale of the upper Mount Hare Formation (65.877133, 135.74485) [UTM 8W, 466031.89E, 7306416.57N, NAD 83]
>
> Upper boundary: Gradational contact with black calcareous shale and limestone of the Vittrekwa Formation (65.872833, 135.7577) [UTM 8W, 465440.11E, 7305944.33N, NAD 83]

Lithology, thickness, and contacts

The Tetlit Formation at its reference section consists of brown-weathering green argillite with prominent ribs of orange-weathering, light grey crystalline dolostone (Fig. 4, 7). At sections north and southeast of the reference section the dolostones are replaced by yellow- and orange-weathering shaly limestone. The Tetlit Formation parts into flaggy and platy sheets and is likely thin bedded.

At the reference section, on the west side of the Richardson Trough, the Tetlit Formation is 190 m thick; north of the reference section, at section 82-CJA-02 (northwest Richardson Trough), it is 90 m thick; and in well Mobil Gulf Caribou YT N-25, on the east side of the trough, it is 41.5 m thick (*see* Fig. A-11). It is missing beneath the Early to Middle Devonian sub-Tatsieta Formation unconformity on the northwest side of the anticlinorium (well Socony Mobil Western Minerals South Tuttle YT N-05; *see* Fig. A-12).

Contacts are distinct and marked by the first appearance of brown-weathering green argillite above the Mount Hare Formation; the last appearance of argillite going upward marks the contact with the Vittrekwa Formation. At the base

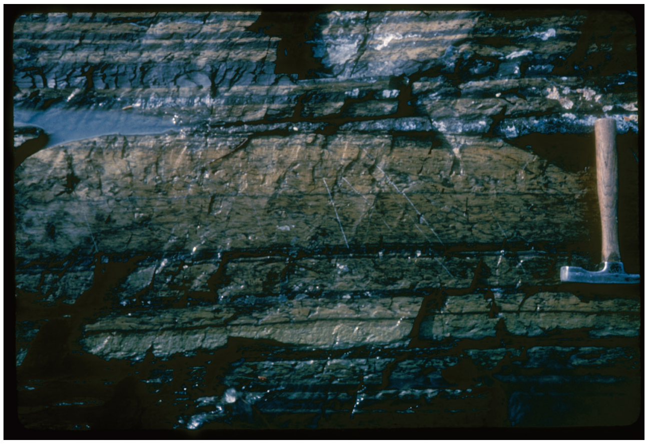

Figure 7. Photograph of Tetlit Formation argillites. Note hammer handle perpendicular to cross-section of feeding trails in the centre argillite. Photograph by M.P. Cecile, Geological Survey of Canada, along section 82-CJA-02, on White Fox Creek. NRCan photo 2019-738

of the reference section, at the base of section 82-CJA-02, and on the east side of the Richardson Trough at combined section 82-CJA-05–04, Tetlit Formation argillite is in contact with Aitch Member shaly limestone. The upper contact at the reference section is marked by an interval of Tetlit Formation argillite talus below black siliceous shale of the Vittrekwa Formation. At the upper contact of section 82-CJA-02, Tetlit Formation argillite is in contact with Vittrekwa Formation black calcareous shale. In the east, at combined section 82-CJA-05–04, Tetlit Formation argillite is in contact with Vittrekwa Formation thin-bedded shaly limestone.

The following description is from Strauss et al. (2020, p. 1202). The Tetlit Formation consists of

> variable succession of black shale, siliceous and calcareous shale/siltstone, argillaceous and dolomitic limestone, and minor chert exposed throughout the Richardson Mountains. Basal contact with underlying strata of the Mount Hare Formation is marked by an abrupt transition from recessive, calcareous black shale of the upper Mount Hare Formation into resistant orange-yellow-weathering dolosiltite and very-fine-grained dolograinstone of the basal Tetlit Formation. Lower 25 m dominated by interbedded orange-yellow-weathering dolosiltite and fine-grained dolograinstone, black to dark grey shale and calcareous shale, dark grey to brown silicified lime mudstone and calcisiltite, and fossiliferous carbonate rudstone and wackestone. Bioturbation, slump folds, synsedimentary truncation surfaces, and distinct Bouma T_{ABCDE} subdivisions are present throughout this interval with the orange-weathering dolomitic beds forming prominent cliffs dominated by medium to thick bedding. These strata are overlain by 20 m of poorly exposed and recessive calcareous black shale and then a second 15 m thick cliff-forming orange-weathering dolosiltite and very-fine-grained dolograinstone succession with local fossiliferous and bioturbated intervals. The overlying 55 m of the Tetlit Formation is dominated by interbedded calcareous and graptolitic shale, calcisiltite, very fine- to coarse-grained grainstone, wackestone, and minor carbonate rudstone. These heterogeneous strata contain Bouma T_{ABCE} subdivisions, channelized horizons, slump folds, erosional scours with shale rip-up clasts, shelf- and slope-derived matrix-supported rudstones, and local evidence for bioturbation and prominent concretionary intervals. This unit is overlain by 100 m of fine-grained strata dominated by black shale that is variably calcareous and silicified, with occasional intervals of thin-bedded calcisiltite and very-fine-grained grainstone, fossiliferous rudstone and wackestone, and concretionary intervals that are nucleated on coarse-grained lithofacies. The contact with the overlying Vittrekwa Formation is a gradational transition into calcareous shale and mudstone that is locally marked by a prominent concretionary interval.

Sedimentary features

The Tetlit Formation argillites are commonly laminated, and the dolostone is microcrystalline and featureless. Feeding trails are commonly abundant in the argillite (Fig. 7). Large, metre-scale slump folds were observed along section 82-CJA-02 in White Fox Creek by L.S. Lane (pers. comm., 2019).

Age and fauna

At the reference section, four dolostone beds were sampled for conodont analysis. These were at 38 to 40, 68, 113 to 115, and 140 to 140.8 m. No conodonts were recovered (*see* Appendix B). Chip samples from the upper two thirds of the Tetlit Formation and the bottom approximately 25 m of the Vittrekwa Formation at section 82-CJA-02 were also barren of conodonts.

Chip sampling through most of the lower half of the Tetlit Formation at combined section 82-CJA-05–04 yielded Silurian conodonts (*see* Appendix B). Chip samples spanning the upper 70 m of the Mount Hare Formation and lower 30 m of the Tetlit Formation at section 82-CJA-02 (*see* Fig. A-3) gave an early Silurian (late Llandovery or younger) age for both the upper Mount Hare and lower Tetlit formations. At section 82-CJA-05–04 (*see* Fig. A-8), chip sampling through the upper half of Tetlit Formation into the basal 30 m of Vittrekwa Formation yielded latest Silurian (late Pridoli) to early Devonian (Lochkovian) ages (for both the upper half of the Tetlit and lowermost Vittrekwa formations; *see* Appendix B).

Thus, given that the youngest Mount Hare Formation ages are latest early Silurian, the Tetlit Formation ranges from as old as latest early Silurian to as young as earliest Devonian. Additional data on Tetlit Formation conodont biostratigraphy can be found in McCracken (1991b).

Strauss et al. (2020; their Fig. S6) reported on several graptolite collections in the Tetlit Formation ranging through the middle and late Silurian (Wenlock to Ludlow). At the top of their section is a unit of Vittrekwa Formation dated as late Silurian (Pridoli).

Distribution

The Tetlit Formation is found throughout the Richardson anticlinorium in the northern Yukon (Fig. 1).

Correlation

The Tetlit Formation is similar to and correlates with the Silurian argillite unit in the Babbage Basin (Cecile, 1988; Lane and Cecile, 1989; Cecile and Lane, 1991). The Tetlit Formation is partly time correlative with the Cloudy Formation, or a correlative unit is missing due to Devonian erosion in the Misty Creek Embayment. It correlates with, and is very similar to, the Steel Formation (Gordey and Anderson, 1993; Cecile, 2000) in the Selwyn Basin. And it correlates with and is similar to the Silurian argillite unit in northeastern British Columbia (Cecile and Norford, 1979), which is now the Kwadacha Formation (Pyle and Barnes, 2000). It is also partly correlative with the Delorme Group (Peel and Tatsieta formations (Pyle et al., 2007)) on the Lac des Bois Platform (Fig. 3). Given its conodont ages, which it shares with the lower Vittrekwa Formation, it could be as young as Early Devonian and could correlate with parts of the Arnica Formation on the Lac des Bois Platform and/or a variety of other Early Devonian carbonate units recognized in the northern Yukon.

In the Richardson Trough, the Tetlit Formation is equivalent to Norris's (1981b, c) ЄDR3 map unit.

Interpretation

Thin bedding and the lack of shallow-water features suggest relatively deep water (but in places above the carbonate compensation depth and below the storm wave-base).

Vittrekwa Formation (new, Road River Group)

Reference section

The reference section for the Vittrekwa Formation (*see* Fig. A-4) (section 82-CJA-02, M.P. Cecile) is on White Fox Creek in Mount Cronin map area NTS 116-I/16 (Fig. 1). The base of this section starts in Cronin Formation (*see* Fig. A-3) at UTM 8W, 446890E, 7422266N, NAD 83, and the top is at UTM 8W, 442250E, 7422866N, NAD 83, at the contact between the Vittrekwa and Canol formations. Vittrekwa Formation is named after the Vittrekwa River, which flows from the northwest and across northern Tsih Mountain map area NTS 106-L/13 in our study area.

Type section

The following description of the Vittrekwa Formation type section is from Strauss et al. (2020, p. 1203):

> Type area: Exposures along the Peel River, southwestern Richardson Mountains, Yukon Territory, Canada
>
> Unit type section: Sections 15-TF-05–J1609–J1610 [their Fig. 3]
>
> Located on south side of the Peel River ~1–4 km upstream of Aberdeen Canyon, Yukon Territory, Canada
>
> Lower boundary: [G]radational contact with upper Tetlit Formation (65.872833, 135.7577) [UTM 8W, 465440.11E, 7305944.33N, NAD 83]
>
> Upper boundary: [S]harp contact with bedded chert of the Canol Formation (65.866016, 135.845633) [UTM 8W, 461419.30E, 7305235.77N, NAD 83]

Lithology, thickness, and contacts

At its reference section, northwestern Richardson Trough, the Vittrekwa Formation is 310 m thick and consists of a lower succession of shaly limestone and limestone units, split by a unit of siliceous shale and black chert. The middle part of the section is a succession of siliceous and calcareous shale. The upper part consists of black shale, followed by a mixed succession of black dolomite and calcareous shale, followed by more siliceous and calcareous shale, and followed finally by a 50 m covered interval (*see* Fig. A-4). The dolomite likely comes from the Porcupine Platform and/or Lac des Bois Platform. At the reference section, the lower contact is distinct and defined by Tetlit Formation argillite changing to Vittrekwa Formation black calcareous shale. The upper contact is not exposed.

On traverses on the west side of the Richardson anticlinorium, we often found that the shale and siliceous shale portions of the Vittrekwa Formation were preferentially exposed, likely because they are more resistant to weathering than the carbonate-rich rocks.

On the east side of the Richardson anticlinorium, at combined section 82-CJA-05–04, the Vittrekwa Formation is a 290 m thick succession of thin-bedded calcareous and siliceous shale and shaly limestone (*see* Fig. A-8, A-11). The presence of a succession of intraclast breccia ('limestone member' in the middle of this succession; *see* Fig. A-8) suggests proximity to a slope connecting the basin to the Lac des Bois Platform. At this section, the lower contact from Tetlit Formation argillite to yellow-weathering Vittrekwa Formation shaly limestone is distinct, and the upper contact is defined where Vittrekwa Formation black shale changes to Canol Formation black chert.

The following description of the Vittrekwa Formation is from Strauss et al. (2020, p. 1203).

> Variable succession of black shale, calcareous shale/siltstone, chert, and argillaceous limestone exposed throughout the Richardson Mountains. Basal contact with underlying strata of the Tetlit Formation is gradational and marked by an increase in calcareous shale content and decrease in coarser-grained lithofacies. Lower 92.9 m dominated by interbedded recessive dark grey to black calcareous and pyritic shale, calcisiltite, and fine-grained bioclastic to silicified grainstone with Bouma T_{ABCE} subdivisions, slump folds, synsedimentary truncation surfaces, convolute lamination, concretionary intervals, and localized bioturbation and crinoidal debris. The upper 10–20 m of these strata are duplicated in a small thrust fault at 93 m, which is then overlain by 100 m of dominantly dark grey to black calcareous and pyritic shale, silty lime mudstone, and calcisiltite with resistant intervals dominated by laminated or bioturbated calcisiltite. These strata locally contain concretionary intervals dominated by ~0.5–2 m wide calcareous concretions and local convolute lamination that dissipate up-section. This recessive interval is overlain by 110 m of more resistant and homogeneous calcisiltite, calcareous shale, and silty lime mudstone that contain tentaculids, local concretionary intervals, and zones of thin- to very-thin-bedded Bouma T_{BCE} subdivisions. These strata are overlain by 45 m of very poorly exposed calcareous shale, which are then overlain by 38 m of well-exposed interbedded silicified shale, calcareous mudstone, and siliceous calcisiltite to very-fine-grained grainstone that contain Bouma T_{CDE} subdivisions, local barite nodules and concretions, and abundant pyrite. These strata are abruptly overlain by the very-thin- to thin-bedded black to dark grey chert of the overlying Canol Formation.

Sedimentary features

Bedding is thin to medium thick, massive or finely laminated. There are some limestone nodules with black shale or chert chips, intraclasts, chert and limestone clast conglomerates, and some biocalcarenite. Partings are fissile to blocky. The strata can be pyritic.

Age and fauna

In the reference section (*see* Fig. A-4), the Vittrekwa Formation yielded graptolites of late Silurian (Ludlow) and Early Devonian (Pragian) age. Pragian graptolites were also collected from three traverse locations (*see* Appendix B). In combined section 82-CJA-05–04 (*see* Fig. A-8), the Vittrekwa Formation yielded Early Devonian (early Lochkovian) conodonts and Early Devonian (Pragian) graptolites.

At section 82-CJA-06 (*see* Fig. A-10), a collection of macrofauna yielded echinoderm and bryozoan fragments, straight cephalopods, atrypid and other brachiopods, and *Favosites*? sp. At traverse station 82-CJA-114-2 (C-104241, *see* Appendix B), the following macrofauna were collected from the limestone member of the Vittrekwa Formation: stromatoporoids, alveolitid corals, *Taimyrophyllium* sp. nov. (colonial coral), indeterminate solitary corals, an indeterminate atrypid fragment, and twin-axial crinoid ossicles, all of which gave an age of Early Devonian (Zlichovian, ~ early Emsian). Thus, the Vittrekwa Formation ranges in age from late Silurian (Ludlow) to Early Devonian (Zlichovian).

Strauss et al. (2020) reported Middle Devonian conodonts from the Vittrekwa Formation. They also (p. 1197) reported that "graptolites are more common throughout the Lower Devonian strata, and diagnostic Middle Devonian (*Polygnathus eiflius* to *Polygnathus ansatus* Zone) conodonts were found at the top of the composite section in a thin, mineralized interval beneath the overlying Canol Formation (Gadd et al. 2020)." In their supplemental stratigraphic figures (section J1610), they showed the top approximately 25 m of the Vittrekwa Formation as consisting of Middle Devonian (Eifelian to Givetian) bedded chert and shale.

Distribution

The Vittrekwa Formation is found throughout the Richardson anticlinorium, northern Yukon (Fig. 1).

