Devonian conodont biostratigraphy of the Mackenzie Mountains, western part of the Northwest Territories

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Abstract: In this paper, a review of the current understanding of Devonian conodont biostratigraphy in the Mackenzie Mountains in the Northwest Territories is presented. The Devonian stratigraphy of the northern and southern Mackenzie Mountains is presented on two chronostratigraphic charts, from the first deposits on top of the sub-Devonian unconformity to the lower part of the Imperial and Fort Simpson formations. Schematic maps give an overview of the regional distribution of the formations in the Mackenzie Mountains. This update revealed that several of the assemblage and formation contacts are younger than presumed in an earlier time-stratigraphic chart; several formations and members are now better constrained in the updated charts. The update also pointed out intervals in the charts for which no data were available and for which more research is needed to constrain formations in the Devonian conodont biozonation.

Résumé : Cet article passe en revue les connaissances actuelles sur la biostratigraphie des conodontes du Dévonien dans les monts Mackenzie (Territoires du Nord-Ouest). Deux tableaux chronostratigraphiques présentent la stratigraphie du Dévonien des parties nord et sud des monts Mackenzie, depuis les premiers dépôts surmontant la discordance subdévonienne jusqu'à la partie inférieure des formations d'Imperial et de Fort Simpson. Des cartes schématiques offrent un aperçu de la répartition régionale des formations dans les monts Mackenzie. Cette mise à jour révèle que plusieurs des contacts d'assemblages et de formations sont plus récents que ne le laissait supposer un tableau chronostratigraphique antérieur. Plusieurs formations et membres sont maintenant mieux encadrés dans les tableaux mis à jour. La mise à jour a aussi permis de mettre en lumière les intervalles des tableaux où aucune donnée n'était disponible et pour lesquels d'autres recherches sont nécessaires pour encadrer les formations dans la biozonation des conodontes du Dévonien.

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INTRODUCTION

The purpose of this work was to use state-of-the-art conodont biostratigraphic data to provide a summary of the Devonian stratigraphic relationships as recorded in chronostratigraphic charts for the Mackenzie Mountains. The goal was to deliver a comprehensive document that will be useful in geological mapping and stratigraphy, will give researchers an idea of the age of the formations they are mapping, and will become an additional tool for stratigraphers, structural geologists, and anyone working on or interested in the Devonian of the Mackenzie Mountains. This summary also highlights significant gaps in the biostratigraphic constraints needed to accurately locate the formations and members in the geological time frame.

The starting point for this summary was the overview published by T.T. Uyeno in 1991, based on the rock-stratigraphic charts of Morrow and Geldsetzer (1988), and a similar way of representing the data is used in this update. Morrow and Geldsetzer (1988) outlined the interformational relationships of Devonian deposits on the Mackenzie Shelf (and adjacent areas) and tentatively located the formations in the then-current conodont biozonation scheme. They grouped the Devonian formations into assemblages or 'allogroups', based on lateral equivalence within the assemblage and a distinct change in stratigraphic relationships across the assemblages: Delorme, Bear Rock–Stone, Hume–Dunedin, Fairholme, Kakisa–Graminia, and Palliser. Additional conodont data allowed Uyeno (1991) to update the overview of the redefined and renamed Devonian stages and conodont zonation. Uyeno (1991) also added a chronostratigraphic chart for the Selwyn Basin. Morrow (2012, 2018) adjusted and reorganized the formations and relocated them in the time-stratigraphic chart (omitting the conodont biozonation). The renamed assemblages (Delorme, Bear Rock, Hume–Lonely Bay, Slave–Kakisa, and Tetcho–Kotcho) were now linked to depositional-sequence cycles. Morrow's chart is used as the basis for the updated chronostratigraphic chart in this paper when dealing with the stratigraphic relationships of formations. The same assemblage names are loosely used here for the Lower and Middle Devonian.

Since the last update by Uyeno (1991), a large amount of conodont material has become available, part of it through the first and second phases of the Geo-mapping for Energy and Minerals (GEM) program that included several mapping and stratigraphy projects in the Mackenzie Mountains. Some of the most recent conodont material sampled since 2017 is not yet available due to renovation work undertaken (2017–2019) at the Geological Survey of Canada (GSC) conodont laboratory in Calgary. Although samples were partially processed at the Illinois State University laboratory (Normal, Illinois), several processing steps still need to be completed at the Calgary conodont facility. GSC personnel are currently working through the sample backlog (as of opening in April 2019), which should shortly lead to significant updates in conodont biostratigraphy.

The Mackenzie Mountains region (Fig. 1) includes several paleotectono-sedimentological environments or elements (Fig. 2; Morrow, 2012, 2018): the Mackenzie Shelf, Root Basin, Misty Creek Embayment, Prairie Creek Embayment, Camsell Subbasin, Godlin Salient, and eastern part of the Selwyn Basin. These different settings are represented in the chronostratigraphic charts (Fig. 3, 4) by different formations, which are described in the text below. Some of the formations were the subject of detailed studies and provided a large amount of conodont data (e.g. formations of the Prairie Creek Embayment); other formations are more widespread and their ages are constrained only by a few reconnaissance samples taken for mapping purposes (e.g. Arnica and Landry formations). In addition to the variable interest and need of field researchers for conodont biostratigraphic ages and the amount of conodont samples they bring from the field, the amount of conodont material available is also largely linked to the nature of the deposits characteristic of the study area, which includes depositional environments not suitable for the preservation or extraction of conodonts, such as evaporitic or shallow-marine deposits or noncalcareous siliceous shale (e.g. Tsesto and Bear Rock formations, parts of the Canol Formation).

Associated with the chronostratigraphic charts are overview maps (Fig. 5–9) based on regional geological maps published before 2019 and showing the regional distribution (limited to the Mackenzie Mountains) of the formations discussed in this paper. The delineation of the Mackenzie Mountains is based on the outline by Morrow (2012; Fig. 2 in Morrow, 2018). The limit between the northern and southern Mackenzie Mountains was placed at latitude 64°N. The list of NTS map areas and the references to the published geological maps used to construct Figures 5–9 can be found in Appendix A. As is also specified elsewhere in this paper, several formations cannot be accurately outlined on Figures 5–9 because of out-of-date terminology or due to the fact units have been combined on some of the geological maps available. More recently defined formations were identified during recent mapping projects, but older maps of adjacent areas have not yet been adjusted to the new subdivisions and nomenclature. Updating of the older geological maps of the area is clearly necessary.

DATA

Most of the conodont data used are based on the GSC Devonian conodont collection assembled by T. Uyeno since the 1970s, which also provided data used in the Uyeno (1991) paper. Additional information was taken from, for the most part, unpublished paleontological reports (including paleontological reports from GEM activities in the area produced by the GSC and authored by T.T. Uyeno, A.D. McCracken, M.J. Orchard, and S.A. Gouwy), most of them linked to post-1991 mapping projects. Some of that data was reinterpreted and updated to the current taxonomy (GSC collections by Uyeno and McCracken). New conodont

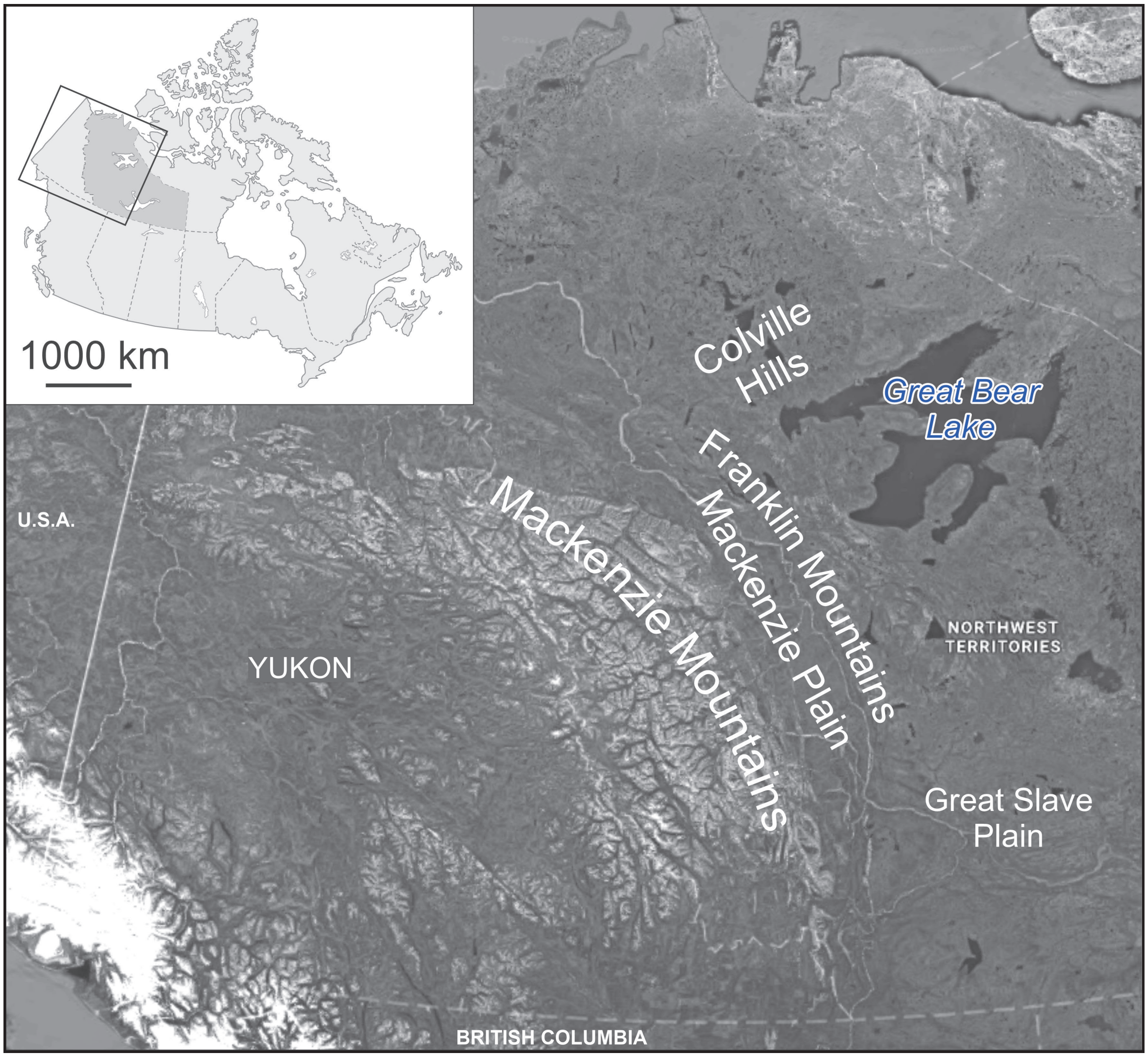

Figure 1. Regional geography and location of the Mackenzie Mountains in the Northwest Territories. Image *modified from* the relief map of Canada published by Natural Resources Canada (2020).

material from recent mapping and Devonian studies (part of the GEM program) was also included. Additional information, particularly for the southern Mackenzie Mountains, comes from the literature (Perry, 1974; Chatterton and Perry, 1977; Chatterton, 1978) and conodont studies that are in progress (as of March 2019). Since the data are taken from the literature, conodont names have not yet been updated to recently changed taxonomy (for Lower Devonian taxa).

CONODONT BIOSTRATIGRAPHY

Conodont biostratigraphy is one of the most used tools for providing a constrained age of marine sedimentary rocks and the construction of detailed stratigraphic charts in the Paleozoic, and especially in the Devonian. The Devonian conodont zonation is based on first appearances of index conodont species. Several biozonation schemes were developed and updated in the literature during the last few decades. The chronostratigraphic charts in Figures 3 and 4 show the conodont zonation based on Kaufmann (2006) and Becker et al. (2012) for the Lower and Middle Devonia; and based on Ziegler and Sandberg (1990), Becker et al. (2012), and Klapper and Kirchgasser (2016) for the Upper Devonian. Both charts were linked to an absolute-age scale (Ma) updated to the International Stratigraphic Chart (version 2019/05; Cohen, 2013) produced by the International Commission on Stratigraphy.

In this section of the paper, each of the assemblages is summarized in terms of stratigraphic units and what is currently known about the depositional environment and conodont biostratigraphy of each unit. Only the most important samples are mentioned in the text and are referred to by their 'GSC curation number' used in the GSC database. The biostratigraphic ranges per unit are illustrated in Figures 10 and 11.