Correlation

The Vittrekwa Formation correlates with platform carbonates in the flanking Lac des Bois and Porcupine platforms (Fig. 3). These platform carbonates include those of the Ogilvie, Michelle, Cranswick, Tatsieta, Landry, and Arnica formations (*see* Morrow, 1999, his Fig. 4) and the Delorme Group (Peel and Tatsieta formations (Pyle et al., 2007)).

In the Richardson Trough, the Vittrekwa Formation is equivalent to Norris's (1981b, c) ЄDR4 map unit.

Interpretation

The Vittrekwa Formation consists of deep-water basinal facies strata, with some transitional to platform slope breccias on the east of the Richardson Trough (*see* Fig. A-8). Water depths would have ranged from below to above the carbonate compensation depth. A limestone unit at the top of the Vittrekwa Formation in section 82-CJA-06 (*see* Appendix A) contains shallow-water fauna and is likely a tongue of platform carbonate. Intraclast debris flows in section 82-CJA-06 and combined section 82-CJA-05–04 indicate a slope or proximal to slope facies.

Canol Formation, Horn River Group

Type section

The reference section for the Canol Formation is on the northwest side of Powell Creek NTS map area 106-H, Mackenzie Mountains (Chi and Hills, 1981). The top of combined section 82-CJA-05–04 (*see* Fig. A-9) and the top of section 82-CJA-06 (*see* Fig. A-10) are reference sections for the Richardson Trough. Pyle et al. (2014) described the Canol Formation in the area where it overlies Ramparts Formation as a dark grey to black, highly organic and siliceous shale that results in strongly contrasting gamma and sonic logs, compared to the underlying massive Ramparts Formation, and having a pyritic base.

Lithology, thickness, and contacts

On traverses, we found that the Canol Formation in the Richardson Trough is typically a black siliceous shale that is commonly white or white-blue weathering. At section 82-CJA-06, the formation consists of an incomplete 252.5 m section of black siliceous shale and chert with some pyrite and large limestone nodules; and at combined section 82-CJA-05–04, it consists of 100 m of black chert with pyrite nodules overlain by 150 m of siliceous black shale, with large limestone nodules toward the top.

Sedimentary features

The Canol Formation is typically thin bedded with fissile partings. It has small pyrite nodules (centimetres) and large limestone nodules (decametres). Nodules tend to have flat bases and curved tops (Fig. 8) and are thought to have formed contemporaneously with sedimentation. In some cases, large elongate calcite crystals grew at 90° to bedding surfaces to form the nodules (*see* Fig. A-9, A-10). Their formation may be contemporaneous with sedimentation or diagenetic.

Age

In the Richardson Trough, samples collected from limestone nodules at section 82-CJA-06 and combined section 82-CJA-05–04 (*see* Appendix B) were barren of microfossils. At the type section, Chi and Hills (1981) identified Late Devonian (Frasnian) conodonts. Recently, Gouwy refined the faunal identifications at the Powell Creek type section, noting that "the entire Canol Formation is early to middle Frasnian" in age (S.A. Gouwy, unpub. GSC Paleontological Report 3-SAG-201, 2017).

Distribution

The Canol Formation is found over much of Yukon and the western Northwest Territories.

Correlation

The Canol Formation is correlated with the Besa River Formation in northwestern British Columbia (Chi and Hills, 1981).

Figure 8. Limestone nodule in the Canol Formation. Note flat base and curved upper surface. Nodule is 30 cm high and 70 cm long. Photograph by M.P. Cecile, Geological Survey of Canada, along Dempster Highway near the Yukon–N.W.T. border. ISPG photo 1862-14

Interpretation

The Canol Formation is a deep-water euxinic chert and shale facies.

REGIONAL CORRELATIONS BETWEEN NORTHERN BASINS

The sedimentary-fill Road River Group, in the Richardson Trough, is more than 2 km thick and is distinctly similar to basin facies found in its sister rift, the Misty Creek Embayment (Cecile 1982). The Slats Creek Formation is equivalent to the Hess River Formation and Hess River flysch in the Misty Creek Embayment. The Slats Creek Formation and middle Cambrian shale are equivalent to Cambrian argillite, clastic rocks, and/or limestone units in Babbage Basin; and to unconformities and subcarbonate platform units in the Porcupine and Lac des Bois platforms, on Ogilvie Arch, and on the White Mountains Uplift. The Cronin Formation, a basin facies limestone and minor shale succession representing much of the lower half of the Road River Group in the Richardson Trough, is equivalent to, and very similar to, the Rabbitkettle Formation in the Misty Creek Embayment and parts of the Selwyn Basin. The Cronin Formation is not found in the Babbage Basin, where it is equivalent to Cambrian argillites and Ordovician cherts. The Cronin Formation is equivalent to the ЄDb platform carbonate unit of Norris (1981b, c, 1982a, b, c, 1985) and the Bouvette Formation of Morrow (1999) under the Blackstone supra-basin, which Norris described as grey limestone and dolomite with minor shale. In the Porcupine and Lac des Bois platforms, the Cronin Formation is equivalent to the Franklin Mountain Formation. It correlates with the Bouvette Formation (Fig. 3) on the Ogilvie Arch and with the Vunta Formation in the White Mountains Uplift. The Mount Hare and Tetlit formations are equivalent to very thin successions of chert and argillite in the Babbage Basin; also in the Babbage Basin, the Vittrekwa Formation is missing below or incorporated into Devonian clastic rocks. The Mount Hare Formation, the Tetlit Formation, and all or parts of the Vittrekwa Formation are equivalent to the undivided ЄDR (Road River) unit that overlies Norris's ЄDb carbonates in the Blackstone supra-basin and to unconformities and possibly some platform carbonates in the adjacent Porcupine and Lac des Bois platforms, as well as on the Ogilvie Arch and the White Mountains Uplift. And the Mount Hare Formation, the Tetlit Formation, and all or parts of the Vittrekwa Formation are equivalent to the Duo Lake and Cloudy formations in the Misty Creek Embayment (Cecile, 1982).

RICHARDSON TROUGH: PALEOGEOGRAPHY AND TECTONIC HISTORY (RIFTING AND ITS CONNECTION TO A NORTHERN OCEAN)

The geometry and scale of the Richardson Trough compare well with those of segments of the east African rift system (Fig. 2, 9). The Kenya Rift was described by Baker et al. (1977) as a 68 km wide graben with a length of about 120 km and flanked by fault escarpments as high as 1500 m on the west and 200 to 500 m on the east; the rift floor slopes from north to south (900 m change in elevation along the rift). The Richardson Trough is 50 to 70 km wide and 150 to 160 km long and thus is geometrically similar to the Kenya Rift. The Richardson anticlinorium is cut by the Richardson Fault Array (Norris, 1997a, b) (*see* Knorr, Deception, and other faults in Fig. 1). These faults are likely reactivated and expanded versions of the extensional faults that formed the Richardson Trough. The late middle Cambrian to Early Devonian sedimentary basin centre fill is about 3 km thick, compared to 1 km for correlative strata on the edge of adjoining platforms, giving the basin fill a relief of 2 to 3 km (Fig. 4). The presence of lower Paleozoic alkalic basalts in its sister rift, the Misty Creek Embayment, and throughout most of the Canadian Cordillera (Goodfellow et al., 1995) strongly suggests an extensional origin. In addition, geochemical analysis of basin facies strata in the Misty Creek Embayment shows a widespread signature of alkali volcanic input (Goodfellow et al., 1980a, b). We found two occurrences of basic volcaniclastic rocks in the Mount Hare Formation in the Richardson Trough. And Strauss et al. (2020) reported tephras and bentonite in the Mount Hare Formation. In Nash Creek map area NTS 106-D, on the Ogilvie Arch, Green (1972) noted that his unit 5 (Slats Creek Formation), with a thickness exceeding 3500 ft. (1067 m), consisted of sandstone and siltstone with interbedded 'volcanic flows'. D.K. Norris collected a pebble conglomerate with green mafic volcanic clasts from a Slats Creek Formation exposure west of Bonnet Plume Basin (Issler et al., 2021).

On a regional scale, the Richardson Trough, Misty Creek Embayment, Babbage Basin, Blackstone supra-basin, and Mackenzie and Ogilvie arches (Fig. 2) can all be regarded as related basins and uplifts. In fact, the size and geographic distribution of these features and of the Richardson Trough and Misty Creek Embayment compare well to the broad, variously oriented, complex pattern of grabens, horsts, and plateaus associated with the east African rift zone (*see* Brock, 1966, his Fig. 12). In particular, the Richardson Trough and the Misty Creek Embayment are likely distinct segments of a rift system. The known ages of these northern Cordilleran tectonic features suggest that they all probably formed during the late early Cambrian to pre-late Cambrian time

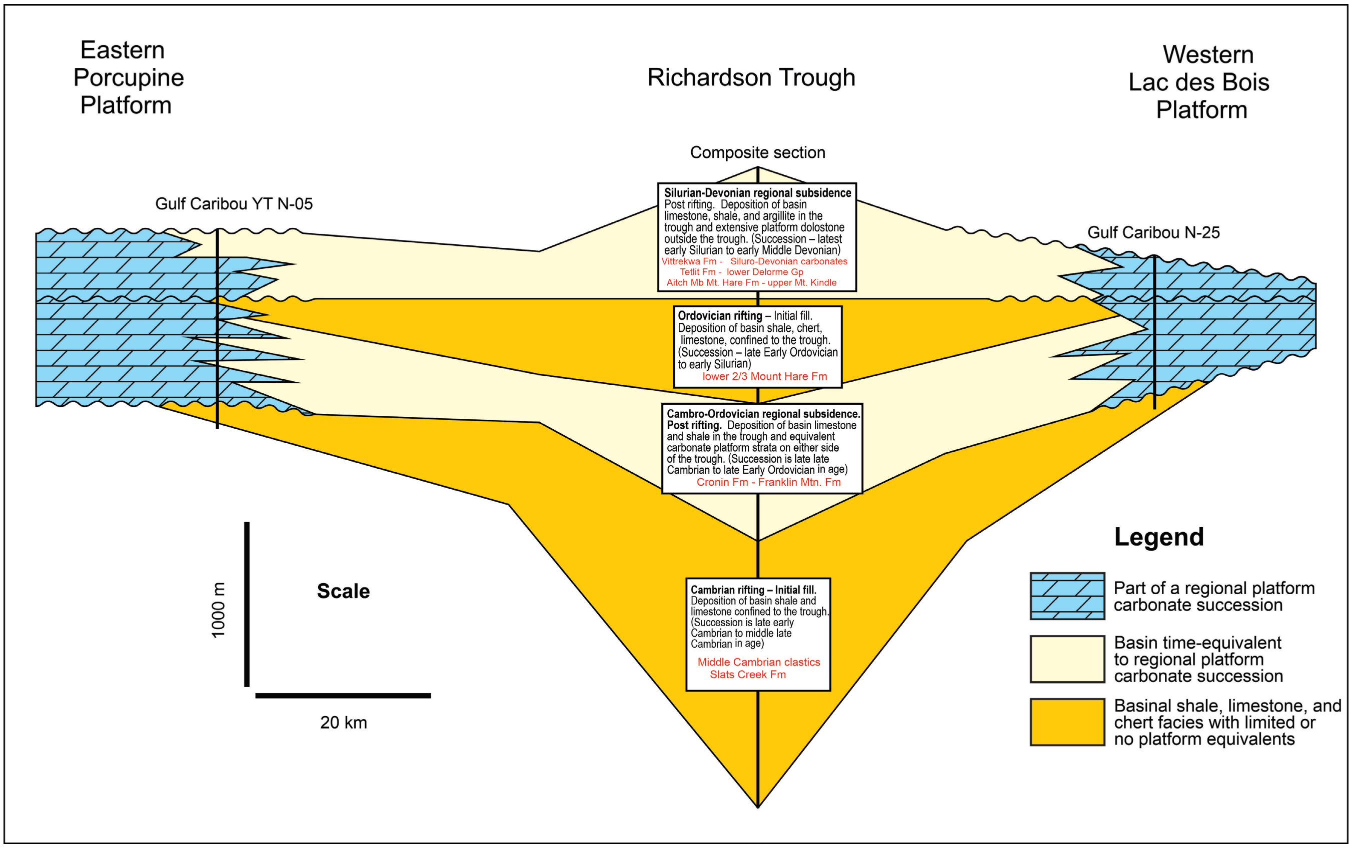

Figure 9. West to east cross-section through the Richardson Trough and into adjacent platforms. The cross-section shows two classic rift 'steer's head' profiles (*after* Dewey (1982) and White and McKenzie (1988)). The first profile shows a cycle of late early to middle late Cambrian rifting followed by late late Cambrian to late Early Ordovician post-rift subsidence. The second shows a cycle of late Early Ordovician to early Silurian rifting followed by late early Silurian to early Middle Devonian post-rift subsidence.

(Fig. 9). The Ogilvie Arch, Mackenzie Arch, and platform areas north and east of the Misty Creek Embayment were also positive areas, undergoing erosion sometime during the Middle Ordovician.

A cross-section through the Richardson Trough, like the Misty Creek Embayment (Cecile et al., 1997), shows the classic rift 'steer's head' profile described by Dewey (1982) and White and McKenzie (1988). This is shown in Figure 9, where two rift cycles are illustrated. The first consists of the Slats Creek Formation and middle Cambrian clastic rocks representing a rift initial fill, followed by Franklin Mountain–Cronin Formation post-rift regional subsidence. The second cycle is recorded by the lower-middle Mount Hare Formation initial rift fill, which was accompanied by a period of erosion between the Franklin Mountain and Mount Kindle formations on the Lac des Bois Platform. This was followed by the upper Mount Hare Aitch Member–Mount Kindle, Tetlit, and Vittrekwa Siluro-Devonian (including Delorme Group and Arnica Formation; *see* Fig. 5 of Morrow (1999)) carbonate deposition associated with regional post-rift subsidence. In addition, this carbonate succession includes a sub-Delorme Group unconformity, which may suggest an additional pulse of rifting during this subsidence.

Lower Paleozoic strata in the arctic North American assemblage comprise a facing west to ocean set of facies belts in the Franklinian Basin (Canadian Arctic Islands) and a facing north to ocean set of facies belts in northern Yukon, Alaska, and Chukotka. These strata indicate that the basin of an ocean, the Iapetus, lay in the position of the present-day Canada Basin during the early Paleozoic (Cecile et al., 2001), thus supporting a triple-junction-rift model for the formation of this lower Paleozoic ocean basin. The arctic Siberian assemblage (i.e. the Siberian Craton) is shown in plate reconstructions as being close to northern North America in the Paleozoic (Lawver et al., 2011). Our data favour a reconstruction where both the Siberian and North American assemblages faced an ancestral ocean (Iapetus Ocean (Johnson et al., 2019)). In this model, the Richardson Trough represents a failed rift, an aulacogen (Burke, 1977), as first proposed by Churkin (1975); the other two rifts opened to form the Babbage Basin in the west and Franklin Basin to the north. Together, they all represent an expanded Franklinian shelf (miogeocline) bordering a northern ocean, given it has deep-water facies sitting on what likely is attenuated basement.

CONCLUSIONS

The Richardson Trough was an aulacogen or failed arm of a triple rift system that formed when a northern ancestral early Paleozoic Ocean developed (Iapetus Ocean (Johnson et al., 2019)). The Richardson Trough displays a classic steer's head profile with two rift fill cycles, one from late early Cambrian to Early Ordovician and the other from late Early Ordovician to Early Devonian. Lower Paleozoic strata exposed in the Richardson Trough range in age from middle Cambrian to early Middle Devonian. In ascending order, these strata are the Slats Creek Formation and the Road River Group.

The Road River Group is divided into new formations, which in ascending order are the Cronin, Mount Hare, Tetlit, and Vittrekwa formations. These Road River Group strata are underlain by the middle Cambrian Slats Creek Formation and overlain by the Late Devonian Canol Formation.

In the Road River Group, the approximately lower half of the Cronin Formation is middle to late Cambrian, most of the rest is late Cambrian, and the topmost interval is Early Ordovician in age. The Mount Hare Formation, at its reference section, ranges in age from early Early Ordovician (early-middle Tremadocian) to latest early Silurian. The Tetlit Formation ranges from as old as latest early Silurian to as young as earliest Devonian. The Vittrekwa Formation ranges in age from late Silurian (Ludlow) to Middle Devonian (Eifelian to Givetian).

The paleogeography of the area surrounding the Richardson Trough is part of a western Franklinian ancestral shelf (miogeocline) in an ocean basin that during the early Paleozoic was located in the position of present-day Canada Basin.

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Appendix A: Stratigraphy

[Appendix A consists of Figures A-1 to A-12]

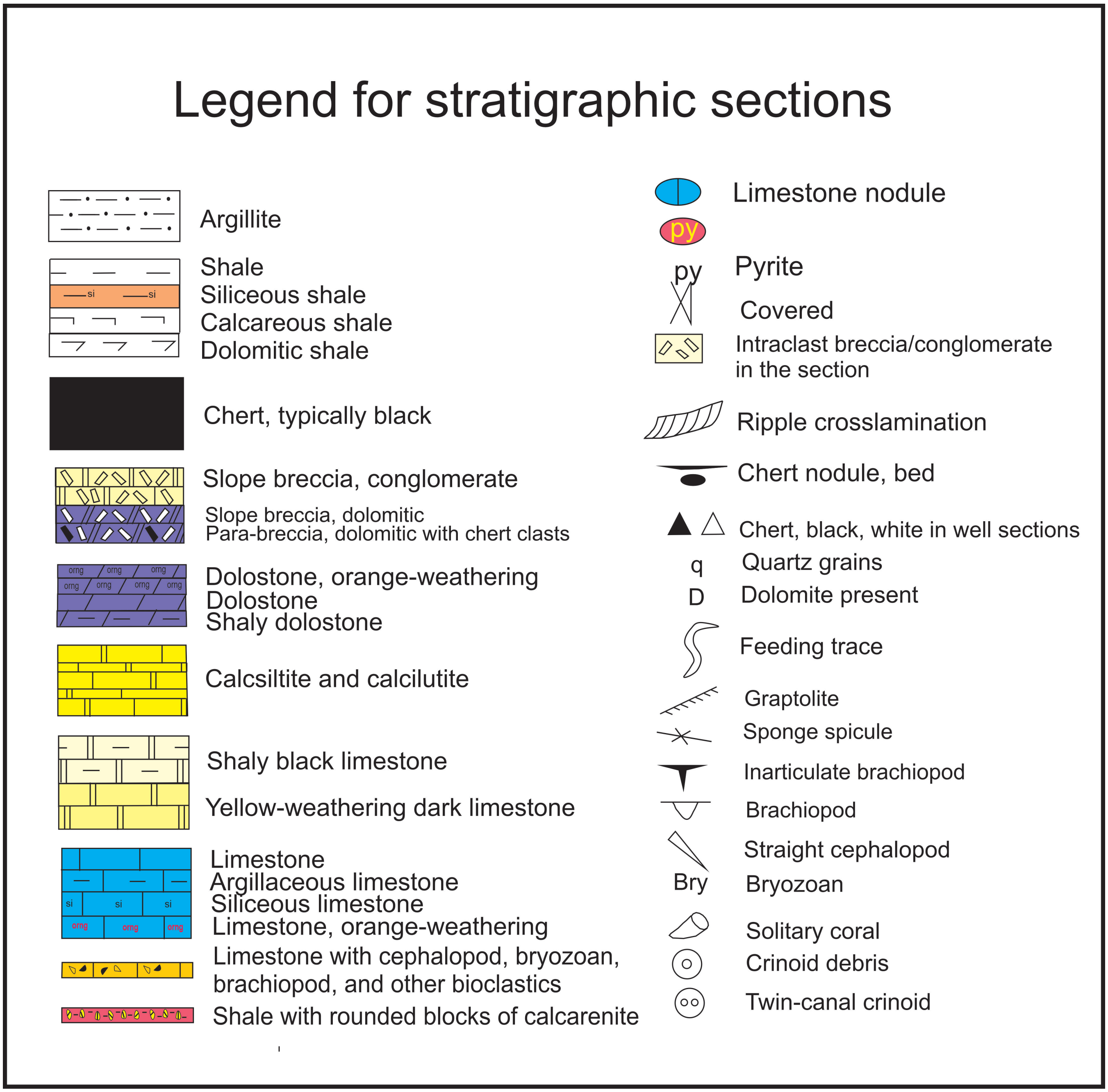


Figure A-1. Legend for stratigraphic figures in Appendix A.

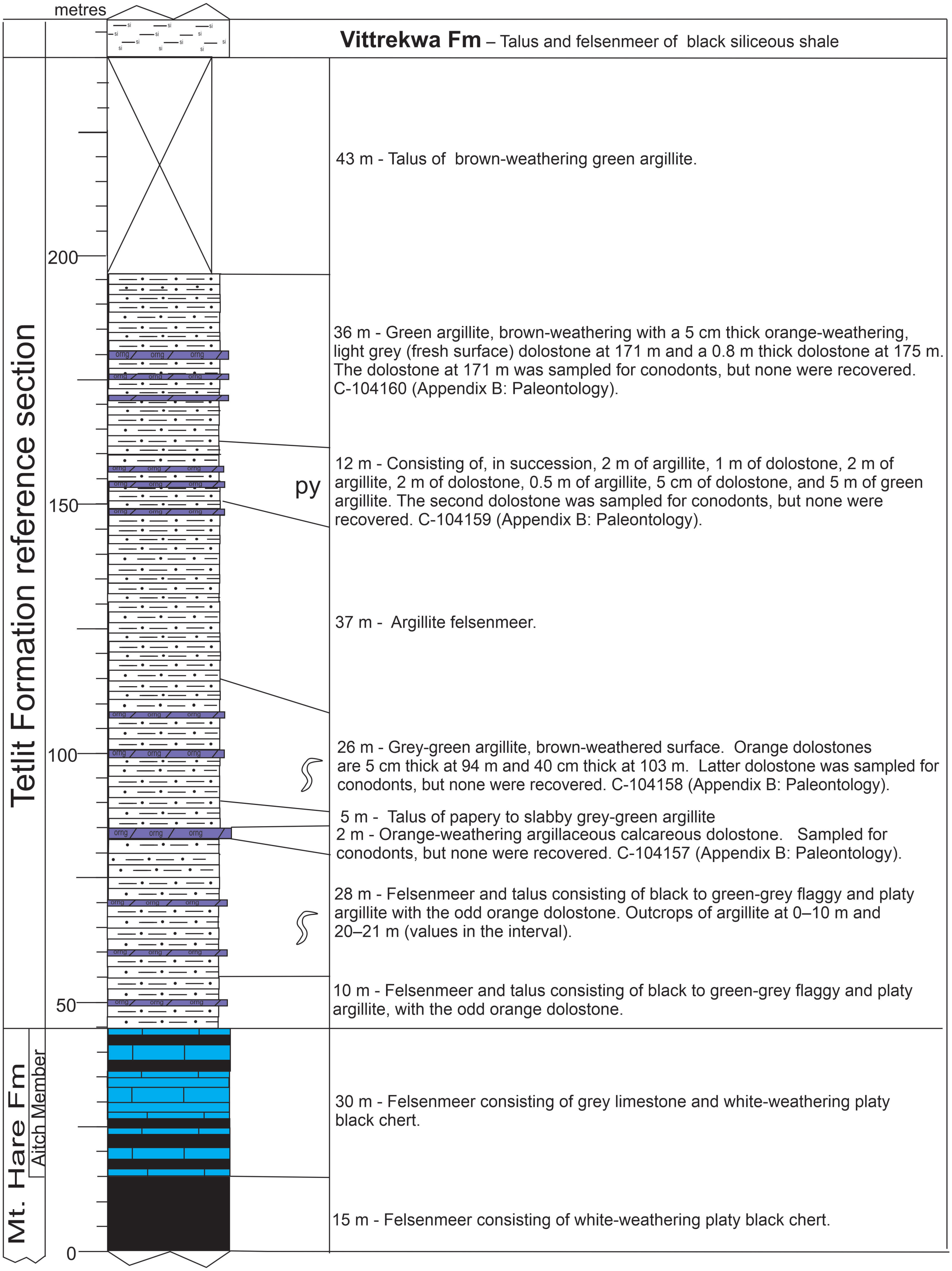


Figure A-2. Reference section of Tetlit Formation. Section 82-CJA-01, M.P. Cecile, located on a ridge east of milepost 412, Dempster Highway, in NTS map area 116-I/9. Base of section is at UTM 8W, 443016E, 7391532N in upper Mount Hare Formation; top is at UTM 8W, 442759E, 7391400N, NAD 83 (North American Datum of 1983), at the contact with Vittrekwa Formation.

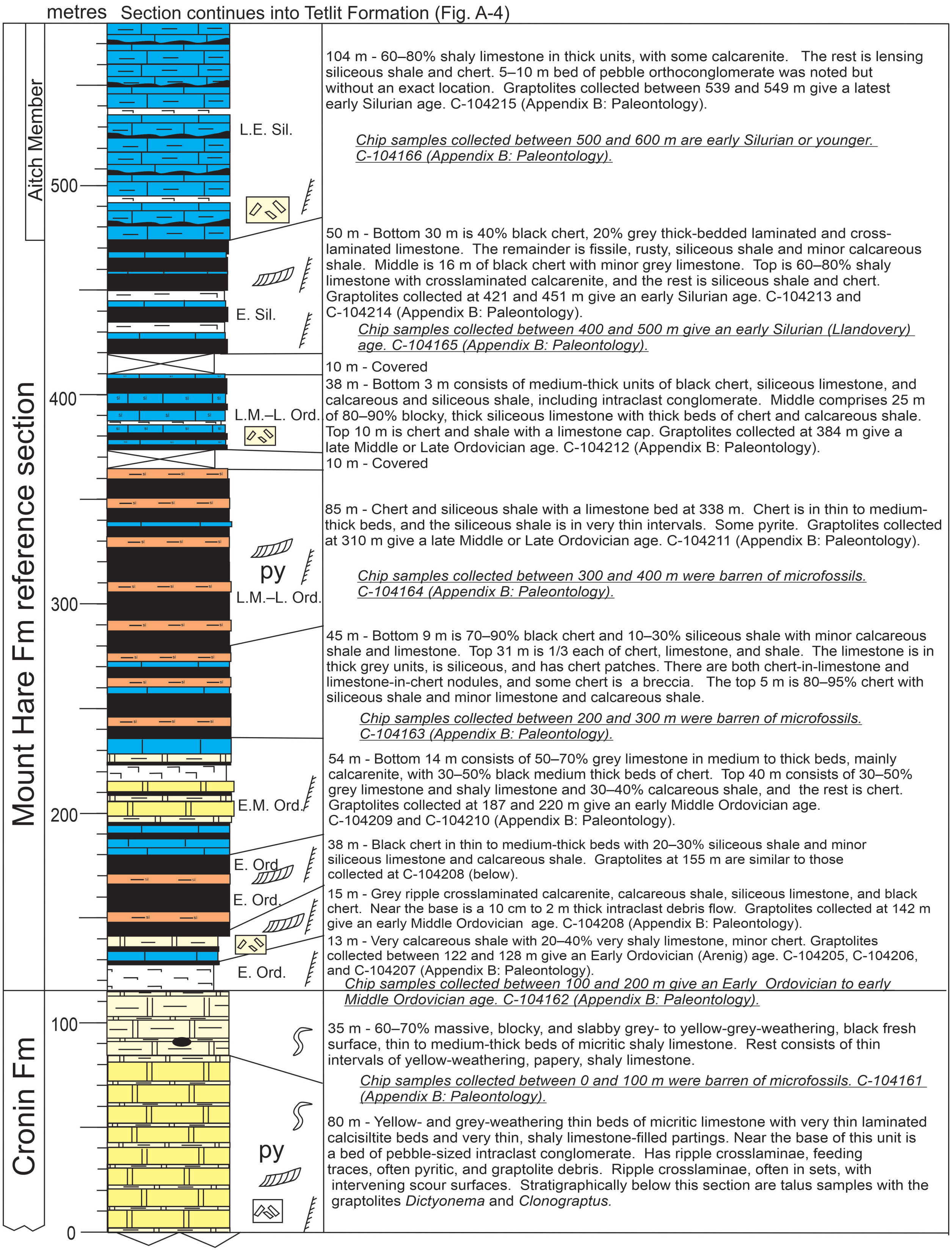


Figure A-3. Reference section of Mount Hare Formation. Lower part of section 82-CJA-02, M.P. Cecile, located on White Fox Creek in NTS map area 116-I/16. Base of section is at UTM 8W, 446890E, 7422216N in upper Cronin Formation; top, at the contact with Tetlit Formation (*see* Fig. A-4), is at UTM 8W, 442266E, 7422866N, NAD 83 (North American Datum of 1983). Age abbreviations from top to bottom: L.E. Sil. = late early Silurian; E. Sil. = early Silurian; L.M.–L. Ord. = late Middle to Late Ordovician; E.M. Ord. = early Middle Ordovician; E. Ord. = Early Ordovician. (Note: lowercase indicates informal time division; uppercase, formal.)