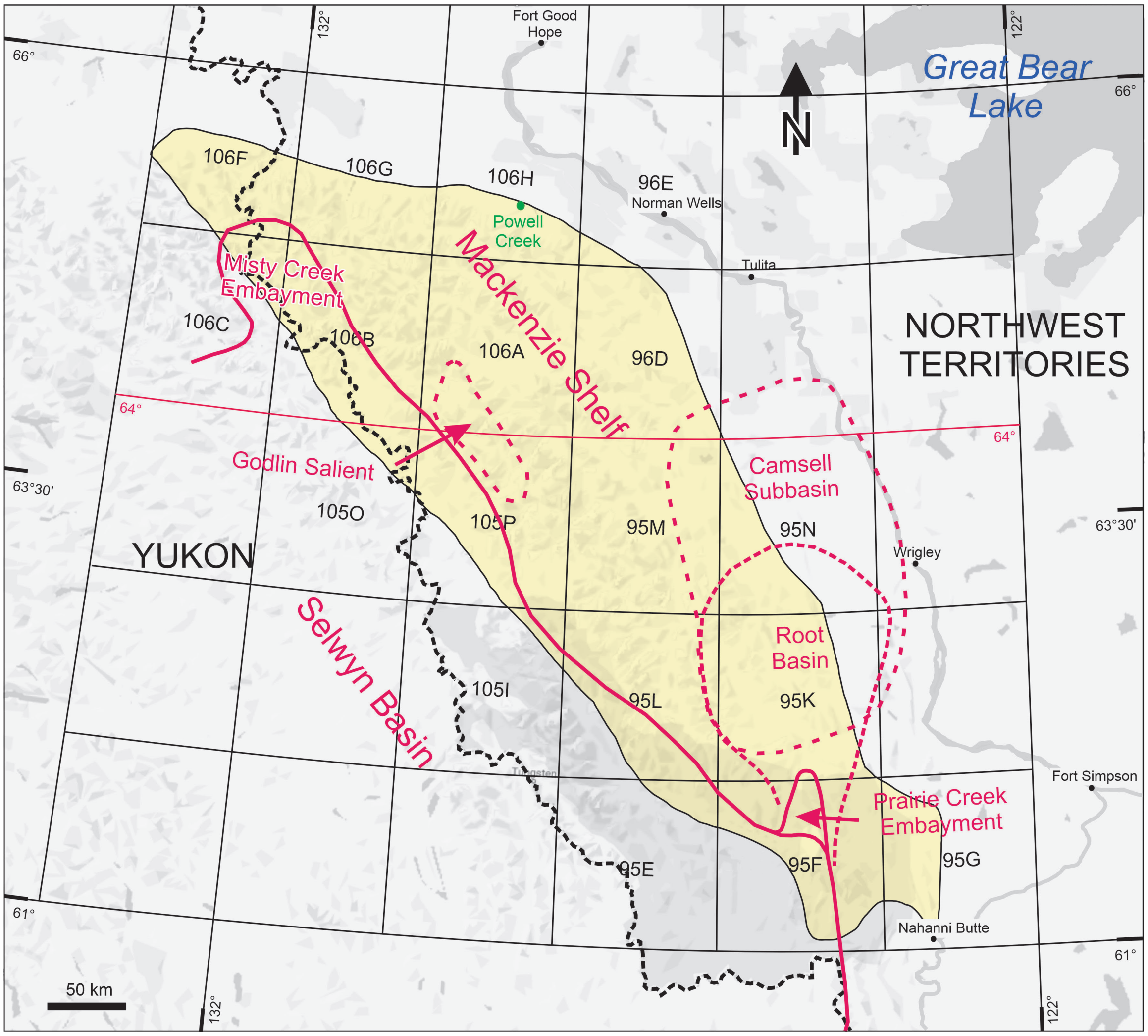

Figure 2. Distribution of the paleotectono-sedimentological elements in the Mackenzie Mountains during the Devonian, *based on* Morrow and Cook (1987) and Morrow (1991). The area of the Mackenzie Mountains is indicated in yellow. Latitude 64°N divides the northern and southern Mackenzie Mountains in this study.

Lower Devonian

Delorme assemblage

The Delorme assemblage corresponds to the Delorme Group of Morrow (1991) and time-equivalent formations and the Delorme Assemblage of Morrow and Geldsetzer (1988), Uyeno (1991), and Morrow (2012, 2018). It extends over the whole of the Mackenzie Mountains, except for the northeastern portion (Fig. 5), close to Norman Wells and Tulita, an area that might have been land at the time (‘Norman Wells High’ of Morrow and Geldsetzer (1988)). These were the first strata deposited on the sub-Devonian unconformity.

The Delorme Group on the Mackenzie Shelf was largely deposited in a restricted marine environment consisting of evaporite basins that developed on the shelf with thicker, silty evaporites of the Camsell Formation accumulating in intra-shelf subbasins (Camsell Subbasin and Godlin Salient; Fig. 2) and a thin cover of silty dolostone being deposited on the surrounding shelf regions (Tsetso Formation). In the northern part of the northern Mackenzie Mountains, these deposits are grouped into the undifferentiated Delorme Group.

Undifferentiated Delorme Group

The undifferentiated Delorme Group, in the northern part of the Mackenzie Mountains (NTS 106-F–H), is easily recognizable as a whole and is described by Morrow (1999, p. 71) as “brightly coloured silty to sandy dolostones sandwiched between the drab, grey to brown coloured clean carbonates of the Ronning Group and the Arnica Formation.” On reconnaissance maps (Aitken and Cook, 1975; Norris, 1982), there is no distinction between ‘Delorme formation’

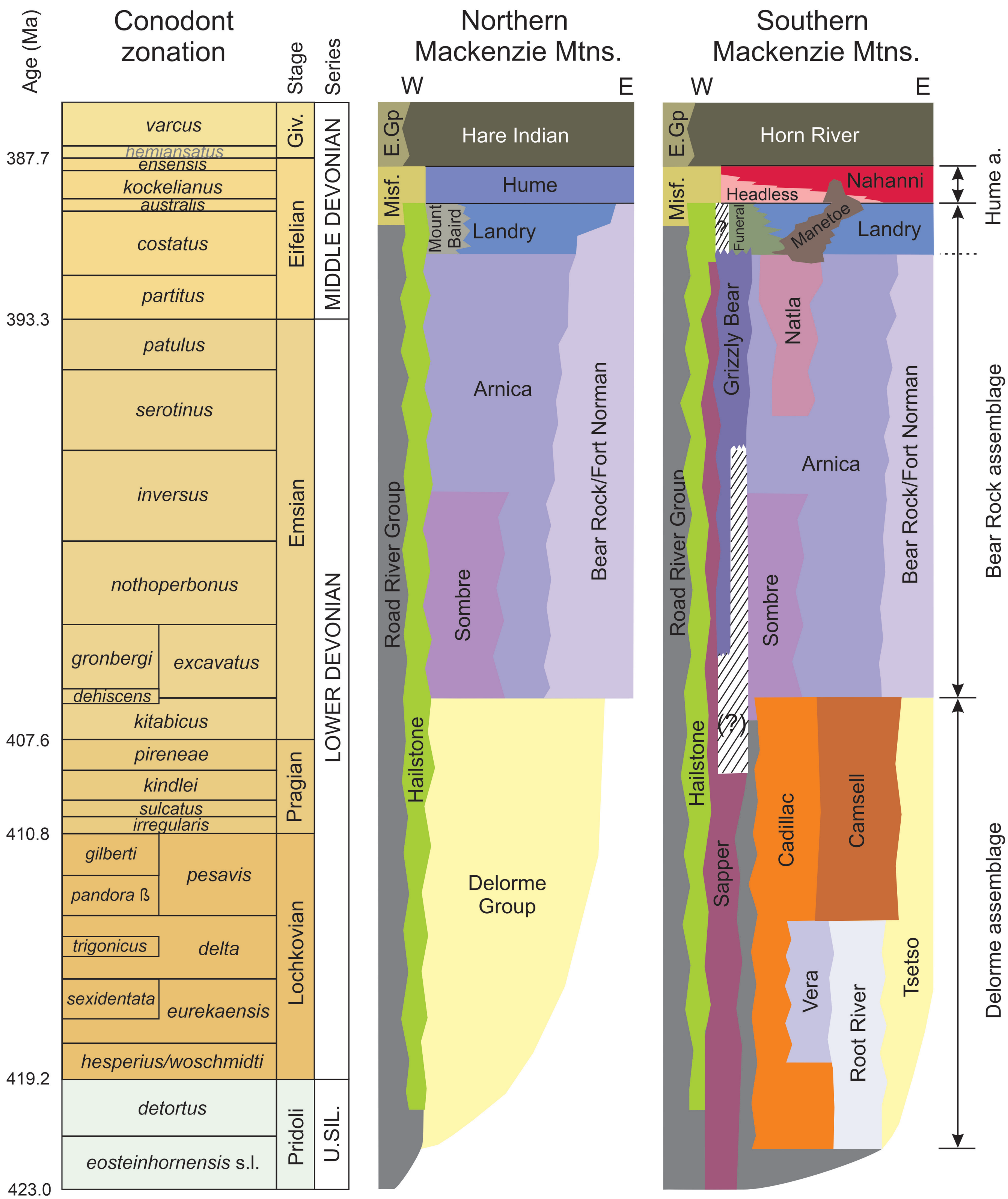

Figure 3. Chronostratigraphic chart of the Lower and lower Middle Devonian units in the northern and southern Mackenzie Mountains. Conodont zonation *based on* Becker et al. (2012) and Kaufmann (2006), and updated to the International Chronostratigraphic Chart (v2019/05; Cohen et al., 2013) produced by the International Commission on Stratigraphy. Hatching indicates a hiatus. Abbreviations: a., assemblage; E. Gp., Earn Group; Giv., Givetian; Misf., Misfortune Formation; Mtns., Mountains; s.l., *sensu lato*; U. Sil., upper Silurian.

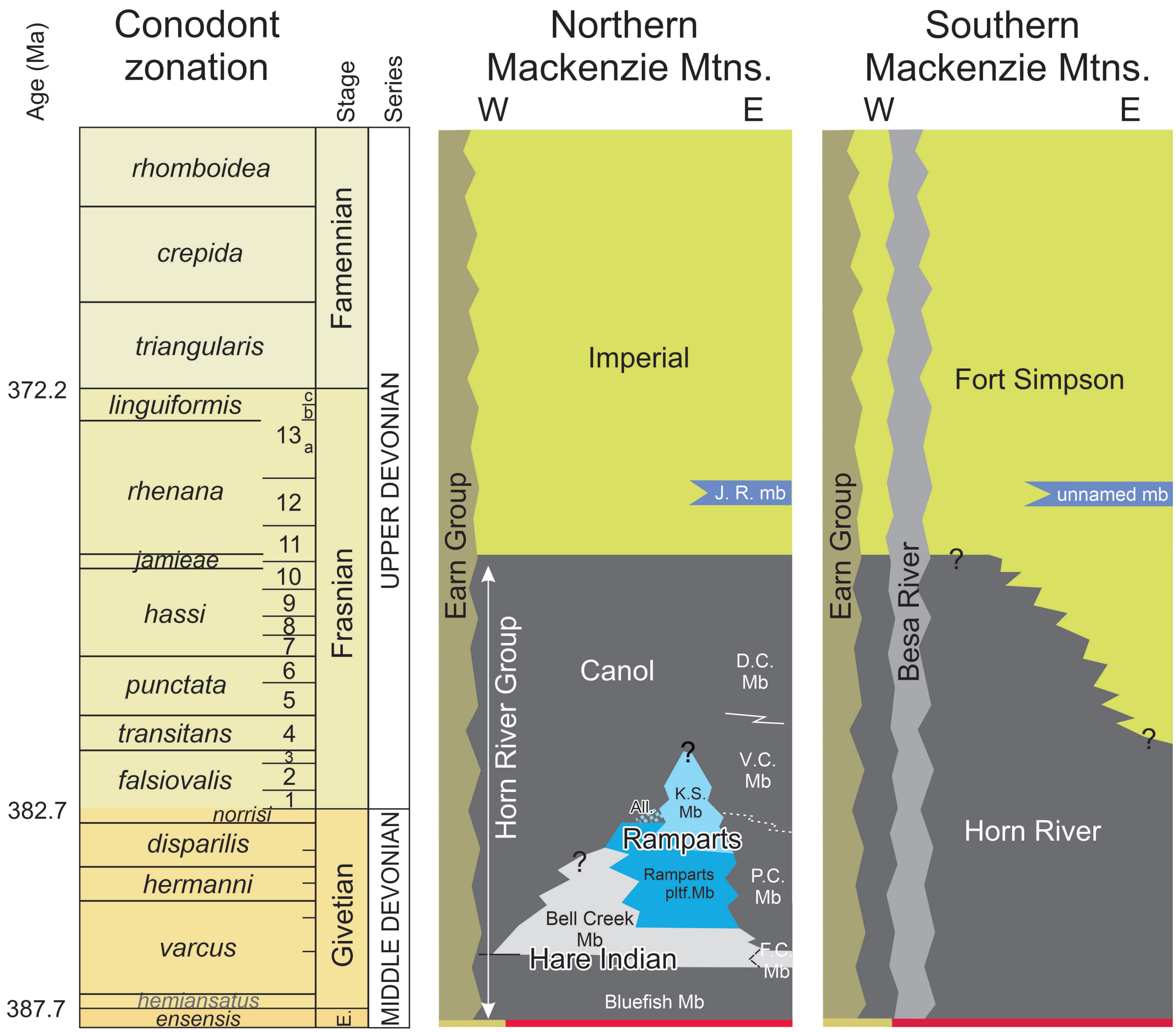

Figure 4. Chronostratigraphic chart of upper Middle and Upper Devonian units in the northern and southern Mackenzie Mountains. Conodont zonation *based on* Ziegler and Sandberg (1990), Becker et al. (2012), and Klapper and Kirchgasser (2016). Abbreviations: All., Allochthonous limestone beds; D.C. Mb, Dodo Canyon Member; E., Eifelian; F.C. Mb, Francis Creek Member; J.R. mb, Jungle Ridge member; K.S. Mb, Kee Scarp Member; Mtns., Mountains; P.C. Mb, Prohibition Creek Member; pltf., platform; V.C. Mb, Vermillion Creek Member. Question marks indicate uncertain location of member or formation contacts.

and Camsell, Peel, Tsetso, or Tatsieta formations, and these strata were all grouped into the same unit. The Peel and Tatsieta formations are widely distributed in the Peel plateau and Peel Plain areas, north of the Mackenzie Mountains. Morrow (1999), Gal et al. (2009), and Kabanov et al. (2016) identified the units in several outcrops along the northern front of the Mackenzie Mountains, but the units have not been identified southward into the mountains (Morrow, 1991). Conodont material recently sampled from these units is being processed.