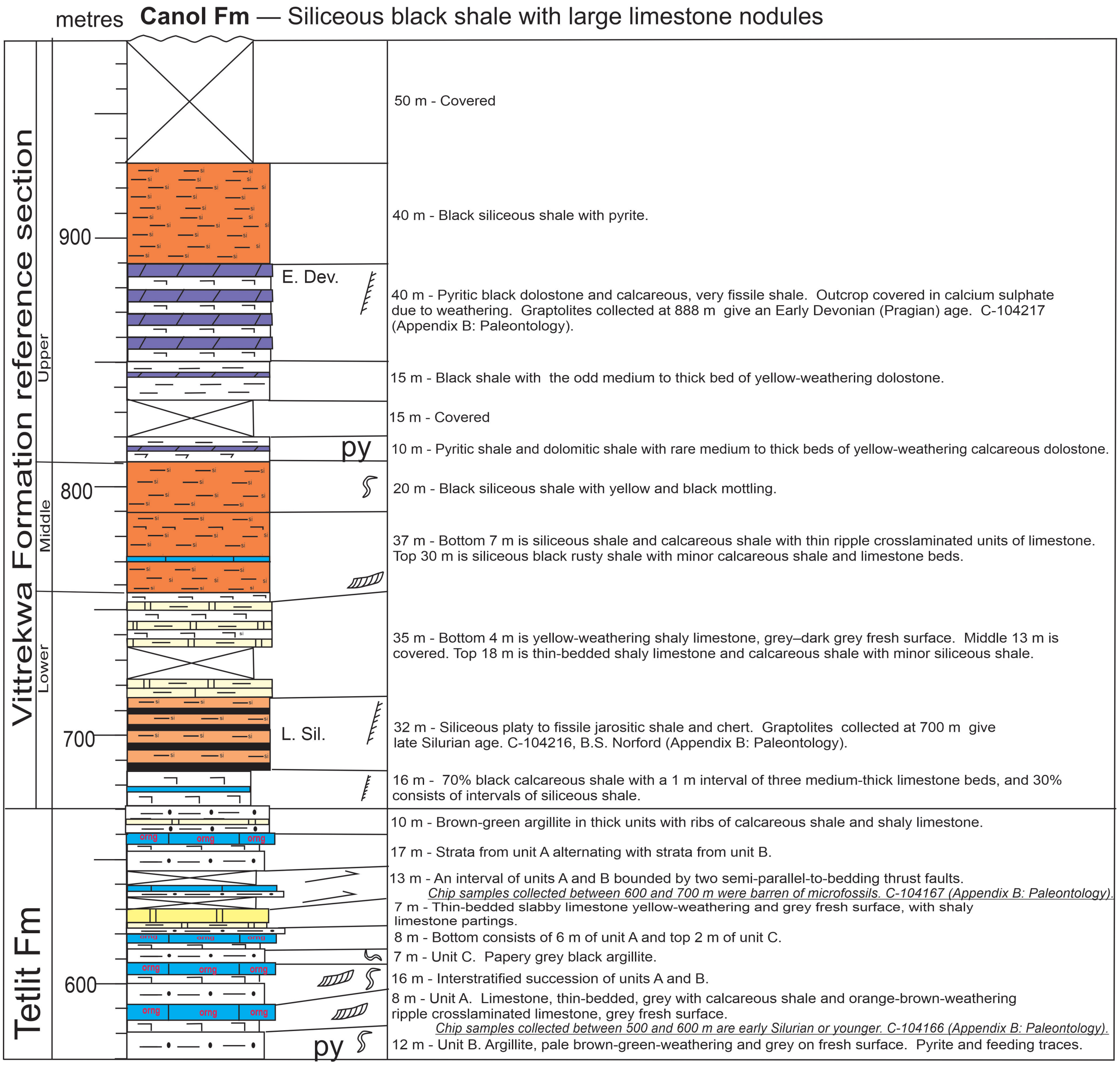


Figure A-4. Reference section of Vittrekwa Formation with Tetlit Formation, upper part of section 82-CJA-02, M.P. Cecile, located on White Fox Creek in NTS map area 116-I/16. Base of section, starting in upper Cronin Formation (*see* Fig. A-3), is at UTM 8W, 446890E, 7422266N; top, at the contact with Canol Formation, is at UTM 8W, 442250E, 7422866N, NAD 83 (North American Datum of 1983). Age abbreviations from top to bottom: E. Dev. = Early Devonian; L. Sil. = late Silurian. (Note: lowercase indicates informal time division; uppercase, formal.)

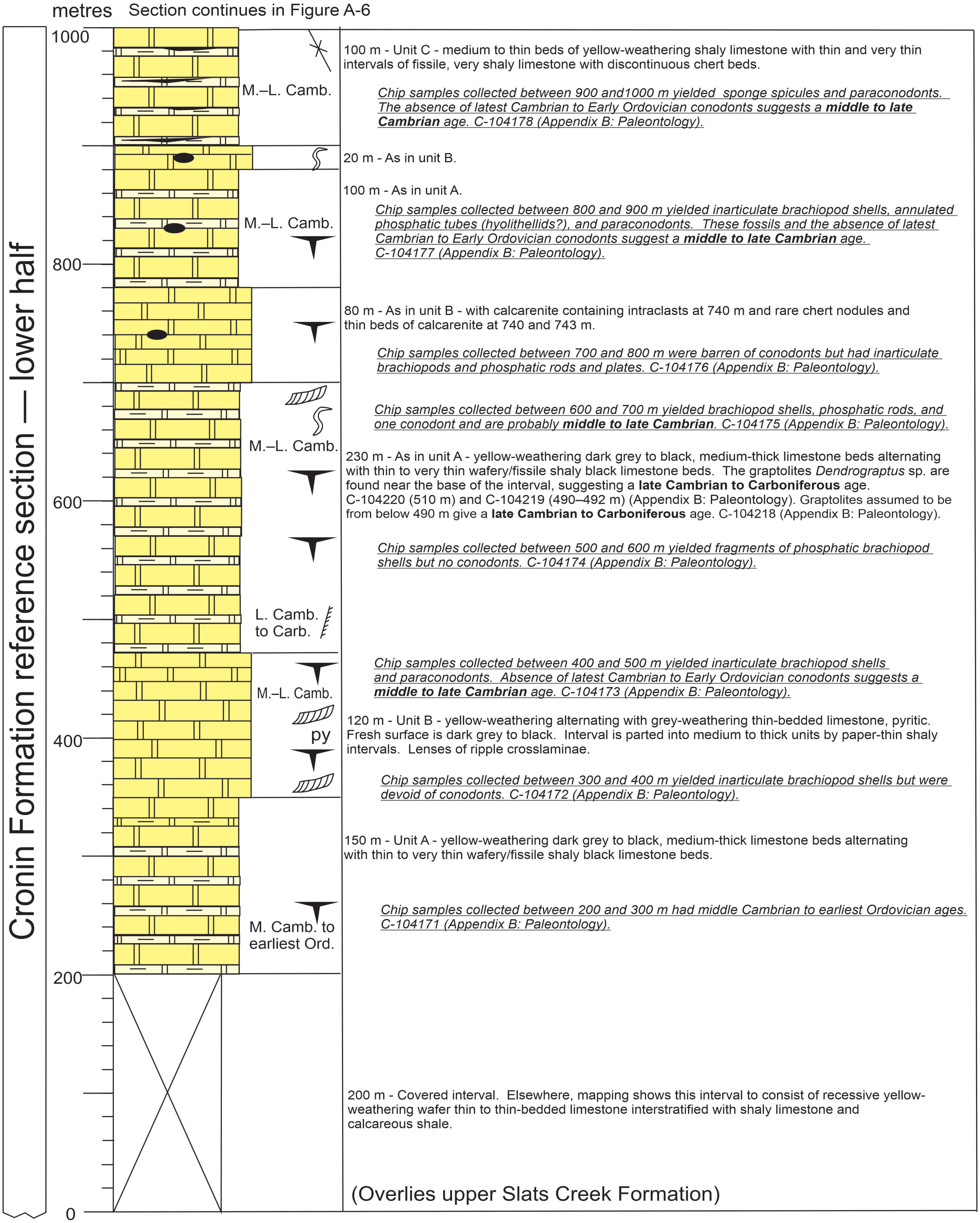


Figure A-5. Lower half of reference section of Cronin Formation (upper half is shown in Fig. A-6). Section 82-CJA-03, M.P. Cecile, located on Rock River in NTS map area 116-I/16. Base of section is at UTM 8W, 449099E, 7403767N, NAD 83 (North American Datum of 1983). Age abbreviations from top to bottom: M.–L. Camb. = middle to late Cambrian; L. Camb. to Carb. = late Cambrian to Carboniferous; M.–L. Camb. = middle to late Cambrian; M. Camb. to earliest Ord. = middle Cambrian to earliest Ordovician. (Note: lowercase indicates informal time division; uppercase, formal.)

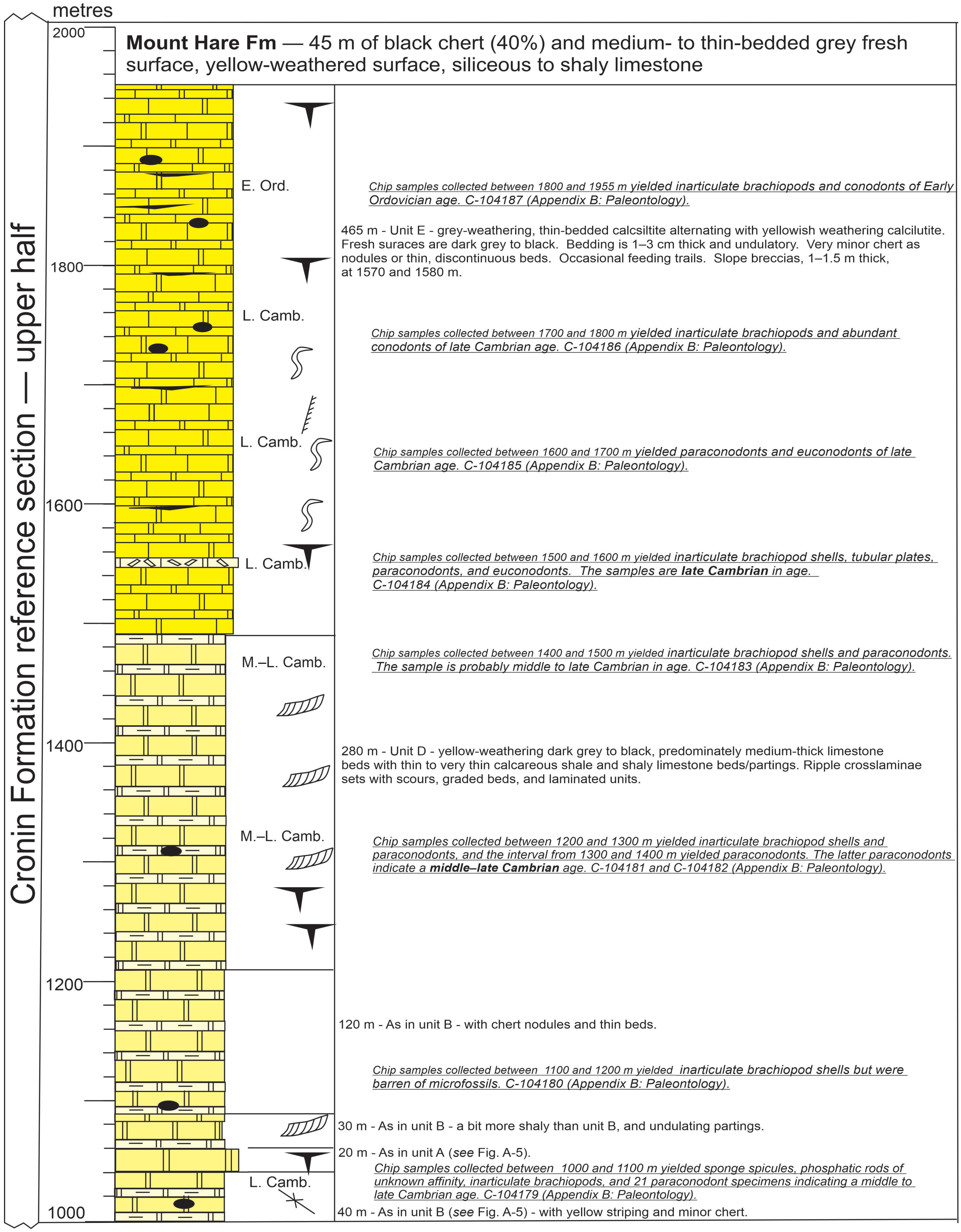


Figure A-6. Upper half of reference section of Cronin Formation (lower half is shown in Fig. A-5). Section 82-CJA-03, M.P. Cecile, located on Rock River in NTS map area 116-I/16. Top of section in lower Mount Hare Formation is at UTM 8W, 443349E, 7406667N, NAD 83 (North American Datum of 1983). Age abbreviations from top to bottom: E. Ord. = Early Ordovician; L. Camb. = late Cambrian; M.–L. Camb. = middle to late Cambrian; L. Camb. = late Cambrian. (Note: lowercase indicates informal time division; uppercase, formal.)

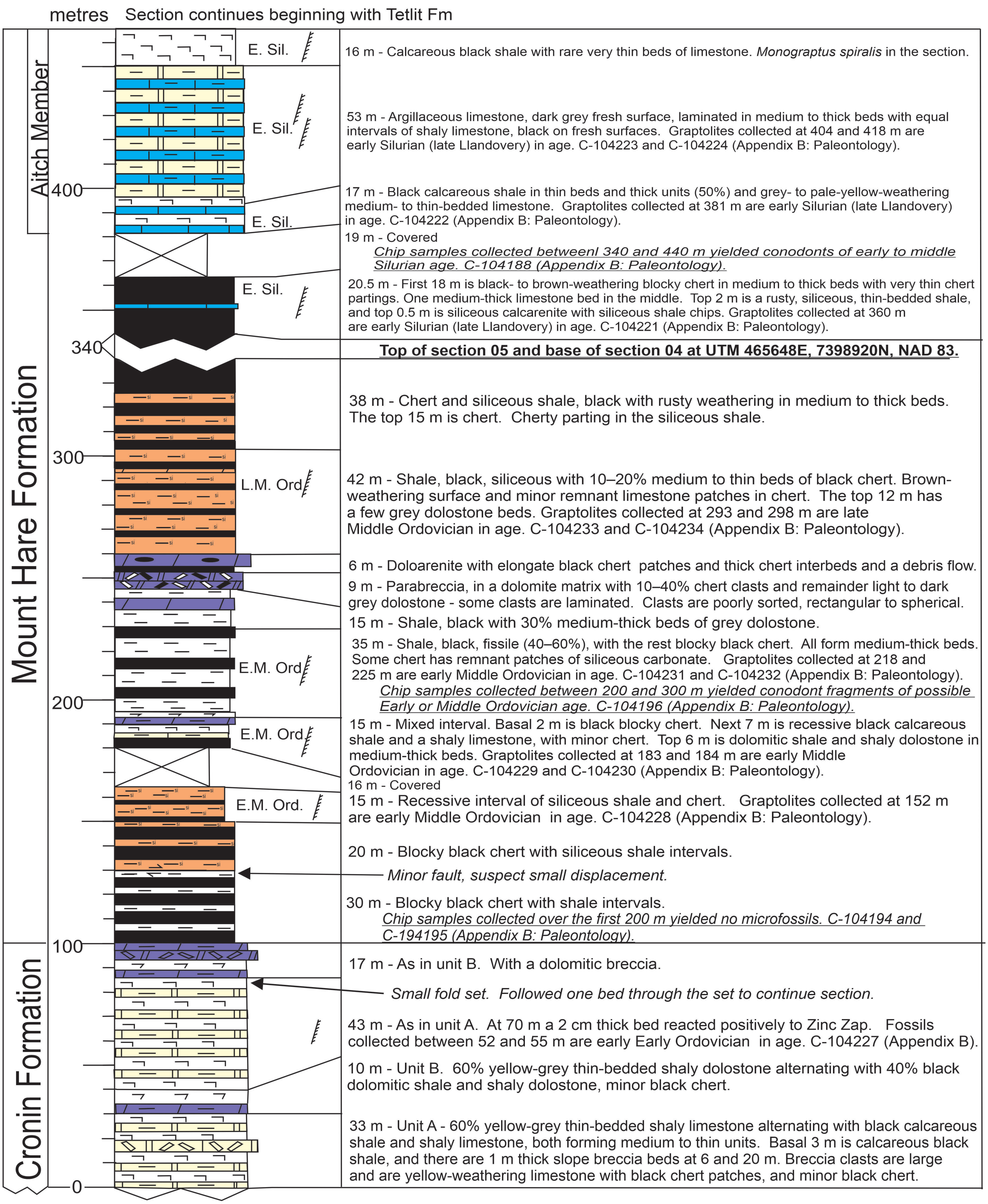


Figure A-7. Cronin Formation to Mount Hare Formation. Bottom part of combined sections 82-CJA-05 and 82-CJA-04, M.P. Cecile, located on Tetlit Creek in NTS map area 106-L/12, 2 km south of the type Road River Formation (Jackson and Lenz 1962). Base of combined section, which is the base of section 05 in upper Cronin Formation, is at UTM 8W, 463898E, 7398569N, NAD 83 (North American Datum of 1983). Here, top of section 05 joins the base of section 04 at 340 m, which is located at UTM 8W, 465648E, 7398920N, NAD 83. Section continues in Figures A-8 and A-9. Age abbreviations from top to bottom: E. Sil. = early Silurian; L.M. Ord. = late Middle Ordovician; E.M. Ord. = early Middle Ordovician. (Note: lowercase indicates informal time division; uppercase, formal.)

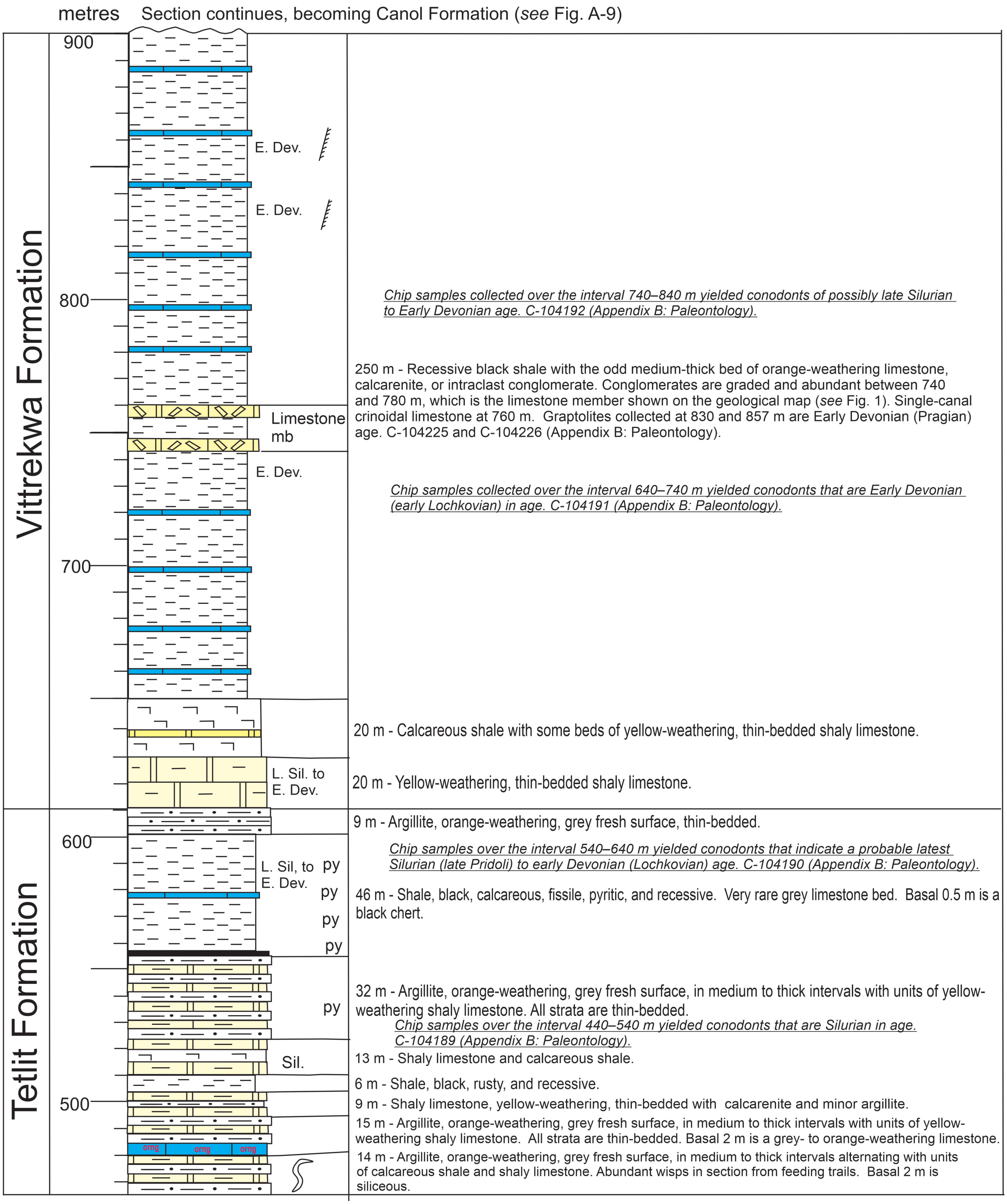


Figure A-8. Middle part of sections 82-CJA-05 and 82-CJA-04, Tetlit and Vittrekwa formations, on Tetlit Creek in NTS map area 106-L/12. *See* Figure A-7 for location and section data. Section continues from Figure A-7 and into Figure A-9. Age abbreviations from top to bottom: E. Dev. = Early Devonian; L. Sil. to E. Dev. = late Silurian to Early Devonian; Sil. = Silurian. (Note: lowercase indicates informal time division; uppercase, formal.)

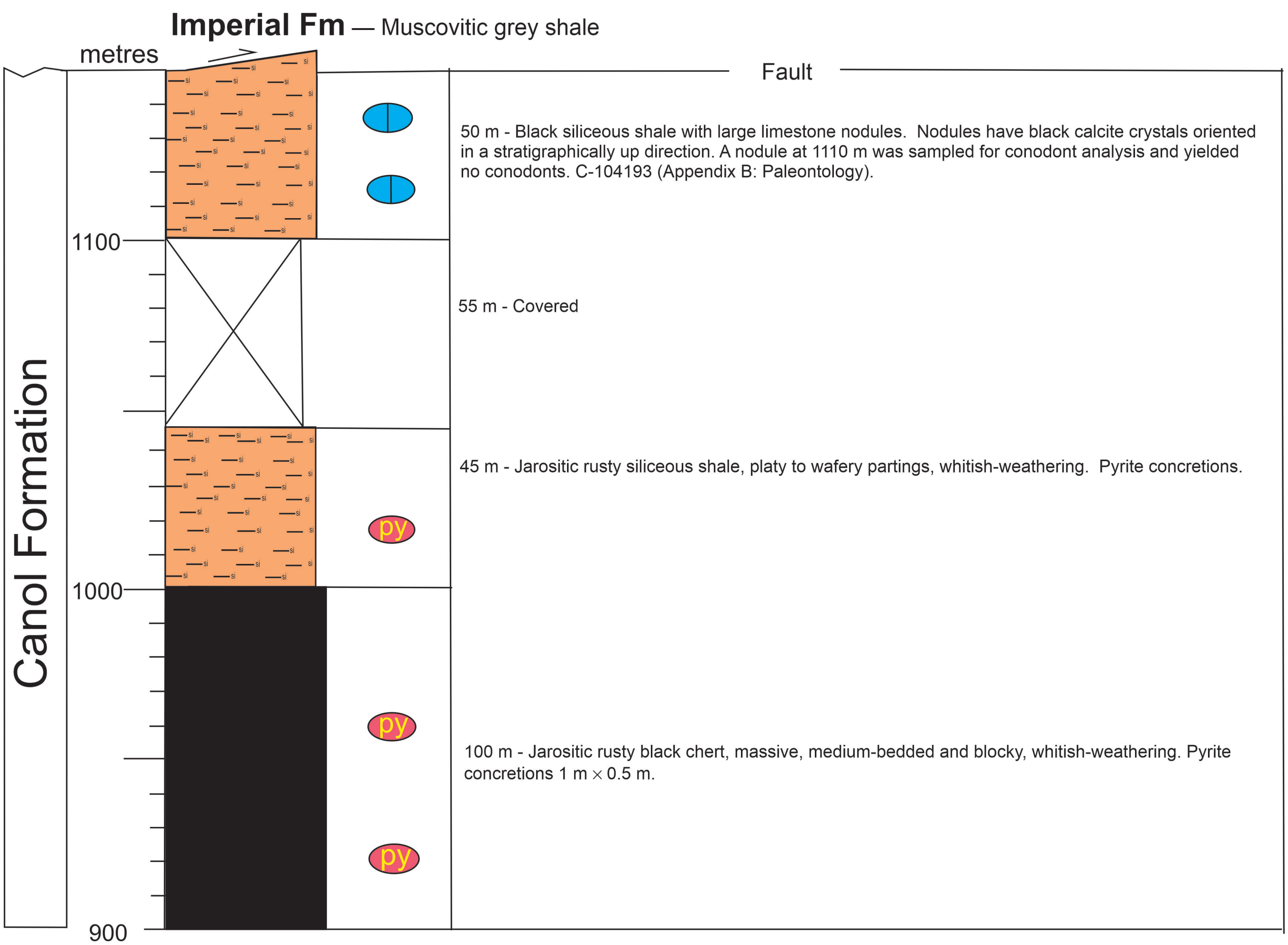


Figure A-9. Top of sections 82-CJA-05 and 82-CJA-04, Canol Formation, on Tetlit Creek in NTS map area 106-L/12. The top of combined section 05–04, which is the top of section 04, is at UTM 8W, 467148E, 7398669N, NAD 83 (North American Datum of 1983). This is the top of Canol Formation. *See* Figures A-7 and A-8 for the lower and middle parts of the section and full location information.

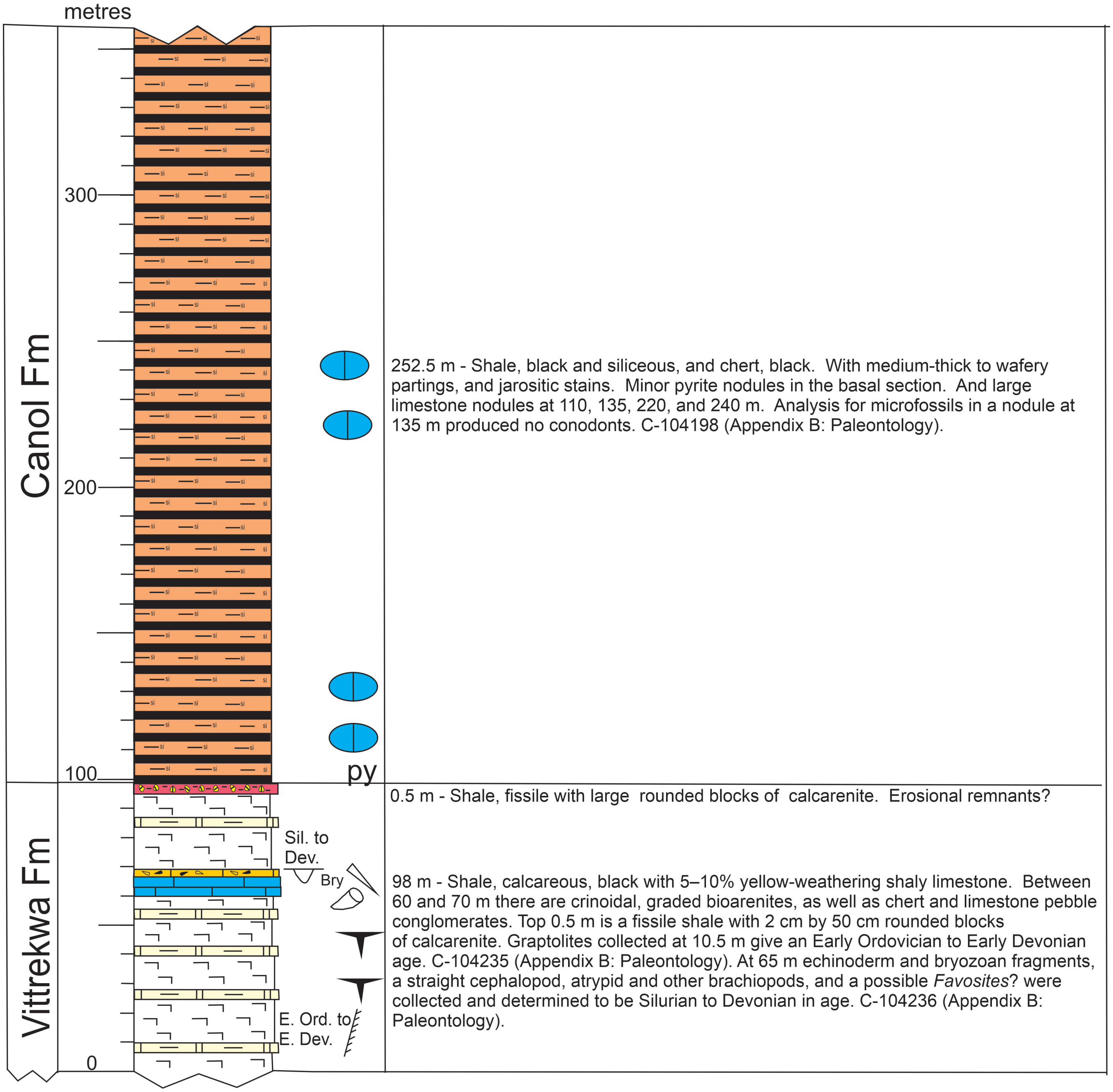
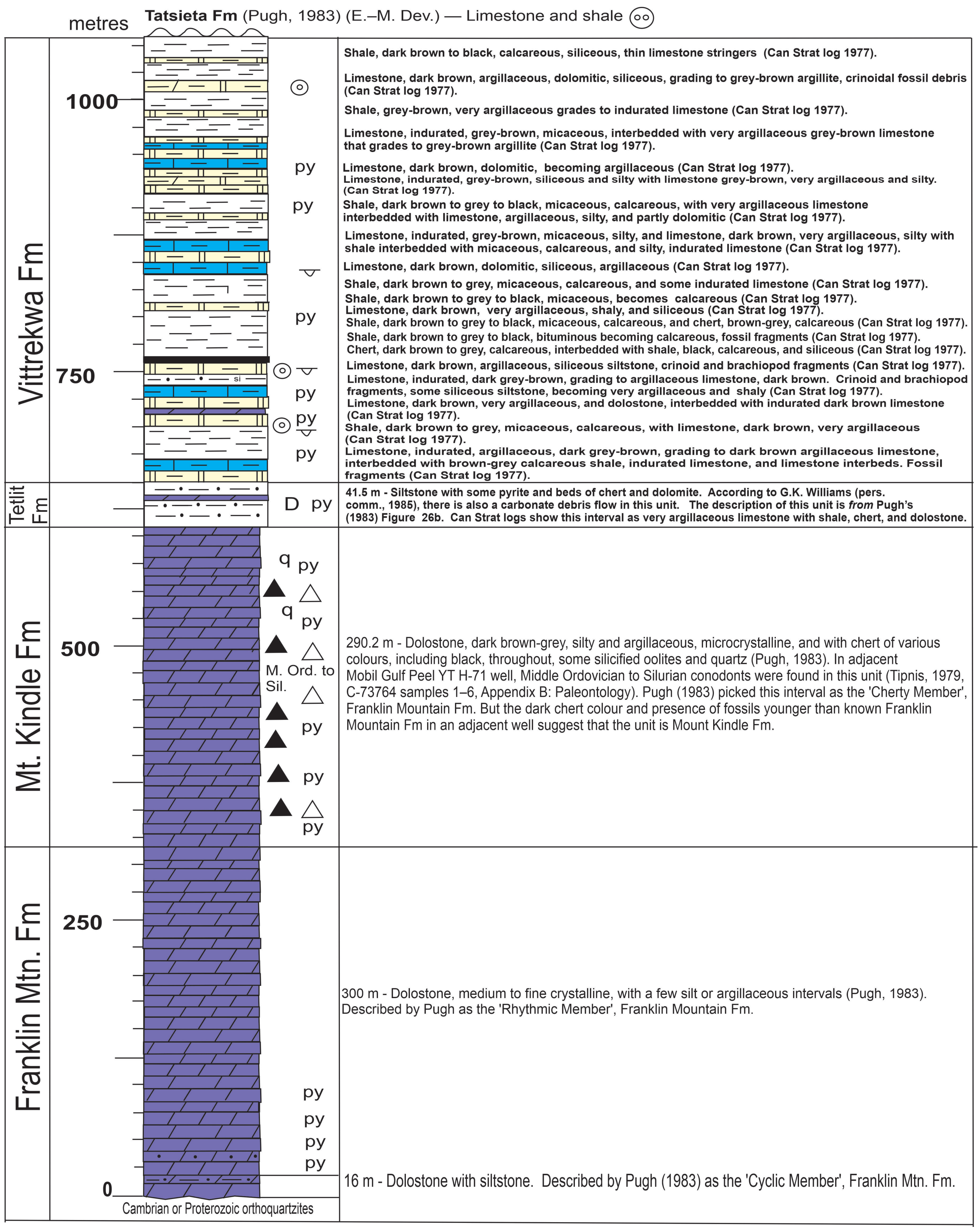