Tsetso Formation

The Tsetso Formation (Meijer-Drees, 1993) is a succession of yellow-grey to orange-yellow bedded dolostone or dolomitic siltstone and sandstone and more recessive orange silty and sandy beds at the base and the top of the formation. The formation, which is interpreted as a peritidal deposit, disconformably overlies older deposits (Mount Kindle Formation and equivalents of early Silurian age) and is itself overlain by the Camsell or Bear Rock formations. The Tsetso Formation is largely the lateral equivalent of the Peel

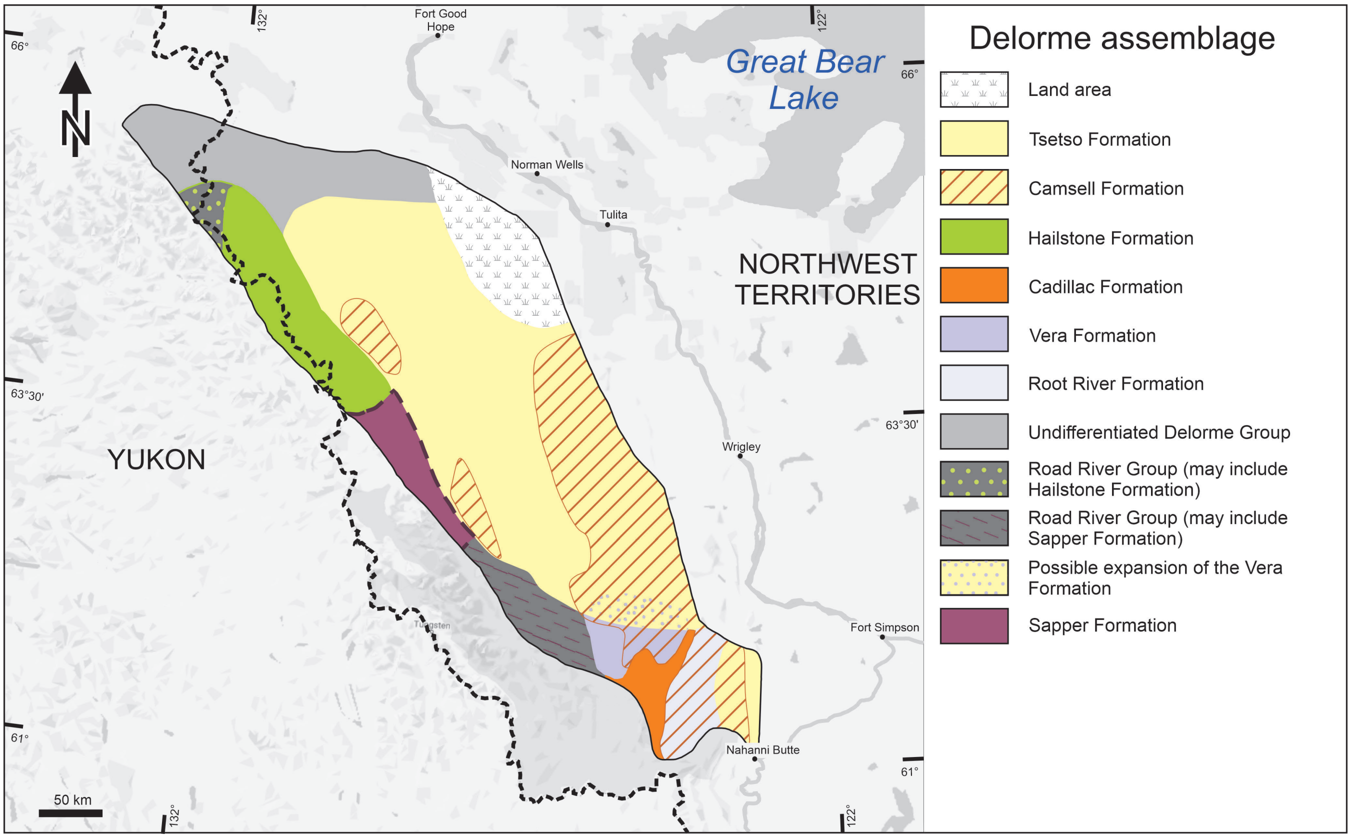

Figure 5. Unit-distribution map of the Delorme assemblage (Delorme Group and time-equivalent units).

and Tatsieta formations to the north (Peel Plain, Peel plateau, and Anderson Plain; Morrow, 2012), which are estimated to be of late Silurian to Early Devonian age (Morrow, 1999). The northeastern limit of the Tsetso Formation is based on Morrow (1991). Tsetso conodont samples from the northern part of the Mackenzie Mountains indicate a Pridolian to Lochkovian age (*O. eosteinhornensis* to *A. delta* zones; GSC Curation no. C-75783 and C-75784: *'Ozarkodina' remscheidensis* s.l. Ziegler, 1960). New data from samples collected in 2016 and currently being processed may further refine the age constraints for this formation in the northern Mackenzie Mountains. Samples from the southern part of the Mackenzie Mountains (NTS 95-K; Chatterton and Perry, 1977), near the contact between the Tsetso and the Camsell formations, also point to a Lochkovian age (*O. eurekaensis* to *A. delta* zones; *'Ozarkodina' r. remscheidensis* (Ziegler, 1960), *Pelekygnathus csakyi* (Chatterton and Perry, 1977), and *Caudicriodus hadnagyi* (Chatterton and Perry, 1977)). Perry (1974) identified *Polygnathus dehiscens* Philip and Jackson, 1967 in the top of the Delorme Formation (NTS 105-P; lower Emsian) and placed the base of the formation in the Pridoli (uppermost Silurian) (*O. eosteinhornensis* to *C. woschmidti* zones; *'O.' r. eosteinhornensis* (Walliser, 1964) and *Wurmiella excavata* (Branson and Mehl, 1933) collected 10 m above the base).

Cadillac Formation

The Cadillac Formation (Morrow and Cook, 1987) is dominated by recessive bright orange- to brown-weathering dolomitic siltstone and sandstone, minor limestone debris and megabreccia beds in the lower part of the formation, and pink shale beds in the upper part. These units are considered a westward-prograding mud bank forming a submarine escarpment at the western end of the Root River shelf, with the megabreccia beds closer to the shelf edge. The limestone debris is interpreted as turbiditic debris originating from calcareous mounds that slid down the escarpment (Morrow and Cook, 1987). At the South Tundra 1 section (Morrow and Cook, 1987; C-52706; NTS 95-F), a fauna from 48 m below the contact with the overlying Vera Formation contains *Amydrotaxis sexidentata* Murphy and Matti, 1983, *'O.' r. remscheidensis* (Ziegler, 1960), and *Pedavis* sp. cf. *P. pesavis* (Bischoff and Sanneman, 1958) and indicates an *O. eurekaensis* Zone age (updated from Uyeno in Morrow and Cook, 1987; Uyeno, 1991). *Panderinellina exigua philipi* (Klapper, 1969) was identified from a sample taken in the pink shale beds, 45 m below the contact with the Arnica Formation in the West Headless section (Morrow and Cook, 1987; C-52985; NTS 95-F) and suggests an age range of *E. sulcatus* Zone to *P. gronbergi* Zone. The lowermost part of the Cadillac Formation could be Silurian as the presence of several brachiopod samples from the lower part of the formation suggests (Norris in Morrow and Cook, 1987); no conodont samples are available to confirm this supposition.

Root River Formation

The Root River Formation (Morrow and Cook, 1987) is a resistant, light grey to yellowish grey dolostone with local biostromal beds or even reefal beds and is interpreted as a shallow-water shelf deposit (Morrow and Cook, 1987). Biostratigraphic data from the Root River Formation are scarce. Only one brachiopod sample is useful (C-59399, cf. *Trimerella ohioensis* Meek, 1871; South Tundra 7 section of Morrow and Cook (1987)) and gives a Silurian age for the lower part of the formation. The formation age is therefore mostly inferred from the ages of the surrounding formations. The upper part of the Root River Formation is a lateral equivalent of the Vera Formation, which would suggest that this part is of Lochkovian age. Both are overlain by the Camsell Formation. The Root River Formation extends northward into the Root River map area (NTS 95-K; Morrow and Cook, 1987) but is not delineated in the most recent geological map (Douglas and Norris, 1977).

Time-equivalent deposits of the Delorme assemblage in the Selwyn Basin are the Lower Devonian deposits within the Road River Group and the Sapper and Hailstone formations, representing deeper, off-shelf basin and slope deposits.

Vera Formation

The Vera Formation (Morrow and Cook, 1987) is a recessive sequence of yellow, orange, or pink weathered argillaceous limestone arranged in rhythmically bedded couplets with local coral and crinoid-bearing mounds formed and deposited in the photic zone of a partially filled Root Basin (Morrow and Cook, 1987). The Vera Formation extends farther north than indicated on the map (Fig. 5); the formation was included in the 'Delorme Formation' on the most recent Root River geological map (NTS 95-K; Douglas and Norris, 1977), and therefore its outline is not shown on that map sheet (northward extent only suggested by dot pattern on Fig. 5). Norris and Uyeno (1981) studied the Vera Formation (referred to as the 'Delorme Formation') on Cathedral Mountain (NTS 95-F) and located the formation in the Lochkovian, based on a sample taken 23.1 m above the contact with the underlying Road River Group (*C. woschmidti* to *O. eurekaensis* zones; C-57249: *'O.' r. remscheidensis* (Ziegler, 1960) and *Icriodus hesperius* Klapper and Murphy, 1975) and a sample near the top of the formation, in contact with the Camsell Formation in the North Tundra Ridge section (Morrow and Cook, 1987; *O. eurekaensis* Zone; C-60714: *Caudicriodus hadnagyi* (Chatterton and Perry, 1977) and *'Ozarkodina'* cf. *'O.' remscheidensis* (Ziegler, 1960)). In the South Tundra 1 section (Morrow and Cook, 1987), the Vera Formation sits on top of the Cadillac Formation and is dated as Lochkovian (*C. woschmidti* to *A. delta* zones), based on a conodont sample from the underlying Cadillac Formation (*see* 'Cadillac Formation' section) and *'O.' r. remscheidensis* (Ziegler, 1960) taken 78 m above the base of the Vera Formation (C-52709).

Camsell Formation

The Camsell Formation (Douglas and Norris, 1961), which is traced mostly in the southern Mackenzie Mountains, consists of orange-weathering dolostone, yellowish grey dolostone, anhydritic evaporitic facies in the subsurface, and intensely brecciated strata in outcrops (Morrow, 1991). The formation is colour banded and interpreted as an alternation of intertidal and subtidal deposits, described by Morrow and Cook (1987) as hemicycle-produced facies reflecting slight relative sea-level variations. The Camsell breccia was later formed by dissolution of the anhydrite exposed to surface weathering (Morrow, 1991). A Camsell conodont sample from the Bonnet Plume map area (NTS 106-B) contains *Amydrotaxis chattertoni* Uyeno, 1990, a species restricted to the Lochkovian (*O. eurekaensis* to *A. delta* zones; C-89126). No other fossil data are available from this formation, so its age is further inferred from its stratigraphic position.

In and around the Prairie Creek Embayment map area (approximately NTS 95-F), at the southern end of the Root Basin (Fig. 2), the Delorme assemblage includes the Cadillac, Vera, and Root River (partially) formations (Morrow and Cook, 1987). In the late Silurian, the Root Basin ceased to be a distinctive basin after infilling by the lowermost part of the Cadillac Formation. This infilling, combined with local tectonic activity, created the embayment at the southern edge of the Root Basin. In the Early Devonian, the embayment was filled by the middle and upper parts of the Cadillac Formation and shallow-water deposits like those of the Vera and Camsell formations (Fig. 2; Morrow and Cook, 1987).

Sapper Formation

The Sapper Formation (Gordey and Anderson, 1993) is described as a recessive, thin-bedded, dark grey- to orange-weathering limestone and silty limestone. It is found in the southwest of the Mackenzie Mountains (NTS 105-I, 105-P). The Sapper Formation is a unit deposited in an environment below wave base, just beyond the shelf edge (Gordey and Anderson, 1993), and is the southern time-equivalent of the Hailstone Formation. In earlier work (before definition of the Sapper Formation), these strata were mapped as part of the upper Road River Group or as the Funeral Formation (NTS 95-L, 95-E; Gabrielse et al., 1973; Gordey and Anderson, 1993; Martel et al., 2011); this is indicated on Figure 5 by purple hatching in the pattern used to identify the Road River Group. The age of the Sapper Formation ranges from the latest Ordovician up to the early Middle Devonian *P. costatus* Zone (C-86337: *Polygnathus c. costatus* Klapper, 1971 identified in the top of the Formation and capped by the Funeral Formation, starting within the *P. costatus* Zone). Conodonts from the top of the Sapper Formation covered by the Grizzly Bear Formation are of Pragian age (*P. pireneae* to *P. dehiscens* zones; C-86350: *Eognathodus sulcatus kindlei* Lane and Ormiston, 1979 and *Polygnathus pireneae* Boersma, 1974).

Hailstone Formation

The Hailstone Formation (Cecile, 2000) is a basin-and-slope deposit consisting of a poorly sorted conglomerate or breccia in its basal part, overlain by calcareous black shale and weathered, platy bioclastic limestone characterized by crinoid ossicles with twin canals (Cecile, 2000). It is present in the northwestern part of the Mackenzie Mountains. The formation is capped by the Misfortune Formation. Martel et al. (2011) interpreted the Hailstone Formation as a unit deposited below wave base. Cecile (2000) considered it a deeper water debris fan derived from the Grizzly Bear Formation. Based on the age reconstruction of both formations, that is surely a possibility for both the upper and middle parts of the Hailstone Formation, but another source of debris would be required for the Pragian and Lochkovian parts of the formation. On a recent geological map of the Niddery Lake and Sekwi Mountain areas (NTS 105-O, 105-P; Yukon Geological Survey, 2018), the few outcrops of the Hailstone Formation are interpreted as Grizzly Bear Formation. To the north, the updated map for the Nadaleen River area (NTS 106-C; Yukon Geological Survey, 2018) shows a deposit of the Road River Group as the lateral continuation of the Hailstone Formation in map area NTS 106-B (indicated by pattern with green dots on Fig. 5). The age of the Hailstone Formation is estimated as Early Devonian (or even late Silurian) to early Middle Devonian. The basal conglomerate clasts and matrix contain a sample of Pridoli (Silurian) to Lochkovian conodonts (*O. detortus* to *A. delta* zones; C-89106: *'O.' r. remscheidensis* (Ziegler, 1960)). A sample with *Polygnathus serotinus* Telford, 1975 and *Panderinellina exigua exigua* (Philip, 1966) comes from the middle part of the formation (*P. excavatus–P. serotinus* zones; C-555861) (A.D. McCracken, unpub. rept., 2013). The species *Polygnathus l. linguiformis* Hinde, 1879 (C-468020) and *P. parawebbi* Chatterton, 1978 (C-468028) appear in the upper part of the formation (*T. australis*–middle *P. varcus* zones) (A.D. McCracken, unpub. rept., 2007).