Figure A-10. Top of Vittrekwa Formation and most of Canol Formation. Section 82-CJA-06 is on Trail River in NTS map area 106-L/6. Base of section is at UTM 8W, 478000E, 7396600N. Top is at UTM 8W, 478800E, 7366600N, NAD 83 (North American Datum of 1983). Age abbreviations from top to bottom: Sil. to Dev. = Silurian to Devonian; E. Ord. to E. Dev. = Early Ordovician to Early Devonian.



metres
Tatsieta Fm (Pugh, 1983) (E.–M. Dev.) — Limestone and shale
1000
750
500
250
0
Vittrekwa Fm
Tetlit Fm
Mt. Kindle Fm
Franklin Mtn. Fm
py
D py
q py
M. Ord. to Sil.
si
Shale, dark brown to black, calcareous, siliceous, thin limestone stringers (Can Strat log 1977).
Limestone, dark brown, argillaceous, dolomitic, siliceous, grading to grey-brown argillite, crinoidal fossil debris (Can Strat log 1977).
Shale, grey-brown, very argillaceous grades to indurated limestone (Can Strat log 1977).
Limestone, indurated, grey-brown, micaceous, interbedded with very argillaceous grey-brown limestone that grades to grey-brown argillite (Can Strat log 1977).
Limestone, dark brown, dolomitic, becoming argillaceous (Can Strat log 1977).
Limestone, indurated, grey-brown, siliceous and silty with limestone grey-brown, very argillaceous and silty. (Can Strat log 1977).
Shale, dark brown to grey to black, micaceous, calcareous, with very argillaceous limestone interbedded with limestone, argillaceous, silty, and partly dolomitic (Can Strat log 1977).
Limestone, indurated, grey-brown, micaceous, silty, and limestone, dark brown, very argillaceous, silty with shale interbedded with micaceous, calcareous, and silty, indurated limestone (Can Strat log 1977).
Limestone, dark brown, dolomitic, siliceous, argillaceous (Can Strat log 1977).
Shale, dark brown to grey, micaceous, calcareous, and some indurated limestone (Can Strat log 1977).
Shale, dark brown to grey to black, micaceous, becomes calcareous (Can Strat log 1977).
Limestone, dark brown, very argillaceous, shaly, and siliceous (Can Strat log 1977).
Shale, dark brown to grey to black, micaceous, calcareous, and chert, brown-grey, calcareous (Can Strat log 1977).
Shale, dark brown to grey to black, bituminous becoming calcareous, fossil fragments (Can Strat log 1977).
Chert, dark brown to grey, calcareous, interbedded with shale, black, calcareous, and siliceous (Can Strat log 1977).
Limestone, dark brown, argillaceous, siliceous siltstone, crinoid and brachiopod fragments (Can Strat log 1977).
Limestone, indurated, dark grey-brown, grading to argillaceous limestone, dark brown. Crinoid and brachiopod fragments, some siliceous siltstone, becoming very argillaceous and shaly (Can Strat log 1977).
Limestone, dark brown, very argillaceous, and dolostone, interbedded with indurated dark brown limestone (Can Strat log 1977).
Shale, dark brown to grey, micaceous, calcareous, with limestone, dark brown, very argillaceous (Can Strat log 1977).
Limestone, indurated, argillaceous, dark grey-brown, grading to dark brown argillaceous limestone, interbedded with brown-grey calcareous shale, indurated limestone, and limestone interbeds. Fossil fragments (Can Strat log 1977).
41.5 m - Siltstone with some pyrite and beds of chert and dolomite. According to G.K. Williams (pers. comm., 1985), there is also a carbonate debris flow in this unit. The description of this unit is *from* Pugh's (1983) Figure 26b. Can Strat logs show this interval as very argillaceous limestone with shale, chert, and dolostone.
290.2 m - Dolostone, dark brown-grey, silty and argillaceous, microcrystalline, and with chert of various colours, including black, throughout, some silicified oolites and quartz (Pugh, 1983). In adjacent Mobil Gulf Peel YT H-71 well, Middle Ordovician to Silurian conodonts were found in this unit (Tipnis, 1979, C-73764 samples 1–6, Appendix B: Paleontology). Pugh (1983) picked this interval as the 'Cherty Member', Franklin Mountain Fm. But the dark chert colour and presence of fossils younger than known Franklin Mountain Fm in an adjacent well suggest that the unit is Mount Kindle Fm.
300 m - Dolostone, medium to fine crystalline, with a few silt or argillaceous intervals (Pugh, 1983). Described by Pugh as the 'Rhythmic Member', Franklin Mountain Fm.
16 m - Dolostone with siltstone. Described by Pugh (1983) as the 'Cyclic Member', Franklin Mtn. Fm.
Cambrian or Proterozoic orthoquartzites

Figure A-11. Well section Mobil Gulf Caribou YT N-25. Cyclic and rhythmic units of Pugh (1983) are re-interpreted as the entire Franklin Mountain Formation, and Pugh's Franklin Mountain cherty member is here re-interpreted as Mount Kindle Formation. Above that, his siltstone unit is interpreted as the Tetlit Formation, which is overlain by his shale units, interpreted as Vittrekwa Formation. All are overlain by Tatsieta Formation. *Data from* Pugh (1983, his Fig. 26a), his text, and Canadian Stratigraphic Services 1977 logs for Mobil Gulf Caribou YT N-25 (paper well logs are stored with the well core information at the GSC Core Lab in Calgary). Section is in NTS map area 106-L at UTM 8W, 507339.3E, 7347333.7N, NAD 83 (North American Datum of 1983). This differs from Morrow (1999, his Fig. 19): he recognized Franklin Mountain Formation, but he assigned our Mount Kindle Formation to the 'Locheux' (our Mount Hare Formation); he also recognized our Tetlit (his Dempster) and Vittrekwa formations. Tipnis 1979 = R. Tipnis, unpub. GSC Paleontology Report RST-09-1979, 1979. Age abbreviations: M. Ord. to Sil. = Middle Ordovician to Silurian.

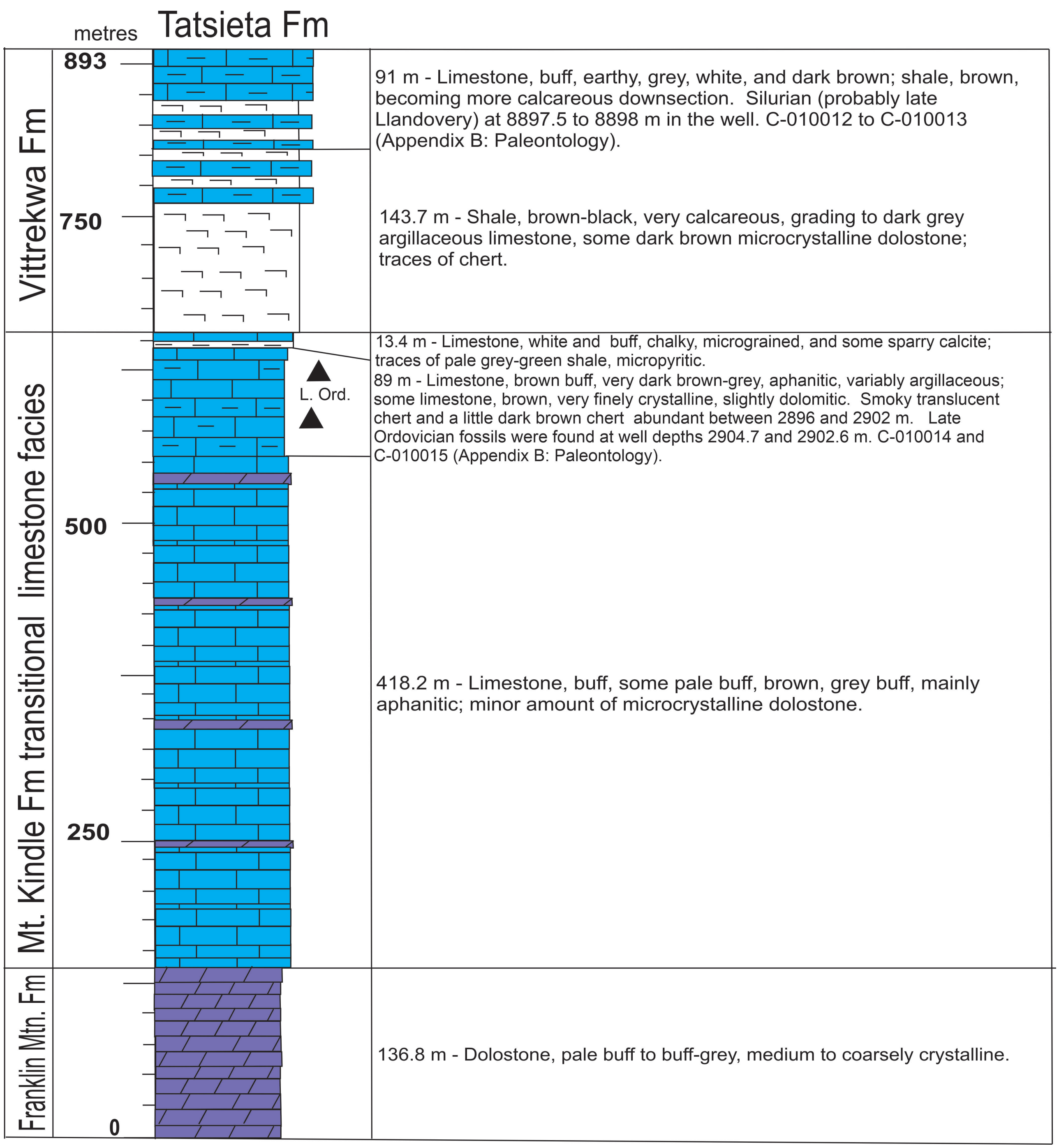


Figure A-12. Well section Socony Mobil Western Minerals South Tuttle YT N-05. *Information from* Pugh (1983, his Fig. 26a and his Appendix II: Log of Wells) and Canadian Stratigraphic Services 1977 well log for N-05 (paper well logs are stored with the well core information at the GSC Core Lab in Calgary). The lower 112 m of Pugh's Figure 26a well plot is re-interpreted as Franklin Mountain Formation. Above that, his limestone and chert unit and a thin limestone unit are re-interpreted as equivalent to part of Mount Kindle Formation. The shale and argillaceous limestone above are considered equivalent to Vittrekwa Formation. This section is in NTS map area 116-I at UTM 8W, 420742.35E, 7367185.35N, NAD 83 (North American Datum of 1983). This differs from Morrow (1999, his Fig. 19), where he would lump the Franklin Mountain and transitional Mount Kindle Formation into his Bouvette Formation and assign Vittrekwa Formation to 'Road River Formation'. Age abbreviations: L. Ord. = Late Ordovician.

Appendix B: Paleontology

In this appendix, B.S. Norford and A.E. Pedder identified macrofauna and G.S. Nowlan and T.T. Uyeno identified microfauna from rocks collected in the Richardson anticlinorium. Microfauna identified by Nowlan were re-examined and identifications revised in 2018. Stage names and faunal zonations used in their reports can be found in Okulitch (2002), Ogg et al. (2016), Norford (1997), and Norford et al. (2002).

Section locations referred to in this appendix are shown on Figure 1; their co-ordinates are given here and in Appendix A. Appendix A gives graphical and text descriptions of each section. In addition, individual field station fossil and microfossil collections taken during field traverses are included in this appendix.

This appendix contains excerpts from Geological Survey of Canada (GSC) unpublished paleontology reports for measured sections in lower Paleozoic rocks of the Richardson Mountains. The 'C' prefix on numbers shown here stands for 'Calgary'. These GSC 'C' numbers connect with 'C' numbers in Appendix A, as well as in figures and bulletin text.

The appendix is arranged first by measured stratigraphic section number, then by formation, and formations are further subdivided into microfauna and macrofauna identifications.

SECTION 82-CJA-01 (FIG. A-2, APPENDIX A), TETLIT FORMATION REFERENCE SECTION

Section 82-CJA-01, M.P. Cecile, located on a ridge east of milepost 412, Dempster Highway, in National Topographic Series (NTS) map area 116-I/9. Base of section is at Universal Transverse Mercator (UTM) 8W, 443016E, 7391532N, NAD 83 (North American Datum of 1983); top is at UTM 8W, 442759E, 7391400N, NAD 83.

Conodonts, Tetlit Formation (section 01)

C-104157, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-01-MF1. Orange argillaceous dolostone beds 34–35 m above base of Mount Hare Formation. No conodonts recovered.

C-104158, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-01-MF2. Orange dolostone bed 58 m above base of Mount Hare Formation. No conodonts recovered.

C-104159, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-01-MF3. Orange dolostone beds 109–110 m above base of Mount Hare Formation. No conodonts recovered.

C-104160, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-01-MF4. Orange dolostone beds 126 m above base of Mount Hare Formation. No conodonts recovered.

SECTION 82-CJA-02 (FIG. A-3, A-4, APPENDIX A), MOUNT HARE AND VITTREKWA FORMATIONS REFERENCE SECTIONS

Section 82-CJA-02, M.P. Cecile, located on a tributary to Rock River in NTS map area 116-I/16. Base of section is at UTM 8W, 446870E, 7422216N, NAD 83; top is at boundary with Canol Formation (Fig. A-4) at UTM 8W, 442250E, 7422866N, NAD 83.

Conodonts, upper Cronin Formation (section 02)

C-104161, G.S. Nowlan (unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated and revised in this appendix in 2018). Sample 82-CJA-02-MF1. Collected by continuous chip sampling between 0 and 100 m above base of section within upper Cronin Formation. The sample was barren.

Conodonts, upper Cronin and lower Mount Hare formations (section 02)

C-104162, G.S. Nowlan (originally unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF2. Collected by continuous chip sampling between 100 and 200 m above base of section. Sampling was from within upper Cronin and lower Mount Hare formations. The sample contained fragmented conodonts (CAI 5) assignable to the following:

drepanodontiform element
?*Oistodus* cf. *O. multicorrugatus* Harris
Parapanderodus emarginatus (Barnes and Tuke)
Periodon sp.
Protopanderodus sp.

Age: Early Ordovician (late Ibexian, late Tulean) to early Middle Ordovician (early Whiterockian)

Conodonts, Mount Hare Formation (section 02)

C-104163, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF3. Collected by continuous chip sampling within Mount Hare Formation, between 200 and 300 m above base of section. The sample was barren.

C-104164, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF4. Collected by continuous chip sampling within Mount Hare Formation, between 300 and 400 m above base of section. The sample was barren.