Road River Group

The Road River Group (Fritz, 1985) is described as an upper Cambrian to Upper Devonian unit consisting of dark shale, argillaceous limestone, and minor chert, dolostone, sandstone, and siltstone (after the description of the Road River Formation by Jackson and Lenz (1962); Pyle et al., 2003)) and is interpreted as turbiditic sediments and pelagic–hemipelagic sediments deposited in a continental-margin to slope-and-basin environment (Gal and Pyle, 2009). Opinions vary on the nomenclature and extent of this group. As shown on the Nadaleen River geological map (NTS 106-C; Yukon Geological Survey, 2018), Road River deposits are exposed in the northwestern quarter of the map and range up into the Lower Devonian to Middle Devonian. In the Glacier Lake map area (NTS 95-L; Gabrielse et al., 1973), Road River deposits crop out in the southwestern part of the map area and range up into the Lower Devonian. In Morrow's time-stratigraphic charts (*see* Morrow, 2012, Fig. 5; 2018, Fig. 5) the top of the Road River reaches into the lower part of the Middle Devonian in the Mackenzie Mountains; his interpretation is followed here. The South Manetoe 1 section (Morrow and Cook, 1987) contains one conodont sample in the Road River Group below the Cadillac Formation (Pridoli to Lochkovian *A. delta* Zone; C-59338: *'O.' r. remscheidensis* (Ziegler, 1960)). A Road River conodont sample from a ridge section north of the South Nahanni River (C-86548: *Eognathodus sulcatus kindlei* Lane and Ormiston, 1979, *Panderinellina exigua philipi* (Klapper, 1969), *Pan. steinhornensis miae* Bultynck, 1971, *Polygnathus dehiscens* Philip and Jackson, 1967, and *P. pireneae* Boersma, 1974) indicates a Pragian age (*E. s. kindlei* Zone).

Lower Bear Rock assemblage

The Bear Rock assemblage corresponds to the Bear Rock–Stone assemblage of Morrow and Geldsetzer (1988) and Uyeno (1991) and is divided into a lower part consisting of the Arnica Formation and lateral equivalents and an upper part consisting of the Landry Formation and lateral equivalents. The start of the Bear Rock assemblage indicates a shift to deposits of a somewhat more open marine environment on the Mackenzie Shelf compared to the Delorme assemblage.

On the Mackenzie Shelf, the lower Bear Rock assemblage (Fig. 6) is represented by the Arnica, Bear Rock, and Sombre formations; the off-shelf equivalents are the Grizzly Bear and Natla formations. The deeper off-shelf deposits are the Sapper and Hailstone formations and the Road River Group in the Selwyn Basin. The lower Bear Rock assemblage is of Emsian–early Eifelian age.

Arnica Formation

The Arnica Formation (Douglas and Norris, 1961) represents a shelf facies consisting of a series of visibly darker and lighter banded, grey, fetid dolostones with sparse fossil content, deposited in a peritidal environment (Morrow and Cook, 1987; Gordey and Anderson, 1993). The formation was mapped throughout the Mackenzie Mountains and is the lateral equivalent of the Bear Rock Formation to the east. Although the formation is widespread, conodont faunas that can be used for age determination are sparse. Based on data from the Arnica and bracketing formations, the Arnica Formation would range from the Emsian (*P. dehiscens* Zone; C-83240: *Eognathodus sulcatus kindlei* Lane and Ormiston,

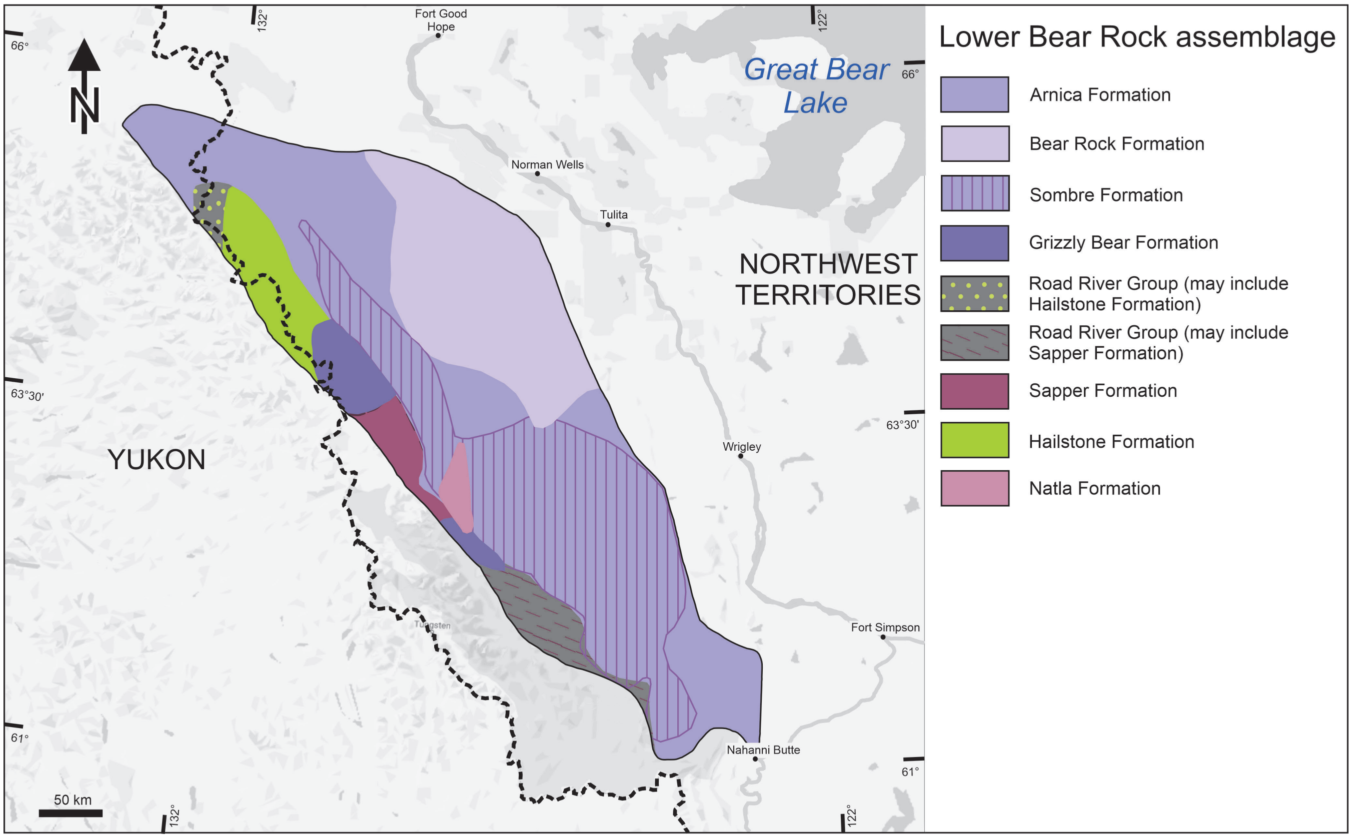

Figure 6. Unit-distribution map of the lower Bear Rock assemblage (Arnica Formation and time-equivalent formations).

1979 and *'O.' linearis* (Philip, 1966)) to the Eifelian (base of the *P. costatus* Zone; C-53031: *Polygnathus costatus*? Klapper, 1971 in the top of the formation). These are data from the southern Mackenzie Mountains; in the northern Mackenzie Mountains, sampling near the formation contacts did not result in the retrieval of any age-diagnostic conodont fauna.

Bear Rock Formation

The Bear Rock Formation (Hume and Link, 1945) consists of brownish grey weathered and (gypsified) lensed to grey bedded or non-bedded dolostone, limestone, calcareous dolostone, and dolomitic limestone; all units display various degrees of brecciation. In outcrop, the Bear Rock Formation is almost entirely breccia; the subsurface equivalent (Fort Norman Formation) is an alternation of anhydrite and dolostone. No conodont samples are available from the Mackenzie Mountains; Bear Rock samples from the Colville Hills indicate an age interval between the *P. dehiscens* and *P. costatus* zones (Gouwy et al., 2017). Morrow (1991) attributes the brecciation of the Bear Rock Formation to the near-surface solution collapse of carbonates due to preferential dissolution of evaporites. In the eastern part of the northern Mackenzie Mountains, the Bear Rock breccia is the lateral equivalent of both the Arnica and Landry formations.

Sombre Formation

The Sombre Formation (Douglas and Norris, 1961) is a thin- to thick-bedded, grey- to brownish grey-banded dolostone, which contains corals and stromatoporoids at some levels. It is interpreted as a peritidal deposit that forms the western edge of the Mackenzie Shelf in the northern and southern Mackenzie Mountains (Morrow, 1991). The formation is time equivalent to the Arnica and Bear Rock formations to the east. The Sombre conodont fauna indicates an Emsian age (*P. dehiscens* to *P. inversus* zones; C-87524: *P. dehiscens* Philip and Jackson, 1967 and *Pelekysgnathus furnishi* Klapper, 1969 near the lower part of the formation; C-87525: *Steptotaxis glenisteri* (Klapper, 1969) near its top (samples from Gordey and Anderson, 1993)). This contrasts with Uyeno (1991), in which the Sombre Formation was identified as Lochkovian to lower Emsian, based on data from bracketing formations.

Grizzly Bear Formation

The Grizzly Bear Formation (Gabrielse et al., 1973), a resistant, massive light to dark grey bioclastic limestone, calcarenite, and local dolostone (Cecile, 2000) characterized by crinoid ossicles with twin axial canals, is interpreted as having been deposited along shoals, off-shelf of the main platform situated immediately to the east (Gordey and Anderson, 1993). In the Mackenzie Mountains, the Grizzly Bear Formation is preserved in two isolated outcrops in map area NTS 106-B (overlying the Hailstone Formation), in map area NTS 95-L (overlying the Arnica Formation), and in map area NTS 105-I (overlying the Sapper Formation). Douglas and Norris (1977) identified a patch of the Grizzly Bear Formation in the northeastern part of NTS 95-F. Morrow and Cook (1987) later reassigned this to the Landry Formation. The lower contact with the underlying facies is considered unconformable (Gordey and Anderson, 1993) and proven to be so by, in this case, missing conodont faunas (Gordey and Anderson (1993) sections 37 and 51 have 5 and 4 conodont zones missing, respectively). Section 46 in the same publication contains the oldest Grizzly Bear conodont fauna (*P. gronbergi* to *P. nothoperbonus* zones; C-87539b: *Polygnathus gronbergi* Klapper and Johnson, 1975, *Panderinellina steinhornensis* (Ziegler, 1956), *Polygnathus* cf. *P. dehiscens* Philip and Jackson, 1967 and *P.* aff. *P. perbonus* (Philip, 1966)). The youngest Grizzly Bear conodont sample indicates a *P. costatus–T. australis* zonal age (C-87539y: *Polygnathus c. costatus* Klapper, 1971, *P. linguiformis* Hinde, 1879 group and *P. robusticostatus* Bischoff and Ziegler, 1957 group). The contact with the overlying Funeral Formation is described as abrupt and sharp, but no gaps were identified in the conodont biozonation, suggesting a conformable succession of strata (*see* conodont ages in 'Funeral Formation' section).

Natla Formation

The Natla Formation (Gabrielse et al., 1973) consists of a recessive succession of black to dark grey-weathering, argillaceous, thin-bedded limestone with abundant tentaculitids, rugose and tabulate corals, brachiopods, trilobites, and echinoderm debris (ossicles with twin axial canals) as common components. According to Gordey and Anderson (1993), it is the off-shelf, fossil-rich equivalent of the Arnica Formation. Depositional slump structures in one of their sections suggest a slope environment. The formation also correlated in part with the Grizzly Bear and Sapper formations. Conodonts from the Natla Formation indicate an age ranging from the *P. serotinus* Zone (C-92574: *Polygnathus inversus* Klapper and Johnson, 1975 and *P.* aff. *P. l. bultyncki* Weddige, 1977) to the *P. costatus–T. australis* zones (C-87585: *P. c. costatus* Klapper, 1971 and *P. robusticostatus* Bischoff and Ziegler, 1957 group in the uppermost part of the formation in contact with the Landry Formation).

Sapper Formation (*see *above)

Hailstone Formation (*see *above)

Middle Devonian

Upper Bear Rock assemblage

On the shelf, the upper Bear Rock assemblage (Fig. 7) is represented by the Landry and Bear Rock formations and the interspersed Manetoe dolomite facies. Off-shelf time-equivalents are the Road River Group and Funeral, Mount Baird, Hailstone, Road River, and Misfortune (lowermost part) formations. This part of the Bear Rock assemblage is entirely Eifelian (middle part) in age.

Hailstone Formation

The upper part of the Hailstone Formation (*see* above) is the western lateral and deeper water (Selwyn Basin) equivalent of the Landry Formation. Fischer (2016) extended the age of the Hailstone Formation up into the lowermost part of the Givetian, making the upper part of the Hailstone Formation the lateral equivalent of the Hume Formation in map area NTS 106-B. Conodonts samples from the upper part of the Hailstone Formation in that map area contain only long-ranging species and are not conclusive of a Givetian age (*T. australis* to *P. ansatus* zones; C-468028: *Polygnathus parawebbi* Chatterton, 1974).