C-104165, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF5. Collected by continuous chip sampling within Mount Hare Formation, between 400 and 500 m above base of section. The sample yielded highly fragmentary assemblage of conodonts (CAI 5), of which 118 specimens are assignable to the following taxa:

Aulacognathus bullatus (Nicoll and Rexroad)
Dapsilodus obliquicostatus (Branson and Mehl)
Decoriconus sp.
Distomodus staurognathoides (Walliser)
Oulodus? *fluegeli* (Walliser)
Ozarkodina polinclinata (Nicoll and Rexroad)
Panderodus gracilis (Branson and Mehl)
Rexroadus cf. *R. kentuckyensis* (Branson and Branson)
Rexroadus? *kentuckyensis* (Branson and Branson)
Walliserodus curvatus (Branson and Branson)

Age: early Silurian (Llandovery; Rhuddanian–Telychian) for sample; probably represents both early and late, but not latest, Llandovery; some simple-cone taxa range into older and younger strata

Conodonts, Mount Hare to lower Tetlit formations (section 02)

C-104166, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF6. Collected by continuous chip sampling between 500 and 600 m above base of section. This includes upper 70 m of Mount Hare Formation, Aitch Member, and basal 30 m of Tetlit Formation. The sample yielded sponge spicules and two conodont fragments:

indeterminate eoligonodiniform element
indeterminate trichonodelliform element

Age: conodonts are late Llandovery or younger (*see* C-104165 above) but not biostratigraphically diagnostic

Conodonts, Tetlit to lower Vittrekwa formations (section 02)

C-104167, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-02-MF7. Collected by continuous chip sampling within Mount Hare Formation, between 600 and 700 m above base of section. The sample was barren.

Macrofossils, Mount Hare Formation (section 02)

C-104205, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F1. Graptolites collected from 7 m above the Cronin Formation yielded the following:

Clonograptus sp.
Dichograptus cf. *D. octobrachiatus* (Hall)
Dictyonema sp.
Didymograptus extensus (Hall)
Tetragraptus cf. *T. quadribrachiatus* (Hall)

Age: Early Ordovician, *Tetragraptus fruticosus* Zone to lower part of *Isograptus victoriae* Zone

C-104206, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F2. Graptolites collected from 10 m above Cronin Formation yielded the following:

Clonograptus? sp.

Didymograptus extensus (Hall)
Tetragraptus fruticosus (Hall), three- and four-branched forms
Tetragraptus cf. *T. quadribrachiatus* (Hall)

Age: Early Ordovician, *Tetragraptus fruticosus* Zone (upper part)

C-104207, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F3. Graptolites collected from 13 m above the Cronin Formation yielded the following:

Didymograptus sp. (extensiform)
Phyllograptus sp.
Tetragraptus? sp.

Age: Early Ordovician, *Tetragraptus fruticosus* Zone to *Isograptus victoriae* Zone

C-104208, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F4. Graptolites collected from 27 m above the Cronin Formation yielded the following:

Dendrograptus sp.
Didymograptus sp. (extensiform)
Glossograptus sp.
Glyptograptus sp.
Goniograptus? sp.
Isograptus caduceus (Salter)
Loganograptus? sp.
Tetragraptus sp.
Tetragraptus cf. *T. quadribrachiatus* (Hall)
Tristichiograptus ensiformis (Hall)

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104209, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F5. Graptolites and fossils collected from 72 m above the Cronin Formation yielded the following:

Caryocaris sp.
Didymograptus spp.
Didymograptus sp. (extensiform)
Glossograptus sp.
Glyptograptus? sp.
Isograptus sp.
Loganograptus sp.
Tetragraptus sp.
Tetragraptus cf. *T. pendens* Elles
Tetragraptus cf. *T. quadribrachiatus* (Hall)
Tylograptus? sp.
Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104210, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F6. Graptolites collected from 105 m above the Cronin Formation yielded the following:

Amplexograptus? sp.
Didymograptus sp.
Pseudobryograptus sp.

Age: early Middle Ordovician, probably *Paraglossograptus tentaculatus* Zone

C-104211, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F7. Graptolites collected from 195 m above the Cronin Formation yielded the following:

Dicellograptus sp.
Glyptograptus sp.

Age: late Middle or Late Ordovician, *Nemagraptus gracilis*–*Climacograptus bicornis* Zone to *Dicellograptus complanatus*–*Dicellograptus ornatus* Zone

C-104212, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F8. Graptolites collected from 269 m above the Cronin Formation yielded the following:

Climacograptus ex gr. *C. bicornis* Hall
Dicellograptus sp.
Orthograptus? sp.

Age: late Middle or Late Ordovician, *Nemagraptus gracilis*–*Climacograptus bicornis* Zone to *Dicellograptus complanatus*–*Dicellograptus ornatus* Zone

C-104213, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F9. Graptolites collected from 306 m above the Cronin Formation yielded the following:

Monograptus spp.
Monograptus cf. *M. planus* (Barrande)
Monograptus cf. *M. turriculatus* (Barrande)
Petalograptus? sp.
Rastrites sp.

Age: early Silurian (late Llandovery), *Monograptus turriculatus* Zone

C-104214, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F10. Graptolites collected from 336 m above the Cronin Formation yielded the following:

Monograptus spp.

Monograptus exiguus primulus Boucek and Pribyl
Monograptus turriculatus (Barrande)
Pseudoplegmatograptus obesus obesus (Lapworth)

Age: early Silurian (late Llandovery), *Monograptus turriculatus* Zone

C-104215, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F11. Graptolites collected from 424 to 434 m above the Cronin Formation yielded the following:

Cyrtograptus cf. *C. lapworthi* Tullberg
Cyrtograptus sakmaricus Koren'
Monograptus spp.
Monograptus ex gr. *M. priodon* (Bronn)
Monograptus ex gr. *M. spiralis* (Geinitz)
Retiolites? sp.

Age: latest early Silurian (latest Llandovery), *Cyrtograptus sakmaricus–Cyrtograptus laqueus* Zone

Macrofossils, Vittrekwa Formation (section 02)

C-104216, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F12. Graptolites collected from 30 m above the Tetlit Formation yielded the following:

Bohemograptus bohemicus (Barrande)

Age: late Silurian (Ludlow), *Neodiversograptus nilssoni* Zone or *Monograptus leintwardinensis primus* Zone

C-104217, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-02-F13. Graptolites collected from 218 m above the Tetlit Formation yielded the following:

Monograptus cf. *M. thomasi* Jaeger

Age: Early Devonian (Pragian), probably *Monograptus thomasi* Zone

SECTION 82-CJA-03 (FIG. A-5, A-6, APPENDIX A), CRONIN FORMATION REFERENCE SECTION

Section 82-CJA-03, M.P. Cecile, located on the northern arm of Rock River in NTS map area 116-I/16. Base of section is at UTM 8W, 449099E, 7403767N, NAD 83; top is at UTM 8W, 443349E, 7406667N, NAD 83.

Conodonts, Cronin Formation (section 03)

C-104171, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF1. Collected by chip sampling between 200 and 300 m. The sample yielded inarticulate brachiopod shells and one possible fragment of the protoconodont genus *Phakelodus*, which may suggest a middle Cambrian to earliest Ordovician age.

C-104172, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF2. Collected by chip sampling between 300 and 400 m. The sample yielded inarticulate brachiopod shells but was devoid of conodonts.

C-104173, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF3. Collected by chip sampling between 400 and 500 m. The sample yielded inarticulate brachiopod shells; it also yielded protoconodonts assignable to the following:

Phakelodus tenuis (Müller)

Age: *Phakelodus tenuis* ranges from middle Cambrian to earliest Ordovician; absence of other latest Cambrian to Early Ordovician conodonts suggests middle to late Cambrian

C-104174, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF4. Collected by chip sampling between 500 and 600 m. The sample yielded fragments of phosphatic brachiopod shells but no conodonts.

C-104175, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF5. Collected by chip sampling between 600 and 700 m. The sample yielded brachiopod shells, phosphatic rods, and one conodont:

Phakelodus sp.

Age: probably middle to late Cambrian

C-104176, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF6. Collected by chip sampling between 700 and 800 m. The sample was barren of conodonts but yielded inarticulate brachiopods and phosphatic rods and plates.

C-104177, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF7. Collected by chip sampling between 800 and 900 m. The sample yielded inarticulate brachiopod shells, annulated phosphatic tubes (hyolithellids?), and paraconodonts identified as follows:

Phakelodus tenuis (Müller)
?*Prooneotodus gallatini* (Müller)

Age: these fossils and absence of latest Cambrian to Early Ordovician conodonts suggest middle to late Cambrian

C-104178, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF8. Collected by chip sampling between 900 and 1000 m. The sample yielded sponge spicules and two paraconodont specimens assignable to the following:

Phakelodus tenuis (Müller)

Age: *Phakelodus tenuis* ranges from middle Cambrian to Early Ordovician; absence of any latest Cambrian or Early Ordovician conodonts suggests this sample is middle to late Cambrian

C-104179, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF9. Collected by chip sampling between 1000 and 1100 m. The sample yielded sponge spicules, phosphatic rods of unknown affinity, inarticulate brachiopods, and 21 paraconodont specimens identified as follows:

Phakelodus tenuis (Müller)
?*Prooneotodus gallatini* (Müller)

Age: sample is middle to late Cambrian

C-104180, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF10. Collected by chip sampling between 1100 and 1200 m. The sample yielded inarticulate brachiopod shells but was devoid of conodonts.

C-104181, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF11. Collected by chip sampling between 1200 and 1300 m. The sample yielded inarticulate brachiopod shells and paraconodonts assigned to the following:

Phakelodus tenuis (Müller)

Age: *Phakelodus tenuis* ranges from middle Cambrian to Early Ordovician; absence of any latest Cambrian or Early Ordovician conodonts suggests that this sample is middle to late Cambrian

C-104182, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF12. Collected by chip sampling between 1300 and 1400 m. The sample yielded paraconodonts and protoconodonts assignable to the following:

Furnishina? sp.
Phakelodus tenuis (Müller)

Age: paraconodont genus *Furnishina* spp. and protoconodont *Phakelodus tenuis* range from middle Cambrian to Early Ordovician

C-104183, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF13. Collected by chip sampling between 1400 and 1500 m. The sample yielded inarticulate brachiopod shells and protoconodonts assignable to the following:

Phakelodus tenuis (Müller)

Age: *Phakelodus tenuis* ranges from middle Cambrian to Early Ordovician; absence of any latest Cambrian or Early Ordovician conodonts suggests this sample is middle to late Cambrian

C-104184, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF14. Collected by chip sampling between 1500 and 1600 m. The sample yielded inarticulate brachiopod shells, tubular plates, paraconodonts, protoconodonts, and euconodonts assignable to the following:

Eoconodontus? sp.
Phakelodus tenuis (Müller)
Proconodontus muelleri muelleri Miller
Prooneotodus gallatini (Müller)

Age: Sample contains *Proconodontus muelleri muelleri,* which is characteristic of strata of late Cambrian (Trempealeauan [late Sunwaptan]) age and referred to the *Proconodontus muelleri muelleri* Zone. It also ranges upward into the *Eoconodontus notchpeakensis* Zone (Miller 1988); a single possible representative of *Eoconodontus* is present. This genus is also latest Cambrian, but it appears in the *E. notchpeakensis* Zone just above the *P. muelleri muelleri* Zone. As noted previously, the species of *Phakelodus* ranges from middle Cambrian to Early Ordovician. This sample is late Cambrian (late Sunwaptan to earliest Skullrockian).

C-104185, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF15. Collected by chip sampling between 1600 and 1700 m. The sample yielded paraconodonts and euconodonts assigned to the following:

Eoconodontus notchpeakensis (Miller)
Proconodontus sp.
Phakelodus tenuis (Müller)
Phakelodus tenuis fused cluster
indeterminate multicostate simple cone

Age: sample is late Cambrian; *Eoconodontus notchpeakensis* Zone is late Cambrian (earliest Skullrockian)

C-104186, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF16. Collected by chip sampling between 1700 and 1800 m. The sample yielded inarticulate brachiopods and abundant euconodonts assigned to the following:

Cordylodus proavus Müller
Eoconodontus notchpeakensis (Miller)
Proconodontus muelleri muelleri Miller
Teridontus nakamurai (Nogami)

Age: sample is late Cambrian (early Skullrockian)

C-104187, G.S. Nowlan (originally from unpub. GSC Paleontological Report 10-GSN-1983, 1983 but updated in this appendix in 2018). Sample 82-CJA-03-MF17. Collected by chip sampling between 1800 and 1955 m. The sample yielded inarticulate brachiopods and euconodonts assigned to the following:

Cordylodus sp.
Teridontus cf. *T. nakamurai* (Nogami)
Variabiloconus bassleri (Furnish)

Age: sample is Early Ordovician (late Skullrockian [late Tremadocian])

Macrofossils, Cronin Formation (section 03)

C-104218, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-03-F1. There is no record in field notes other than the sample is labelled ‘F1’, which normally would indicate collection before sample F2, which is at 490 m. The following graptolites are assumed to have been collected from below 490 m:

Dendrograptus sp.
Dictyonema sp.

Age: collection is late Cambrian to Carboniferous

C-104219, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-03-F2. The following graptolites were collected between 490 and 492 m:

Dendrograptus sp.

Age: collection is late Cambrian to Carboniferous

C-104220, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-03-F3. The following graptolites were collected at 510 m:

Dendrograptus sp.

Age: collection is late Cambrian to Carboniferous

COMBINED SECTION 82-CJA-05–04 (FIG. A-7, A-8, A-9, APPENDIX A)

Combined sections 82-CJA-05 and 82-CJA-04, M.P. Cecile, located on Tetlit Creek in NTS map area 106-L/12, 2 km south of the type Road River Formation (Jackson and Lenz 1962). Base of combined section 05–04, which is base of section 05, is at UTM 8W, 463898E, 7398569N, NAD 83. The 340 m mark of the combined section, which is where top of section 05 joins base of section 04, is located at UTM 8W, 465648E, 7398920N, NAD 83. Top of combined section 05–04, which is top of section 04, is at UTM 8W, 467148E, 7398669N, NAD 83.

Conodonts, top of Cronin to Mount Hare formations (combined section 05–04)

C-104194, G.S. Nowlan (originally unpub. GSC Paleontological Report 003-GSN-1984, 1984 but updated here in 2018). Sample 82-CJA-05-MF1. Collected by continuous chip sampling within Cronin Formation, between 0 and 100 m above base of section. The sample was barren.

C-104195, G.S. Nowlan (originally from unpub. GSC Paleontological Report 003-GSN-1984, 1984 but updated here in 2018). Sample 82-CJA-05-MF2. Collected by continuous chip sampling within basal Mount Hare Formation, between 100 and 200 m above base of section. The sample was barren.

C-104196, G.S. Nowlan (originally from unpub. GSC Paleontological Report 003-GSN-1984, 1984 but updated here in 2018). Sample 82-CJA-05-MF3. Collected by continuous chip sampling within Mount Hare Formation, between 200 and 300 m above base of section. The sample yielded two fragmentary conodont elements:

oistodontiform elements indeterminate

Age: Two specimens are strongly reclined oistodontiform elements with cusps longer than bases; they are similar to those associated with species of *Periodon*, but the better preserved specimen shows no sign of anterior denticulation typical of most species of *Periodon*. The sample is likely Ordovician, possibly Early or Middle Ordovician.

C-104188, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF1. Collected by continuous chip sampling between 340 and 440 m above base of combined section 05–04 within Mount Hare Formation, largely from Aitch Member. The sample yielded the following conodonts:

Carniodus carnulus Walliser
Ozarkodina excavata (Branson and Mehl)
Ozarkodina cf. *O. hassi* (Pollock, Rexroad, and Nicoll)
Panderodus sp.
? *Pterospathodus pennatus* (Walliser)

Age: late Llandovery–early Wenlock, *Pterospathodus celloni* Zone to *Pterospathodus amorphognathoides* Zone

Conodonts, Tetlit Formation (combined section 05–04)

C-104189, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF2. Collected by continuous chip sampling between 440 and 540 m above base of combined section 05–04. The sample yielded the following conodonts:

Decoriconus fragilis (Branson and Mehl)
Panderodus sp.