Landry Formation

The Landry Formation (Douglas and Norris, 1961) is a shallow-water deposit of grey to bluish grey lime mudstone, dolostone with thin interbeds of rare calcareous shale or argillaceous limestone, and rare beds of fossiliferous limestone. Morrow (1991) recognized alternating recessive-resistant beds in the Landry Formation near the shelf edge, east of the Misty Creek Embayment (Fig. 2), and interpreted this as upward-shoaling cycles in a shallow-water environment. South of this area, the Landry Formation contains more fossiliferous beds, indicating a more open marine environment. The lower half of the Landry Formation yielded only sparse conodont faunas. The faunas from sample S19-810 taken in the southern Mackenzie Mountains (Chatterton, 1978) indicate a *P. serotinus–P. costatus* zones age (*Polygnathus serotinus* Telford, 1975 and *P. l. bultyncki* Weddige, 1977) and, combined with the age of the underlying Arnica and Natla formations, this places the base of the Landry Formation in the *P. costatus* Zone. In the upper part of the Landry Formation, *P. parawebbi* Chatterton, 1974 appears in sample S18-1310 of the southern Mackenzie Mountains (Chatterton, 1978); this species occurs in the interval between the *T. australis* and *P. ansatus* zones. The species *Steptotaxis uyenoi* (Chatterton,

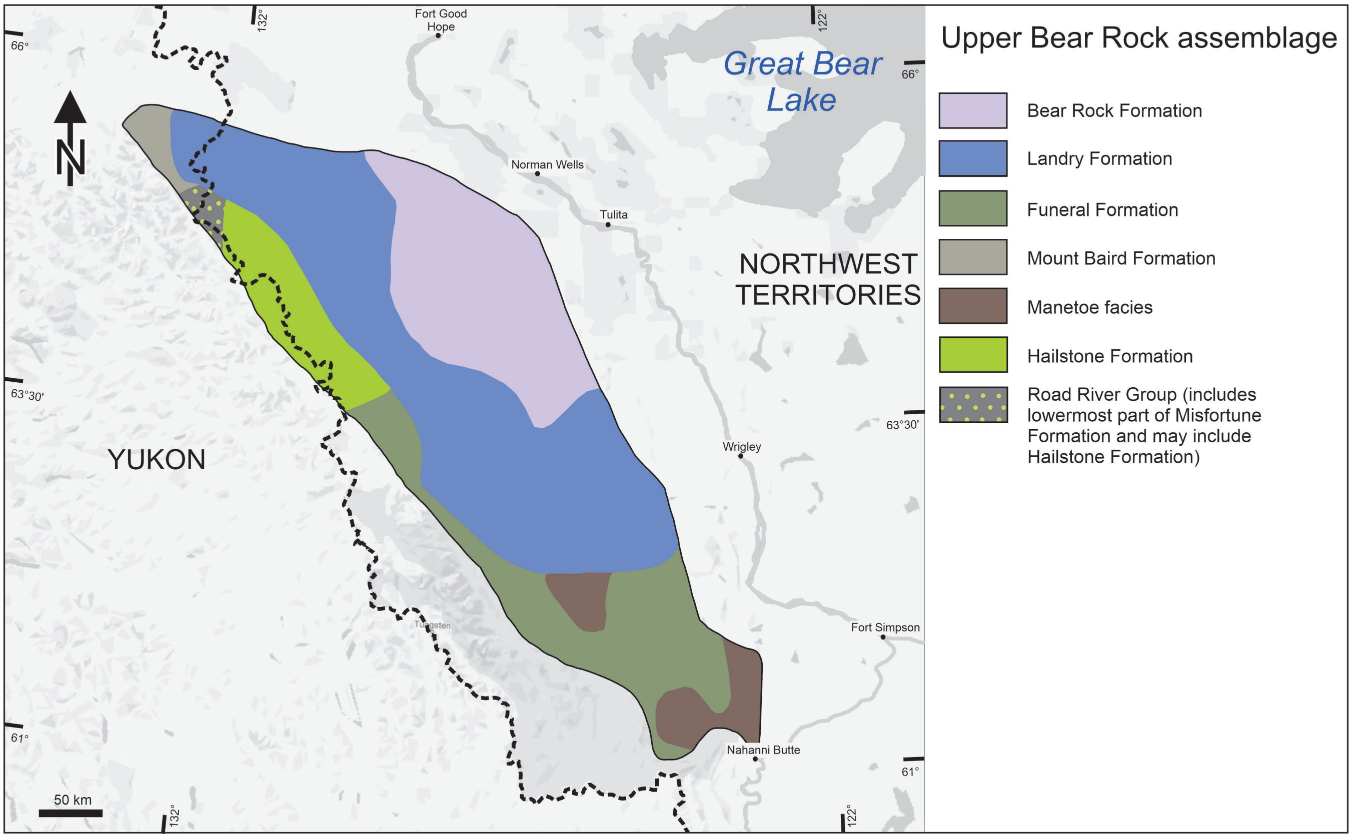

Figure 7. Unit-distribution map of the upper Bear Rock assemblage (Landry Formation and time-equivalent formations).

1978), sampled in the upper part of the Landry Formation in the northern Mackenzie Mountains (C-473018), indicates an Eifelian *T. australis* Zone.

Mount Baird Formation

The Mount Baird Formation (Norris, 1985) consists of brown-weathering calcareous shale and argillaceous limestone. The formation is exposed in the northwestern part of the Mackenzie Mountains (NTS 106-F), where it is overlying the Arnica Formation and underlying the Hume Formation. The Mount Baird Formation probably merges into the Road River Group west of map area NTS 106-F (Morrow, 1999). No conodont data are known from this formation. Gal et al. (2009) considered the Mount Baird Formation a shalier facies of the Landry Formation.

Manetoe facies

The Manetoe facies (Douglas and Norris, 1961) is a white, coarsely crystalline dolomite that is found in Middle Devonian strata of the southern Mackenzie Mountains. The facies is developed largely within the Landry Formation and upper part of the Arnica Formation and locally extends into the Headless and Nahanni formations (Morrow et al., 1990; Morrow, 2012, 2018). Douglas and Norris (1961) described the facies as a formation, but Morrow and Cook (1987) considered the unit to be a diagenetic facies and called it the 'Manetoe facies dolomite'. Morrow et al. (1990) suggested that the Manetoe facies was probably formed by a paleokarst solution-collapse mechanism. No conodont data are known from this unit.

Bear Rock Formation

In the Bear Rock Formation (*see* above), the upper part of the formation is the northeastern lateral equivalent of the Landry Formation in the northwestern and southern part of the Mackenzie Mountains. Data from Chatterton (1978) placed the uppermost part of the Bear Rock Formation in the northern part of the Franklin Mountains in the *T. australis* Zone (sample S8 in Chatterton (1978): *Polygnathus parawebbi* Chatterton, 1974 and *Steptotaxis peddari* (Uyeno and Mason, 1975)).

Funeral Formation

The Funeral Formation (Douglas and Norris, 1961) is a succession of dark grey to black, platy, calcareous shale interbedded with black argillaceous limestone, interpreted as an open marine off-shelf deposit (Gordey and Anderson, 1993). It can be considered a tongue of the Road River Group that passes eastward into the Landry Formation. The formation is the lateral equivalent of the Landry Formation and is placed in the *P. costatus* to *T. australis* zones (sample S18-100 in Chatterton (1978): *Icriodus norfordi* Chatterton, 1978 restricts the lowermost part of the formation to the *P. costatus* Zone; whereas C-86408: *Polygnathus parawebbi* Chatterton, 1974, *P. l. linguiformis* Hinde, 1879, *Tortodus k. australis* (Jackson, 1970), in the upper part of the Funeral Formation, is a fauna that typically appears in the *T. australis* Zone).

Hume assemblage

The Hume assemblage (Fig. 8) corresponds to the upper part of the Funeral–Headless Assemblage of Morrow and Cook (1987); the lower part of the Hume–Dunedin Assemblage of Morrow and Geldsetzer (1988) and Uyeno (1991); and the lower part of the Hume–Lonely Bay Assemblage of Morrow (2012, 2018). This assemblage, which is entirely of late Eifelian age, contains the Hume, Headless, and Nahanni formations on the shelf, and the Misfortune Formation (and partially the Road River Group) as off-shelf equivalents.

Hume Formation

The Hume Formation (Bassett, 1961) is a fossiliferous, argillaceous limestone and grey calcareous shale overlying the Landry and Bear Rock formations in the northern part of the Mackenzie Mountains. The formation is overlain by the Hare Indian Formation, with a locally unconformable sharp erosional contact (Gal et al., 2009). The Hume Formation is subdivided into two members (Morrow, 1991): a recessive lower member of thin-bedded skeletal argillaceous limestone, with shale interbeds and irregular nodular bedding; and an upper resistant member, consisting of thick-bedded skeletal wackestone or coral and stromatoporoid boundstone. Some authors referred to the lower member as the ‘Headless Member’, in correlation with the Headless Formation in the southern Mackenzie Mountains (*see* Kabanov and Deblonde, 2019). The formation is interpreted as a shallow to deep subtidal facies. Conodont data from Uyeno et al. (2017) indicated an Eifelian age (*T. australis* to *P. ensensis* zones) for the Hume Formation (*Polygnathus parawebbi* Chatterton, 1974 and *Steptotaxis uyenoi* (Chatterton, 1978) occurred at the base of the formation in the Hume type section; the brachiopod *Eliorhynchus castanea* (Meek, 1868), which has its first appearance in the *P. ensensis* Zone, was found in the top metre of the formation at the same location).

Headless Formation

The Headless Formation (Douglas and Norris, 1961) consists of argillaceous grey limestone interbedded with calcareous shale. The formation is found in the southern part of the Mackenzie Mountains and overlies the Funeral and Landry formations. It is overlain by the Nahanni Formation (*see* below) and is laterally partially equivalent to the Hume Formation. Conodont faunas place the Headless Formation in the *T. australis* to *T. kockelianus* zones interval (C-53037 from the lowermost part of the formation: *Polygnathus parawebbi* Chatterton, 1974, *P. l. linguiformis* Hinde, 1879, and *Steptotaxis pedderi* (Uyeno and Mason, 1975); and sample S28-1400 in Chatterton (1978) from the uppermost part of the formation: *P. parawebbi* Chatterton, 1974 and *P. curtigladius* Uyeno, 1978).

Nahanni Formation

The Nahanni Formation (Hage, 1945) is dominated by light to dark grey-bedded dolomitic limestone. Its geographic occurrence approximates that of the Headless Formation. The combination of the Headless and Nahanni formations is the lateral equivalent of the Hume Formation to the north (Morrow, 2012, 2018). The lower contact with the Headless Formation is diachronous, becoming younger westward. Conodont data also place the Nahanni Formation in the *T. australis* to *T. kockelianus* zones (sample S6-480 in Chatterton (1978), from the lower part of the formation: *Polygnathus parawebbi* Chatterton, 1974, *Steptotaxis uyenoi* (Chatterton, 1978), and *S. pedderi* (Uyeno and Mason, 1975); sample S11-855 in Chatterton (1978) at the contact with the overlying Horn River Formation: *Polygnathus parawebbi* Chatterton, 1974, *P. l. linguiformis* Hinde, 1879, *P. curtigladius* Uyeno, 1978, *P. pseudofoliatus* Wittekindt, 1965, and *P. schwartzi* Chatterton, 1978). Pedder (1975) specified that the uppermost beds of the Nahanni Formation included the brachiopod *Eliorhynchus castanea* (Meek, 1868), indicating a *P. ensensis* Zone age.

Misfortune Formation

The Misfortune Formation of the Earn Group (Cecile, 2000) consists of black siliceous shale with minor siltstone, sandstone, and some chert pebble conglomerate. The formation contains minor carbonate lenses and concretions and is remarkably similar to the Canol Formation (*see* below). It is interpreted as starved-basin facies consisting of organic-rich shale deposited in a deep-water environment (Cecile, 2000). The presence of conglomerate lenses suggests occasional transportation of coarser material as sediment gravity flows into the deeper water (Martel et al., 2011). A conodont sample from the Niddery Lake map area (NTS 105-O) reported in Cecile (2000) indicated a middle Eifelian age for the lower part of the formation (*P. costatus* Zone; C-84566: *Polygnathus angusticostatus* Wittekindt, 1965, *P. c. costatus* Klapper, 1971 and *P. l. bultyncki* Weddige, 1977). In map areas mapped in the 1960s and 1970s (Flat River NTS 95-E, Virginia Falls NTS 95-F, Glacier Lake NTS 95-L, Snake River NTS 106-F), this unit might have been included in the Road River Group (indicated by the brown pattern with yellow

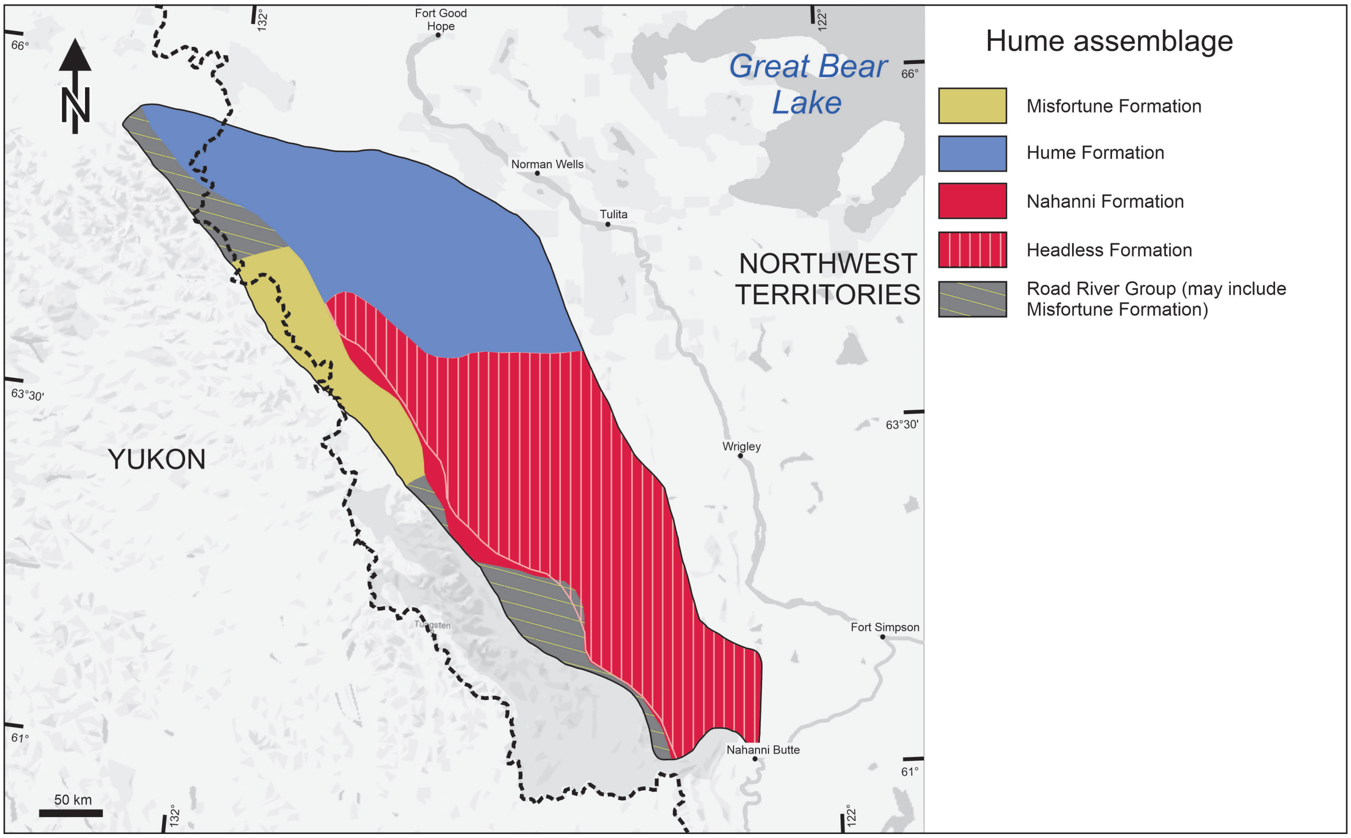

Figure 8. Unit-distribution map of the Hume assemblage.

hatching on Fig. 8), since the unit was not yet defined when the maps were compiled. Two samples from Gordey et al. (1982), from what was previously identified as the top of the Road River but is now included in the Misfortune Formation (Sekwi Mountain map area NTS 105-P; Roots et al., 2011), gave a *P. costatus* Zone age (C-87555: *Polygnathus serotinus* Telford, 1975 and *P. angusticostatus* s.l. Wittekindt, 1965) and *P. ensensis* Zone age (C-87556: *P. pseudofoliatus* Wittekindt, 1965, *P. x. ensensis* Ziegler and Klapper, 1976, *P. schwartzi* Chatterton, 1978, and *P. parawebbi* Chatterton, 1974), respectively.