Age: Silurian

Conodonts, Tetlit to Vittrekwa formations (combined section 05–04)

C-104190, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF3. Collected by continuous chip sampling between 540 and 640 m above base of combined section 05–04. The sample yielded the following conodonts:

Icriodus cf. *I. woschmidti* Ziegler
Ozarkodina excavata (Branson and Mehl)
Panderodus sp.
Pseudooneotodus sp.

Age: probably latest Silurian (late Pridoli) to Early Devonian (Lochkovian)

Conodonts, Vittrekwa Formation (combined section 05–04)

C-104191, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF4. Collected by continuous chip sampling between 640 and 740 m above base of combined section 05–04. The sample yielded the following conodonts:

Icriodus sp.
Ozarkodina paucidentata Murphy and Matti
Ozarkodina remscheidensis remscheidensis (Ziegler)

Age: Early Devonian (early Lochkovian), *Cypricriodus hesperius* Zone to *Caudicriodus postwoschmidti* Zone

C-104192, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF6. Collected by continuous chip sampling between 740 and 840 m above base of combined section 05–04. The sample yielded the following conodonts:

Ozarkodina cf. *O. remscheidensis* (Ziegler)

Age: possibly late Silurian to Early Devonian

Conodonts, Canol Formation (combined section 05–04)

C-104193, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-04-MF8. Collected from a large limestone nodule at 1110 m above base of combined section 05–04. No conodonts were recovered.

Macrofossils, top of Cronin Formation (combined section 05–04)

C-104227, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F1. The following fossils were collected between 52 and 55 m above base of combined section 05–04:

Caryocaris? sp.
Staurograptus tenuis Jackson

Age: early Early Ordovician, *Isograptus tenuis* Zone

Macrofossils, Mount Hare Formation (combined section 05–04)

C-104228, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F2. The following graptolites were collected at 152 m above base of combined section 05–04:

Didymograptus sp. (extensiform)

Glossograptus sp.
Glyptograptus sp.
Isograptus sp.
Tetragraptus aff. *T. bigsbyi* (Hall)

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104229, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F3. The following graptolites were collected at 183 m above base of combined section 05–04:

Cryptograptus cf. *C. tricornis* (Carruthers)
dendroid graptolite?
Didymograptus (pendent form)
Didymograptus sp.
Glossograptus sp.
Glyptograptus sp.
Tristichiograptus? sp.
Tylograptus? sp.

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104230, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F4. The following graptolites were collected at 184 m above base of combined section 05–04:

Loganograptus sp.
Phyllograptus sp.
Tetragraptus cf. *T. pendens* Elles
Tetragraptus aff. *T. serra* (Brongniart)
Tristichiograptus sp.
Tylograptus sp.

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104231, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F5. The following graptolites were collected at 218 m above base of combined section 05–04:

Amplexograptus sp.
Cryptograptus sp.
Cryptograptus cf. *C. tricornis* (Carruthers)
Didymograptus sp.
Isograptus sp.
Phyllograptus sp.
Tetragraptus cf. *T. quadribrachiatus* (Hall)
Tristichiograptus ensiformis (Hall)

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104232, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F6. The following graptolites were collected at 225 m above base of combined section 05–04:

Amplexograptus sp.
Cryptograptus sp.
Cryptograptus cf. *C. tricornis* (Carruthers)
Didymograptus aff. *D. spinosus* Ruedemann
Glossograptus sp.
Loganograptus sp.
Phyllograptus sp.
Tristichiograptus? sp.

Age: early Middle Ordovician, *Paraglossograptus tentaculatus* Zone

C-104233, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F7. The following graptolites were collected at 293 m above base of combined section 05–04:

Climacograptus sp.
Dicellograptus sp.
Glossograptus sp.
Leptograptus sp.
Nemagraptus sp.

Age: late Middle Ordovician, *Nemagraptus gracilis*–*Climacograptus bicornis* Zone

C-104234, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-05-F8. The following graptolites were collected at 298 m above base of combined section 05–04:

biserial graptolite
Dicellograptus spp.
Dicranograptus sp.
Leptograptus sp.
Nemagraptus sp.

Age: late Middle Ordovician, *Nemagraptus gracilis*–*Climacograptus bicornis* Zone

C-104221, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F1. The following graptolites were collected at 360 m above base of combined section 05–04:

Glyptograptus? sp.
Monograptus spp.
Monograptus exiguus primulus Boucek and Pribyl
Monograptus cf. *M. tullbergi spiraloides* (Pribyl)
Monograptus turriculatus (Barrande)

Petalograptus? sp.
Pseudoplegmatograptus sp.
Rastrites sp.

Age: early Silurian (late Llandovery), *Monograptus turriculatus* Zone

C-104222, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F2. The following graptolites were collected at 381 m above base of combined section 05–04:

Barrandeograptus? sp.
Monograptus spp.
Monograptus ex gr. *M. spiralis* (Geinitz)
Stomatograptus sp.

Age: early Silurian (late Llandovery), *Monograptus spiralis* Zone

C-104223, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F3. The following graptolites were collected at 404 m above base of combined section 05–04:

Monograptus spp.
Monograptus ex gr. *M. spiralis* (Geinitz)
Retiolites sp.

Age: early Silurian (late Llandovery), *Monograptus spiralis* Zone

C-104224, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F4. The following graptolites were collected at 418 m above base of combined section 05–04:

Monograptus sp.
Monograptus ex gr. *M. spiralis* (Geinitz)
Retiolites geinitzianus angustidens Elles and Wood
Retiolites cf. *R. geinitzianus geinitzianus* (Barrande)

Age: early Silurian (late Llandovery), *Monograptus spiralis* Zone

Macrofossils, Vittrekwa Formation (combined section 05–04)

C-104225, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F5. The following graptolites were collected at 830 m above base of combined section 05–04:

Monograptus cf. *M. thomasi* Jaeger

Age: Early Devonian (Pragian), probably *Monograptus thomasi* Zone

C-104226, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-04-F6. The following graptolites were collected at 857 m above base of combined section 05–04:

Monograptus yukonensis Jackson and Lenz

Age: Early Devonian (Pragian), *Monograptus yukonensis* Zone

SECTION 82-CJA-06 (FIG. A-10, APPENDIX A)

Top of Vittrekwa Formation and most of Canol Formation. Section 82-CJA-06 is located on Trail River in NTS map area 106-L/6. Base of section is at UTM 8W, 478000E, 7396600N, NAD 83; top is at UTM 8W, 478800E, 7396600N, NAD 83.

Conodonts, Canol Formation (section 06)

C-104198, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-06-MF1. Collected from a large limestone nodule at 135 m above base of section. No conodonts were recovered.

Macrofossils, Vittrekwa Formation (section 06)

C-104235, B.S. Norford (unpub. GSC Paleontological Report C-D-16-BSN-1982, 1982). Sample 82-CJA-06-F1. The following graptolites were collected at 10.5 m above base of section:

graptolite fragments
Dendrograptus sp.

Age: Early Ordovician to Early Devonian

C-104236, B.S. Norford (unpub. GSC Paleontological Report C-D-16-BSN-1982, 1982). Sample 82-CJA-06-F2. The following fossils were collected at 65 m above base of section:

echinoderm and bryozoan fragments
straight cephalopod
atrypid and other brachiopods
Favosites? sp.

Age: Silurian to Devonian

MOBIL GULF PEEL YT H-71

This well is referred to in Fig. A-11. (It provides information extrapolated to well section Mobil Gulf Caribou YT N-25.) Located at UTM 8W, 512150E, 7357972N, NAD 83; lat. 66°20′29″N, long. 134°43′35″W. Note: well depths following the 'C' number were in feet in the original report but have been converted to metres here; the sample numbers are the same.

Microfossils, Mount Kindle Formation

C-73764 sample 1, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3173–3210 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl)
drepanodontiform element

Age: Middle to Late Ordovician (or early Silurian)

C-73764 sample 2, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3213–3240 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl)
Loxodus? sp.
broken indeterminate cones

Age: Middle to Late Ordovician (or early Silurian); *Loxodus* is an Early Ordovician (Tremadocian) taxon

C-73764 sample 3, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3243–3271 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl)
Oulodus sp.
Acanthodus? sp.
microfossils and broken cones

Age: Middle to Late Ordovician (or early Silurian); *Acanthodus* is an Early Ordovician (Tremadocian/?basal Floian [Arenig]) taxon

C-73764 sample 4, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3274–3301 m) yielded the following conodonts:

Drepanoistodus suberectus (Branson and Mehl)
Panderodus gracilis (Branson and Mehl)

Age: Middle to Late Ordovician (or early Silurian)

C-73764 sample 5, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3304–3331 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl)
Panderodus ssp.

Age: Middle Ordovician

C-73764 sample 6, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3335–3362 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl)
Panderodus spp.
Ozarkodina? sp.

Age: probably Middle Ordovician to early Silurian

C-73764 sample 7, R. Tipnis (unpub. GSC Paleontological Report RST-09-1979, 1979). The sample interval (3365–3392 m) yielded the following conodonts:

Panderodus gracilis (Branson and Mehl): three clusters
Panderodus spp.
Plectodina? sp.

Age: probably Middle to latest Ordovician (or early Silurian)

SOCONY MOBIL WESTERN MINERALS SOUTH TUTTLE YT N-05 (FIG. A-12, APPENDIX A)

The well site is at UTM 8W, 420742E, 7367185N, NAD 83; 66.414027N, −136.775298E. Note: well depths following the 'C' number were in feet in the original report but have been converted to metres here.

Macrofossils, Arnica(?) Formation (in this report Tatsieta(?) Formation)

C-10010 to C-10011 (2541.7–2542 m) (Norford et al., 1971). The following fossils were collected:

indeterminate ostracodes
?*Atrypella* sp.

Age: probably late Silurian (Ludlow)

Macrofossils, Mount Clark(?) Formation (in this report Vittrekwa Formation)

C-10012 to C-10013 (2711.8–2712.1 m) (Norford et al., 1971). The following fossils were collected:

indeterminate gastropods and straight cephalopod

?*Alispira* sp.
?*Pentameroides* sp.
Encrinurus cf. *E. princeps* Poulsen

Age: Silurian (probably late Llandovery)

Macrofossils, Mount Kindle Formation

C-10014 to C-10015 (2902.6–2904.7 m) (Norford et al., 1971). The following fossils were collected:

echinoderm debris
Bighornia sp.
Palaeophyllum sp.
Catenipora sp.
Palaeofavosites sp.

Age: Late Ordovician

FOSSILS AND MICROFOSSILS COLLECTED ON TRAVERSES (LOCATION WITH EACH SAMPLE; PALEONTOLOGICAL REPORTS CONTAIN SAMPLES FROM NTS 105-O NOT REPORTED ON HERE)

Macrofauna, graptolites, Cronin Formation

Station 82-CJA-102-7. NTS map area 116-I/16; UTM 8W, 445060E, 7412250N, NAD 83.

C-104239, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-102-F2. The following graptolites were collected at this location:

Caryocaris sp.
Clonograptus? sp.
Dendrograptus sp.
Didymograptus cf. *D. extensus* (Hall)
(on different slab)
Tetragraptus sp.
Tetragraptus approximatus Nicholson

Age**:** Early Ordovician, *Tetragraptus approximatus* Zone and/or *Tetragraptus fruticosus* Zone

Macrofauna, graptolites, Mount Hare Formation

Station 82-CJA-109-13. NTS map area 116-I/16; UTM 8W, 455029E, 7415369N, NAD 83.

C-104243, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-109-F1. The following graptolites were collected at this location:

Clonograptus? sp.
Dendrograptus? sp.
Didymograptus sp.

Age: Early or early Middle Ordovician, *Tetragraptus approximatus* Zone

Microfossils, Tetlit Formation

Station 82-CJA-102-3. NTS map area 116-I/16; UTM 8W, 452599E, 7412919N, NAD 83.

C-104201, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-102-MF1. The following conodonts were recovered:

Dapsilodus obliquicostatus (Branson and Mehl)
Ozarkodina? sp.

Age: early Silurian to Early Devonian

Macro- and microfauna, Vittrekwa Formation

Station 82-CJA-101-2. NTS map area 116-I/16; UTM 8W, 445150E, 7427066N, NAD 83.

C-104237, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-101-F1. The following graptolites were collected from first outcrop west of creek:

Monograptus cf. *M. telleri* Lenz and Jackson

Age: Early Devonian (Pragian), probably *Monograptus thomasi* Zone

Station 82-CJA-101-2. NTS map area 116-I/16; UTM 8W, 445152E, 7427074N, NAD 83.

C-104238, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-101-F2. The following graptolites were collected approximately 8 m upsection from sample CJA-82-101-F1 (*see* above):

Monograptus yukonensis Jackson and Lenz

Age: Early Devonian (Pragian), *Monograptus yukonensis* Zone

Station 82-CJA-102-11. NTS map area 116-I/16; UTM 8W, 443800E, 7424916N, NAD 83.

C-104240, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-102-F3 (note: in the fossil report cited, this sample is incorrectly labelled ‘F2’). The following graptolites were collected at this location:

Monograptus yukonensis Jackson and Lenz

Age: Early Devonian (Pragian), *Monograptus yukonensis* Zone

Station 82-CJA-114-3. NTS map area 106-L/12; UTM 8W, 474298E, 7381370N, NAD 83.

C-104242, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982). Sample 82-CJA-114-F2. The following graptolites were collected at this location:

Monograptus yukonensis Jackson and Lenz

Age: Early Devonian (Pragian), *Monograptus yukonensis* Zone

Station 82-CJA-101-3. NTS map area 116-I/16; UTM 8W, 444350E, 7427366N, NAD 83.

C-104200, T.T. Uyeno (unpub. GSC Paleontological Report 7-TTU-84, 1984). Sample 82-CJA-101-MF3. No conodonts recovered.

Station 82-CJA-112-1. Field notes only. NTS map area 106-L/12; UTM 8W, 470649E, 7394670N, NAD 83, at the Canol/Vittrekwa contact. Compositional layering: 298°/06°N. No sample taken, but straight cephalopods were observed.

Station 82-CJA-114-2. Field notes only. NTS map area 106-L/12; UTM 8W, 473798E, 7382019N, NAD 83.

Carbonate member of the Vittrekwa Formation. Blocky, grey-weathering, grey on fresh surface, crinoidal calcarenite and biomicrite? Equivalent to Ogilvie (Do) unit of Norris (1981c).

Station 82-CJA-114-2, C-104241, NTS map area 106-L/12; UTM 8W, 473798E, 7382019N, NAD 83. Carbonate member of the Vittrekwa Formation equivalent to the Ogilvie Formation.

With horn corals, two-canal crinoid ossicles and bryozoans?

At this station, B.S. Norford (unpub. GSC Paleontological Report C-D 16-BSN-1982, 1982) reported the following from sample 82-CJA-114-F1:

echinoderm columnals (two-hole variety abundant)
atrypid brachiopod
solitary and colonial corals

Age: Early Devonian (Zlichovian to Dalejan)

Also at this station A.E.H. Pedder (unpub. GSC Paleontological Report MPC-118-AEHP-84, 1984) reported the following from the same sample:

stromatoporoid, not studied
alveolitid coral, not studied
Taimyrophyllium sp. nov. (colonial coral)
solitary corals, indet.
atrypid fragment, indet.
double-axis crinoid ossicles

Age: Early Devonian to early Middle Devonian (probably Zlichovian)