Horn River Group

Horn River Group and time-equivalent formations (Fig. 9) correspond to part of the Hume–Dunedin and Fairholme assemblages of Morrow and Geldsetzer (1988) and Uyeno (1991) and to part of the Hume–Lonely Bay and Slave–Kakisa assemblages of Morrow (2012, 2018) and are Givetian–Frasnian (Middle and Late Devonian) in age. The Horn River Group (Pugh, 1983) consists of a thick deposit of dark shale (Hare Indian Formation and Canol Formation) enveloping the platform and reefal limestone of the Ramparts Formation. Time-equivalent units are the Besa River Formation in the southernmost part of the Mackenzie Mountains and the Earn Group in the Selwyn Basin to the west. The Horn River Group is generally understood as recording a transgressive phase that started with the drowning of the Hume platform (Dixon, 1984) in the *P. ensensis* Zone.

Most of the geological maps used to construct the overview map of the Horn River Group and equivalents (Fig. 9) do not distinguish between the different units of dark shale (Hare Indian, Canol, and Horn River formations are included in a single unit of dark pyritic shale on geological maps from the 1970s); therefore, these are also grouped on Figure 9 (dark grey unit). The Besa River Formation is indicated separately on the map (light grey unit).

Hare Indian Formation

The Hare Indian Formation (Bassett, 1961) is subdivided into the dark grey to black, organic-rich shale, with thin limestone interbeds of the basal Bluefish Member, and the grey calcareous shale and argillaceous limestone of the Bell Creek Member, which is interpreted as a progradational clastic wedge (Muir, 1988). The Hare Indian Formation becomes thinner going west and wedges out just east of the Yukon–Northwest Territories border in the northern mountain front (Gal et al., 2009). In the eastern part of the northern Mackenzie Mountains (and in the Mackenzie Plain), the Bell Creek Member is replaced by the fissile grey shale, with minor argillaceous sandstone and siltstone, of the Francis Creek Member (Kabanov and Gouwy, 2017) and the black

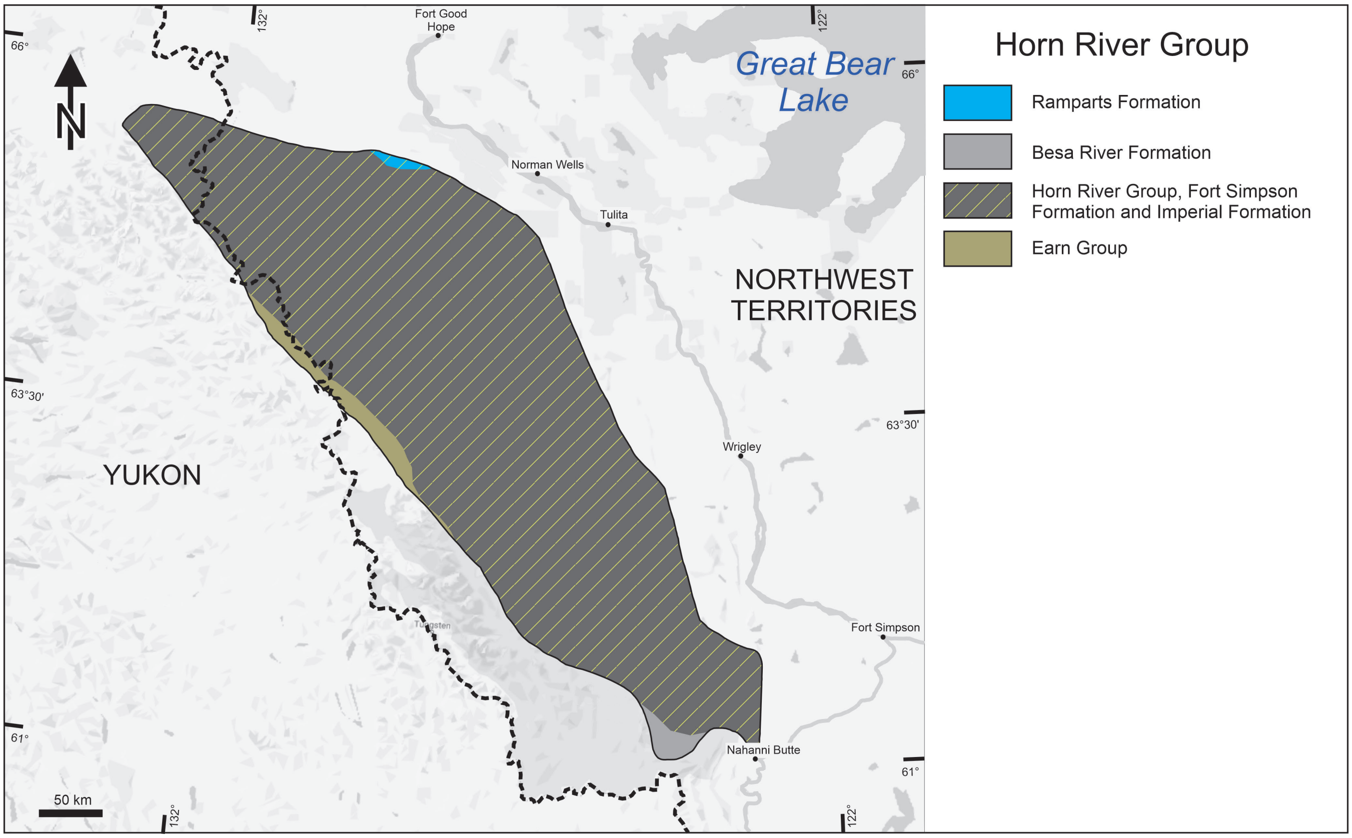

Figure 9. Unit-distribution map of the Horn River and Earn groups and Imperial, Fort Simpson, Besa River, and Ramparts formations.

calcareous shale of the Prohibition Creek Member (Kabanov and Gouwy, 2017). To the northwest, the Canol Formation becomes the lateral and time equivalent of the upper part of the Hare Indian Formation; to the southwest (Selwyn Basin), the latter correlates with part of the Earn Group (Gordey and Anderson, 1993).

The Hare Indian Formation was deposited on top of the Hume Formation and passes laterally into the lower part of the Horn River Formation deposited on top of the Nahanni Formation in the southern Mackenzie Mountains. The well-studied lower contact with the Hume Formation is in the *P. ensensis* Zone (C-24675: first occurrence of *Polygnathus x. ensensis* Ziegler and Klapper, 1976 at the contact in the Hume type section (Uyeno et al., 2017)). Conodont biostratigraphic research does not indicate a significant time gap at this contact. The top of the Hume Formation and the base of the Hare Indian Formation are both assigned to the *P. ensensis* Zone (uppermost Eifelian). The transition from the Bluefish Member into the Bell Creek Member is dated at the Powell Creek section to the *P. rhenanus–P. varcus* Zone (upper part of the lower *P. varcus* Zone; C-12182: first occurrence of *P. rhenanus* Klapper, Philip and Jackson, 1970, *P. timorensis* Klapper, Philip and Jackson, 1970, and *P. varcus* Stauffer, 1940). The age of the contact between the Hare Indian and Canol formations is still only approximate; it is difficult to pinpoint the contact in field outcrops in the absence of the Ramparts Formation, which separates the two deposits of dark shale. Samples from these outcrop settings are a topic of ongoing research. At Prohibition Creek (southeast of Norman Wells, Mackenzie Plain), the contact is roughly situated around the Givetian–Frasnian boundary (upper *K. disparilis* Zone to Frasnian zone (FZ) 3; C-597446: *P. dengleri* Bischoff and Ziegler, 1957 and *Ozarkodina sannemanni sannemanni* (Bischoff and Ziegler, 1957)).

Ramparts Formation

The Ramparts Formation (Kindle and Bosworth, 1921) includes the informal Ramparts platform member, the informal Carcajou member and Allochthonous limestone beds (minor local unit), and the Kee Scarp Member. In the Mackenzie Mountains, the Kee Scarp Member is present only in the northeast (Sans Sault Rapids map area NTS 106-H), an area that was located on the Peel shelf during the deposition of the Ramparts Formation (Uyeno, 1991).

Ramparts platform member. This unit (Pugh, 1983) consists of a fossiliferous argillaceous and silty limestone. The base of the platform member is dated in the Powell Creek section (Fig. 2, northern Mackenzie Mountains) as belonging to the *P. ansatus* Zone (middle *P. varcus* Zone (Kabanov and Gouwy, 2017)).

Carcajou member. This unit (Pyle et al., 2014), consisting of a dark grey calcareous mudstone and dark grey to black shale, is situated in between the Ramparts platform member and the Kee Scarp Member (Tassonyi, 1969) and is used as a marker horizon.

Allochthonous limestone beds. This transitional unit (Pugh, 1983) of reefal debris was deposited along the sides of the Kee Scarp reefs and is interbedded with Canol-type black shale. In the Powell Creek section, the unit is identified as late Givetian (*Sk. norrisi* Zone; C-12163: first occurrence of *Skelethognathus norrisi* (Uyeno, 1967) a few metres below the base of the Allochthonous limestone beds (Gouwy and Uyeno, 2017)).

Kee Scarp Member. This unit (Gal et al., 2009) consists of locally restricted reefal buildups of thick-bedded bioclastic limestone and massive stromatoporoid limestone. The base of the reefal member is assigned to the *K. disparilis* Zone (C-60190: first appearance of *Klapperina disparilis* (Ziegler and Klapper, 1976) a few metres below the base of the member at the Powell Creek tributary section (Muir, 1988)). The top of the reefal member was not sampled for conodonts in the Mackenzie Mountains, but data from the Allochthonous limestone beds at Powell Creek suggest that the adjacent reef might have been still active or at least was eroded in the latest Givetian. At the Kee Scarp quarry near Norman Wells (Mackenzie Plain), conodonts of the late Givetian *K. disparilis* and early Frasnian zones 1–4 have been identified in reworked layers at the top of the reef (McLean and Klapper, 1998).

Upper Middle Devonian–Upper Devonian

Horn River Group

Canol Formation

The Canol Formation (Bassett, 1961) consists of dark grey to black, organic-rich, blocky siliceous mudstone and chertstone, with some calcareous nodules and thin lenses. The formation is deposited on top of the Ramparts Formation or on top of the Hare Indian Formation where the Ramparts is absent. It merges into the upper part of the Horn River Formation in the southern Mackenzie Mountains.

Where the Ramparts Formation is present, the lower layers of the Canol Formation provide conodonts of the Givetian *Sk. norrisi* Zone (Gayna River, at the contact between the Ramparts platform member and the Canol Formation, C-76888: first occurrence of *Skeletognathus norrisi* (Uyeno, 1967) 0.4 m above the base of the Canol (Muir, 1988)) or conodonts of the lower Frasnian zones 2–3 (Powell Creek, at the contact between the Allochthonous limestone beds and the Canol Formation, C-604990: first occurrence of *Ancyrodella rotundiloba* (Bryant, 1921) 3.5 m above the base of the Canol Formation (S.A. Gouwy, unpub. rept., 2017)). On top of the Kee Scarp Member, Canol strata can be very thin or completely missing in some localities (Muir et al., 1985). Cecile (2000) and Martel et al. (2011) subdivided the Canol Formation into a lower recessive shale-dominated member and an upper more resistant chert-shale member in map areas NTS 105-O and 105-P, respectively. Kabanov and Gouwy (2017) distinguished two members in the Canol Formation to the southeast of Ramparts Formation outcrops in the Mackenzie Plain (Prohibition Creek outcrop): the basal recessive Vermillion Creek Member and the resistant Dodo Canyon Member. Preliminary results on conodont biostratigraphy position the contact between the two members near the base of the Frasnian *Pa. punctata* Zone (C-597454: first occurrence of *Polygnathus aequalis* Klapper and Lane, 1985, 3 m above the base of the Dodo Canyon Member). Preliminary data from Powell Creek locate the top of the Canol Formation in the Frasnian zone 11 (C-604422: first occurrence of *Icriodus alternatus alternatus* Branson and Mehl, 1934 and *Palmatolepis muelleri* Klapper and Foster, 1993 in the uppermost Canol bed (S.A. Gouwy, unpub. rept., 2017)).

Horn River Formation

The Horn River Formation (redefined by Douglas and Norris, 1960) is a dark, mainly noncalcareous fissile shale. According to McLean and Klapper (1998), this is the lateral equivalent of the Canol Formation (for the Root River area) and lateral equivalent of the Fort Simpson Formation in the southern district of Mackenzie. No conodont data are available from the Mackenzie Mountains, but farther east, near Great Slave Lake, T.T. Uyeno (unpub. rept., 1980) identified *Ancyrodella rotundiloba* (Bryant, 1921) in the Horn River Formation of the Providence K-45 core and about 3 m below the contact with the overlying Fort Simpson Formation, locating that part of the formation in the Frasnian zones 1–3. Similar results from a core near the northern shore of Great Slave Lake located the contact between the Horn River Formation and the Fort Simpson Formation in the Frasnian zones 1–2 (T.T. Uyeno, unpub. rept., 1984). To the west, on the Great Slave Plain, Uyeno (T.T. Uyeno, unpub. rept., 1980) identified *Palmatolepis punctata* (Hinde, 1879) in the Horn River Formation (FZ 5–10; C-13108, C-44800), indicating a younger age westward. Chatterton (1978) identified minor biohermal mounds in the Horn River Formation (sections S16 and S27 in Chatterton (1978)) and assigned them to the Horn Plateau Formation. Conodonts from these mounds place them in the Eifelian–Givetian (*T. australis* to *P. rhenanus/P. varcus* zones; sample S16-480 in Chatterton (1978): *Polygnathus l. linguiformis* Hinde, 1879 and *'S.' ormistoni* Chatterton, 1978; section S27 in Chatterton (1978): *P. parawebbi* Chatterton, 1974 and *Icriodus expansus* sensu Chatterton, 1978). Horn Plateau reefs outside the study area, closer to Great Slave Lake, are placed in the Eifelian–Frasnian *P. ensensis* to *Pa. punctata* (FZ 5–6) zones (T.T. Uyeno, unpub. rept., 1974, 1986) based on long-ranging conodont species.

Besa River Formation

The Besa River Formation (Kidd, 1963) is composed mainly of dark shale. In the southernmost part of the Mackenzie Mountains, Morrow (2012) indicated the Besa River Formation as a lateral equivalent of the Hare Indian, Horn River, Ramparts, Canol, Imperial, and Fort Simpson formations. Two Besa River conodont samples from the southern Mackenzie Mountains indicate a Givetian and Frasnian age, respectively (C-30515: *Polygnathus* ex. gr. *linguiformis* Hinde, 1879 and *P.* ex. gr. *xylus* Stauffer, 1940 combined to indicate a Givetian age; C-572053: *Mesotaxis asymmetricus* (Ziegler and Klapper, 1982) and *M. falsiovalis* Sandberg, Ziegler and Bultynck, 1989, indicating an upper *M. falsiovalis* to *Pa. punctata* zones (FZ 2–6) age).

Imperial and Fort Simpson formations

Upper Devonian Imperial Formation and Fort Simpson Formation correspond to the upper part of the Fairholme Assemblage of T.T. Uyeno, 1991 and part of the Slave–Kakisa Assemblage of Morrow (2012, 2018). On Figure 9, the Imperial Formation is grouped with the Fort Simpson Formation and the Horn River Group.

Imperial Formation

The Imperial Formation (T.A. Link, unpub. rept., 1921) is a rhythmically bedded, greenish grey to purplish brown sandstone and brown-weathering black shale, with intercalations of shale and siliceous shale. In the northern Mackenzie mountain front (e.g. Powell Creek), a 10 to 15 m thick interval of recessive dark shale lacking the calcareous and pyritic nodules and chert that are typical for the Canol Formation is considered the base of the Imperial Formation (Pyle and Gal, 2007). The formation is interpreted as a distal turbidite succession in the study area (Cecile, 2000; Martel et al., 2011). Conodont samples from Powell Creek (Braman and Hills, 1992), taken 300 m above the base of the Imperial Formation, indicate the uppermost Frasnian *Pa. rhenana–Pa. linguiformis* zones interval (FZ 11–13). At Arctic Red River, a sample (Braman and Hills, 1992) taken 800 m above the base of the Imperial (roughly 50 m below the top of the formation) contains conodonts of the upper *Pa. crepida* Zone (lower Famennian). McLean and Klapper (1998) took a conodont sample in Powell Creek at 334 m above the base of the Imperial and assigned it to Frasnian zones 11–13, based on the identification of *Polygnathus ettremae* Pichett, 1972 and *P. unicornis* Müller and Müller, 1957 (the sample was further restricted to Frasnian zones 12–13 due to the presence of the coral *Phillipsastrea variabilis* Sorauf, 1988). Cecile (2000) conodont samples from the lower shale unit of the Imperial Formation in the Niddery Lake map area (NTS 105-O) indicated an early–middle Famennian age (uppermost *Pa. crepida* Zone, C-119580: *Palmatolepis glabra acuta* Helms, 1963, *Pa. g. glabra* Ulrich and Bassler, 1926, *Pa. tenuipunctata* Sanneman, 1955 and *Pa. perlobata schindewolfi* Müller, 1956; *Pa. rhomboidea* Zone, C-89103: *Polygnathus subgracilis* Bischoff, 1956, *Palmatolepis g. pectinata* Ziegler, 1962, and *Pa. rhomboidea* Sannemann, 1955).

A locally developed silty limestone, the Jungle Ridge member, is exposed just east of the Mackenzie Mountains in the Mackenzie Plain (between the towns of Norman Wells and Tulita and southwest of Tulita; Fig. 2). According to Morrow (Fig. 45 in Morrow, 2012), the area where this limestone member is preserved reaches into the northern Mackenzie Mountains. McLean and Klapper (1998) sampled the member on the bank of the Mackenzie River, close to the mouth of Bluefish Creek, and identified *Polygnathus samueli* Klapper and Lane, 1985 and *Ancyrodella ioides* Ziegler, 1985 in the conodont fauna; both species are restricted to Frasnian zone 12.

Fort Simpson Formation

The Fort Simpson Formation (renamed by Douglas and Norris, 1961) consists of a greenish grey to grey calcareous, silty or sandy shale and mudstone, with some limestone nodules in the lower part. The upper part is interbedded with fine-grained argillaceous limestone and thin-bedded calcareous siltstone and sandstone. No conodont data are available from the Mackenzie Mountains, but samples taken near the northern shore of Great Slave Lake indicated an age for the base of the formation as old as Frasnian zones 1–2 or slightly younger (*see* 'Horn River Formation' section). Within the primarily clastic Frasnian deposits in the southern Mackenzie Mountains, an unnamed distinctive limestone unit was mapped by Douglas and Norris (1961) and later studied by McLean and Pedder (1984, 1987). Outcrops of the member contain diagnostic corals and conodonts indicating Frasnian zone 12 (McLean and Klapper, 1998) and supporting a correlation with the Jungle Ridge member.

Earn Group

The Earn Group (Campbell, 1967), which consists of chert conglomerate, sandstone, and shale, is a unit interpreted as having been deposited in below wave-base submarine-fan settings by sediment gravity flows directed east to southeast (Gordey and Anderson, 1993) and originating from a westerly source area (Cecile, 2000). Gordey and Anderson (1993) subdivided the Earn Group in the Little Nahanni River map area (NTS 105-I) into the Portrait Lake and Prevost formations. A sample set from the northeastern quarter of the map area places part of the Portrait Lake Formation in the lower to middle Frasnian (FZ 4–6) zones; C-101978: *Palmatolepis* cf. *Pa. transitans* Müller, 1956, *Polygnathus* cf. *P. dubius* Hinde, 1879, and *Mesotaxis asymmetricus* (Ziegler and Klapper, 1982)). In the Niddery

Lake map area (NTS 105-O; Cecile, 2000), the Earn Group is subdivided into the Misfortune Formation (overlying the Hailstone Formation and partially the lateral equivalent of the Canol Formation) and the Thor Hills Formation (as the lateral equivalent of the Imperial Formation). Cecile (2000) samples from the lower and middle part of the Thor Hills Formation indicated an early Famennian age (*Pa. crepida* Zone; C-87561: *Palmatolepis minuta* Branson and Mehl, 1934, *Pa. subperlobata* Branson and Mehl, 1934, *Pa*. cf. *Pa. crepida* Sanneman, 1955, *Pa*. cf. *Pa. triangularis* Sanneman, 1955, and *Pa. tenuipunctata* Sannemann, 1955).

CHRONOSTRATIGRAPHIC CHARTS, DEPOSITIONAL HISTORY, AND MAJOR EVENTS

Construction of the chronostratigraphic charts (Fig. 3–4) was based on the time-stratigraphic charts of Gal and Pyle (2009), Gal et al. (2009), and Morrow (2012, 2018). Conodont zonation on the chart is based on Kaufmann (2006) and Becker et al. (2012), updated to the International Chronostratigraphic Chart (v.2019/05; Cohen et al., 2013) produced by the International Commission on Stratigraphy. The new Frasnian conodont zonation (numbered zones; Klapper and Kirchgasser, 2016) is shown in Figure 4 and used in addition to the standard Frasnian and Famennian conodont zonation of Ziegler and Sandberg (1990).

Deposition of Devonian sediments in the region now forming the Mackenzie Mountains started after a major regression that created the sub-Devonian unconformity in the area (Morrow, 1991, 2012, 2018). Although no angular unconformity can be seen in outcrops in the study area, evidence for exposure and possible erosion that indicate a depositional hiatus covering the middle to upper part of the Silurian is recognized based on biostratigraphy (Aitken et al., 1982) and can be correlated with the basal Kaskaskia unconformity and the start of the 'Kaskaskia Sequence' of Sloss (1963, 1988) (Morrow, 2012, 2018). The extent and recognition of the sub-Devonian unconformity is critically discussed by P. Kabanov (Kabanov, this volume). The Kaskaskia I depositional sequence includes deposits from the Lower to Upper Devonian (Burgess, 2019). Morrow's (2012, 2018) subdivision of the Devonian into assemblages is followed here for the Lower and Middle Devonian. Siliciclastic evaporitic and calcareous sediments were deposited in supratidal to shallow subtidal and neritic conditions during emplacement of the Delorme assemblage, which spanned from the lower part of the Lochkovian (or possibly uppermost part of the Silurian) to the lower part of the Emsian. Gal and Pyle (2009) attributed the extent in time and space of the shallow-marine to peritidal deposits to a very shallow gradient of the shelf that persisted into the Early Devonian. In the Prairie Creek Embayment area and Root Basin, an influx of coarse terrigenous material of the Cadillac Formation probably started during the sea-level lowstand at the end of the Silurian (Morrow and Cook, 1987). The Root Basin partially filled up, as indicated by the deposition of the shallow-water wackestone of the Vera Formation during the Lochkovian. The peritidal Camsell Formation was deposited around the edges of the embayment, while the Cadillac Formation, and later the Sombre and Arnica formations, filled the embayment (Morrow and Cook, 1987).

The transition from silty shallow-water carbonates to cleaner carbonates in the early Emsian (start of the Bear Rock assemblage) suggests a continuing transgression across the shelf (Morrow, 1991; Gal et al., 2009). After deposition of the Arnica Formation, large parts of the southern Mackenzie Shelf subsided below wave base (Morrow and Cook, 1987) in the early Eifelian (*P. costatus* Zone). The Landry Formation was deposited on the shelf, while the Funeral Formation filled the off-shelf areas. The limestone of the lower part of the Hume Formation has a distinct argillaceous component. Morrow (1999, 2012, 2018) suggested a sub-Hume unconformity to explain the terrigenous material, interpreted to derive from an erosional surface exposed before the deposition of the Hume. Kabanov and Deblonde (2019) interpreted the basal shaly (with minor black shale) unit of the Hume Formation as a highstand and the Landry–Hume transition as a conformable deepening-upward succession (Pugh, 1993; Kabanov et al., 2016). Conodont research places this transition in the *T. australis* Zone (middle Eifelian) and does not suggest any significant biostratigraphic gap.

In the Middle Devonian, sedimentation changed abruptly from carbonate-dominated to siliciclastic, when transgressive shale (Horn River Group) was deposited across the Mackenzie Shelf during the latest Eifelian. The drowning of the Hume platform marked the onset of the anoxic black shale in the area (Bluefish Member). This onset in the *P. ensensis* Zone coincides with the global Kačák extinction event associated with the deposition of black shale (Kabanov and Gouwy, 2017; Uyeno et al., 2017; Kabanov, this volume). This rapid transgression created space that started to be filled up again locally by the progradational clastic wedge of the Hare Indian Formation (Bell Creek Member; Muir, 1988). Away from the prograding wedge, the dark shale interbedded with muddy siltstone of the Francis Creek Member continued accumulating in deeper basinal settings. On the existing Hare Indian mudbank, the Ramparts Formation formed as a carbonate buildup (Muir and Dixon, 1984) during the mid- to late Givetian. The Carcajou member at the top of the formation indicates another smaller magnitude drowning event. In the area where the Ramparts platform was developed, Kee Scarp reefs started to grow in several phases, keeping pace with the changes in sea level. The continuing transgression eventually drowned the reefs in the early Frasnian (probably FZ 4, work in progress). Deposition of the Canol Formation that had started around the Givetian–Frasnian boundary in areas without Ramparts Formation, now also covered the Kee Scarp Member and continued to do so until the start of the late Frasnian. Within the Canol Formation, Kabanov (2019) recognized three anoxic horizons, one within the Vermillion Creek Member and two within the Dodo Canyon Member, tentatively linked to the Frasnes event and to the Middlesex and Rhinestreet black shale events, respectively (Kabanov, 2019, this volume). The influx of the turbiditic Imperial Formation started in the late Frasnian and continued into the early Famennian (at least until the *Pa. rhomboidea* Zone).

SIGNIFICANT CHANGES IN THE TIME-STRATIGRAPHIC CHARTS

The many important differences and adjustments in the time-stratigraphic charts (Fig. 3–4), compared to the charts compiled by Uyeno (1991), illustrate the need for continuing biostratigraphic research. Several formation contacts and assemblage contacts have been moved up in the chart (i.e. are now considered to be younger) or their contacts have become better constrained in the biostratigraphy:

- the Delorme–Bear Rock assemblage contact moved up to the lower Emsian (*P. dehiscens–P. gronbergi* zones)
- the contact between the lower and upper part of the Bear Rock assemblage shifted up to the lower Eifelian (*P. costatus* Zone)
- the Vera Formation is now located in the *C. woschmidti* to *A. delta* zones (lower Lochkovian)
- the Sombre Formation was moved up into the *P. dehiscens* to *P. inversus* zones (Emsian)
- the base of the Grizzly Bear Formation was lowered to the *P. gronbergi* Zone (Emsian)
- the top of the Sapper Formation moved up into the *P. costatus* Zone (Eifelian)
- the contact between the Landry and the Hume formations moved up to the middle Eifelian (*T. australis* Zone)
- within the Horn River Group of the northern Mackenzie Mountains, several formations and members are now more accurately delineated in the biozonation
- the contact between the Canol and the Imperial formations is situated in Frasnian zone 11 (upper part of the Frasnian)
- the Jungle Ridge member is located within Frasnian zone 12 (upper part of the Frasnian).

The biostratigraphic ranges of the discussed formations are shown separately in Figures 10 and 11. Arrowhead lines indicate the uncertainty of the location of the lower and upper boundaries in the conodont zonation chart. The uncertainty is the largest in the Lower and Middle Devonian formations, especially in the Selwyn Basin, impeding a detailed correlation between basin and platform units. Upper Devonian formations are better constrained, except for the Horn River Group and the Fort Simpson Formation in the southern Mackenzie Mountains, and the Imperial Formation in the northern Mackenzie Mountains.

CONCLUSIONS

This update of the conodont biostratigraphy brings much new information and much more detail to the time-stratigraphic charts of the Mackenzie Mountains since the Uyeno (1991) version. Important contributions to this update came from researchers responsible for geological mapping and stratigraphic studies, who still find biostratigraphy an important asset to their projects and who continue to sample for conodonts. Another crucial contribution is the detailed conodont biostratigraphic studies done by conodont researchers (T. Uyeno, M. Orchard, A. McCracken, S. Gouwy, G. Klapper, B. Chatterton, and the late D. Perry), not only on reconnaissance samples provided through mapping projects but also on detailed sections studied for biostratigraphic purposes.

The state-of-the-art charts (Fig. 3, 4, 10, 11) also highlight the fact that much work still needs to be done. Updating the charts revealed several areas for which very little or no conodont data were available (especially in the Lower Devonian of the northern Mackenzie Mountains); the large uncertainty intervals (Fig. 10, 11) underline these.

Ongoing conodont biostratigraphic research on the Lower Devonian Delorme Group in the southern Mackenzie Mountains, the Horn River Group in the northern Mackenzie Mountains, and the Grizzly Bear, Hailstone, and Sapper formations in the Selwyn Basin will start to refine the age constraints on these units in the near future.

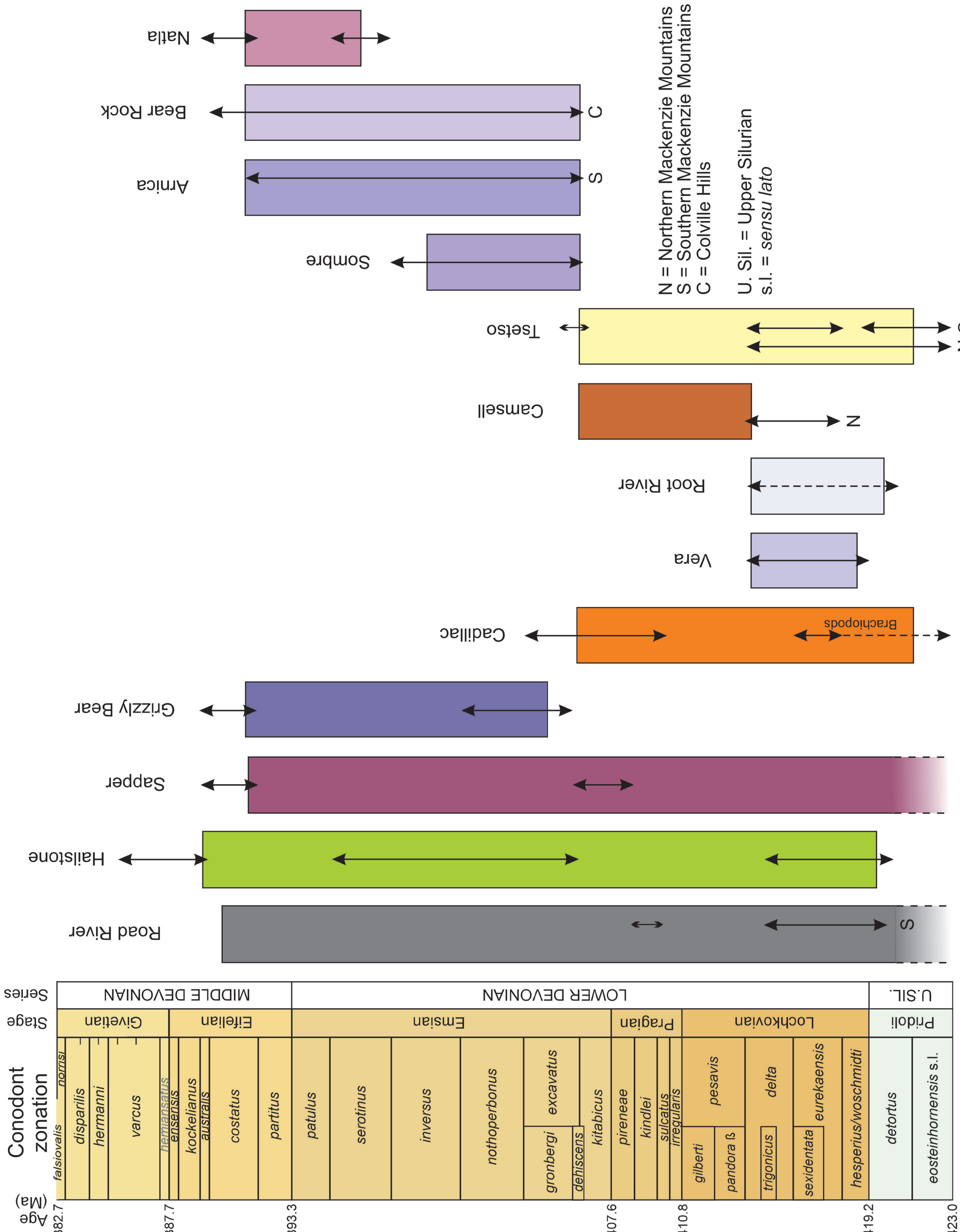

Figure 10. Correlation of the conodont biostratigraphic ranges of the Lower and Middle Devonian units of the Mackenzie Mountains. Arrowhead lines show uncertainty intervals of samples discussed in the paper.

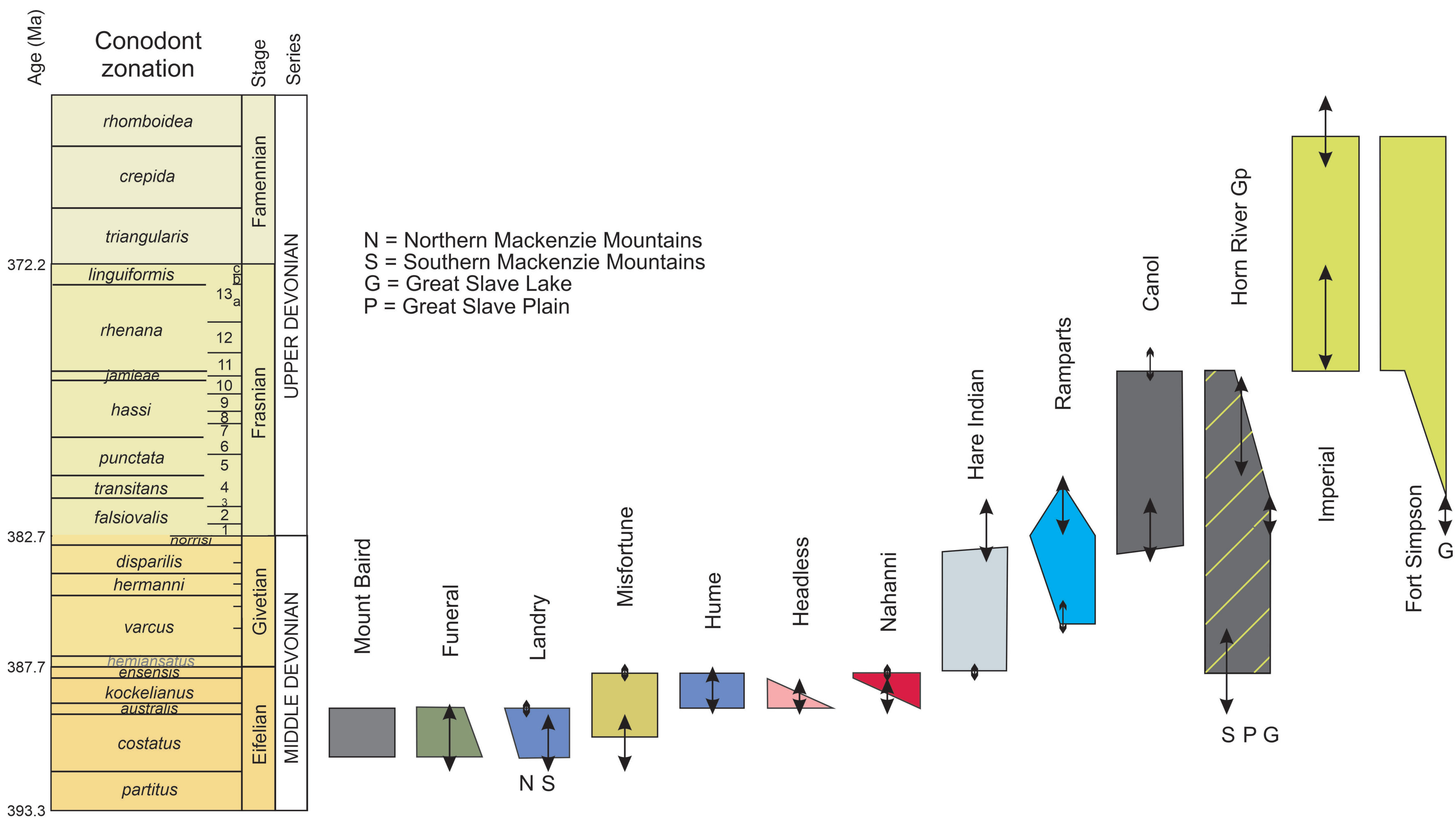

Figure 11. Correlation of the conodont biostratigraphic ranges of the Middle and Upper Devonian units of the Mackenzie Mountains. Arrowhead lines show uncertainty intervals of samples discussed in the paper.

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Appendix A

A list of NTS map areas and the references to the published geological maps used to construct Figures 5–9

95-E Flat River:

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95-F Virginia Falls:

Douglas, R.J.W. and Norris, D.K., 1977. Geology, Virginia Falls, District of Mackenzie; Geological Survey of Canada, Map 1378A, scale 1:250 000. https://doi.org/10.4095/109052

95-G Sibbeston Lake:

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95-K Root River:

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95-L Glacier Lake:

Gabrielse, H., Roddick, J.A., and Blusson, S.L., 1973. Geology, Glacier Lake, District of Mackenzie: Geological Survey of Canada, Map 1314A, scale 1:250 000. https://doi.org/10.4095/107938

95-M Wrigley Lake:

Fallas, K., Roots, C.F., Martel, E., and MacNaughton, R.B., 2011. Geology of Wrigley Lake, NTS 95M Northwest, Mackenzie Mountains, Northwest Territories; Northwest Territories Geoscience Office, NWT Open File 2010-17, 2 p., scale 1:100 000.

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95-N Dahadinni River:

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96-D Carcajou Canyon:

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96-E Norman Wells:

Fallas, K.M., MacNaughton, R.B., MacLean, B.C., and Hadlari, T., 2013. Geology, Norman Wells (southwest), Northwest Territories; Geological Survey of Canada, Canadian Geoscience Map 101, scale 1:100 000. https://doi.org/10.4095/292293

105-I Little Nahanni River:

Gordey, S.P., 1992. Geology, Little Nahanni River, Northwest Territories – Yukon Territory; Geological Survey of Canada, Map 1762A, scale 1:250 000. https://doi.org/10.4095/184006

105-O Niddery Lake:

Cecile, M.P., 1986. Geology, Keele Peak, Elmer Creek, Thor Hills, Hailstone Creek, Yukon Territory – Northwest Territories; Geological Survey of Canada, Open File 1326, 7 sheets, scale 1:50 000. https://doi.org/10.4095/130164

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105-P Sekwi Mountain:

Roots, C.F., Martel, E., MacNaughton, R.B., and Gordey, S.P., 2011. Geology, Sekwi Mountain, Northwest Territories; Geological Survey of Canada, Open File 6592, scale 1:250 000. https://doi.org/10.4095/288748

106-A Mount Eduni:

Gordey, S.P., Roots, C.F., Martel, E., MacDonald, J., Fallas, K.M., MacNaughton, R.B., 2011. Bedrock geology, Mount Eduni, Northwest Territories. Geological Survey of Canada, Open File 6594, scale 1:250 000. https://doi.org/10.4095/288750

106-B Bonnet Plume Lake:

Fischer, B.J., 2016. Bedrock geology of part of the Misty Creek paleo-embayment, Mackenzie Mountains (NTS 106B); Northwest Territories Geological Survey, NWT Open File 2016-01, scale 1:100 000.

106-C Nadaleen River:

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106-F Snake River:

Norris, D.K., 1982. Geology, Snake River, Yukon–Northwest Territories; Geological Survey of Canada, Map 1529A, scale 1:250 000. https://doi.org/10.4095/109233

106-G Ramparts River:

Aitken, J.D. and Cook, D.G., 1979. Geology, Upper Ramparts River, District of Mackenzie; Geological Survey of Canada, Map 1452A, scale 1:250 000. https://doi.org/10.4095/123318

106-H Sans Sault Rapids:

Aitken, J.D. and Cook, D.G., 1979. Geology, Sans Sault Rapids, District of Mackenzie; Geological Survey of Canada, Map 1453A, scale 1:250 000. https://doi.org/10.4095/123316