

**Biostratigraphy and paleoecology of a unique trilobite fauna from the Mount
Clark and Mount Cap formations (early and middle Cambrian), eastern
Mackenzie Mountains, Northwestern Canada**

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By

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ABSTRACT

Cambrian strata of the eastern Mackenzie Mountains, Northwest Territories, Canada, were deposited in the semi-enclosed, Colville Basin along the eastern flank of the Mackenzie Arch. The Mount Clark Formation is composed of nearshore sandstone and is overlain by deeper water siltstones, mudstones, and carbonates of the Mount Cap Formation. The contact between these formations is interpreted as recording a flooding event. Trilobite biostratigraphy indicates the presence of the traditional *Bonnia*–*Olenellus* through *Glossopleura walcotti* zones (Cambrian Series 2, Stage 4–Miaolingian, Wuliuan) and the diachronous nature of the flooding surface, spanning the late Dyeran–early Delamaran boundary. Above the *Olenellus* Zone, the *Amecephalus arjosensis*–*Eokochaspis nodosa* Zone, the new Zacanthoidid n. gen. 1, n. sp. 1 Zone, the new *Albertelloides mischi* Zone, and *Glossopleura walcotti* Zone are recognized. Trilobite faunas from the *Albertelloides mischi* and *Glossopleura walcotti* zones are dominated by zacanthoidids and dolichometopids in contrast to other areas in Laurentia. They have a lower diversity of ptychoparioids and oryctocephalids and lack agnostoids, eodiscoids, dorypygids, and ogygopsidids. This suggests that zacanthoidids and dolichometopids were able to tolerate conditions that were unfavourable to the other groups, probably related to the semi-restricted nature of the basin. Four new, endemic species exhibit characteristics which are considered paedomorphic. This developmental process took place in three separate lineages, suggesting that heterochrony was also environmentally controlled. Five new genera and ten new species are described.

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Research into the systematics and biostratigraphy of the middle Cambrian trilobites of North America has been conducted since the late 1800's, though the overwhelming majority of this effort was primarily focused on collections from the Great Basin of the southwestern U.S. (White, 1874; 1877; Walcott, 1910) and southern Canadian Rocky Mountains (Walcott, 1908a; 1916a; b; 1917a; b) and less so with those of Greenland (Poulsen, 1927) and northwest Mexico (Cooper et al., 1952). The limited geographic distribution of Cambrian formations in North America has led to large gaps in the dataset. This is especially true for the far north of Canada, where the remoteness of the region produces logistical issues. In most cases, only reconnaissance collections are compiled from this area and compared with the larger collections from the south for generic identification and biostratigraphic purposes. However, as new methods are established in paleontology that increase our understanding of trilobites, reconnaissance collections rarely ever have these new methods applied to them. Examples of new methods are quantitative growth measurements, paleoecological reconstructions and population sampling. The project here involves one such example of a relatively understudied fauna: the trilobites from the early and middle Cambrian Mount Clark and Mount Cap formations of the eastern Mackenzie Mountains, Northwest Territories.

1.2 Literature Review

1.2.1 Paleogeography and Basin Characteristics

Paleogeographic reconstructions of the Cambrian indicate a different continental configuration than that which exists in the present (Fig. 1.1) (Scotese et al., 1979; Ziegler et al.,

1979; Lieberman, 1997; Torsvik and Cocks, 2017). The Australian, Antarctic, Indian, African, South American and Arabian plates comprised the supercontinent Gondwana, the middle of which was likely situated over the paleosouth pole (Keppie and Keppie, 2014), whereas Baltica, Kazakhstan, North China, South China, Avalonia, Siberia and Laurentia were all separate paleocontinents. It is thought that the Australian and Antarctic plates of Gondwana extended into lower latitudes, based on the thick carbonate accumulations there and shared trilobite fauna with North and South China (Jell, 1974). A similar proposal was put forward for Moroccan Gondwana which contains thick accumulations of carbonates as well (Landing, 2004), although faunal evidence supports a closer relationship to Avalonia (Jell, 1974). Medial latitudes for North China and Baltica are suggested by the thinness of carbonate shelf deposits there; Baltica was present in the southern hemisphere (Cocks and Torsvik, 2005) and North China was present in the northern hemisphere (Xiao et al., 2020). Avalonia, composed today of the British Isles, parts of northern Europe and areas around Atlantic Canada and the northeastern Atlantic U.S.A., is hypothesized to have been at low latitudes either between Gondwana and Baltica (Pollock et al., 2012) or Laurentia and Gondwana (Keppie and Keppie, 2014). Well-developed carbonate platforms are preserved in Laurentia, Siberia, South China and Kazakhstan, suggesting these locations were equatorial (Ziegler et al., 1979). It has been suggested that the presence of two separate faunas along the shelves of Laurentia and Siberia is evidence of thermal stratification of the oceans along equatorial continents: proximal-shelf faunas are endemic to each continent, whereas distal-shelf faunas are globally distributed (Robison, 1976; Pegel, 2000). Climate during the Cambrian was likely overall warmer than it is today (Berner, 1990; Hearing et al., 2018), though it has been suggested that synchronous sea-level fluctuations indicate glacial expansion and contraction (Babcock et al., 2015), and possible tillites and glacial dropstones are documented in Avalonian strata (Landing and MacGabhann, 2010).

During the early Cambrian Laurentia was rotated approximately 90 degrees clockwise, with the modern-day West Coast facing paleonorth and located slightly north of the equator (Fig. 1.2) (Ziegler et al., 1979; Torsvik and Cocks, 2017). Various small terranes which were sourced from Laurentia had rifted from the continent during the Cambrian, such as the Precordillera of Argentina (Torsvik and Cocks, 2017). Facies successions and trilobite biostratigraphy along the paleonorth and paleosouth coasts indicate passive margin settings with near-synchronous flooding of the continent (Fritz, 1972; Palmer, 1998; Landing et al., 2002). Three rimming facies

belts are recorded (Robison, 1960; Aitken, 1966; 1978), with regional variations (Chow and James, 1987). From proximal to distal, they are the inner-detrital, carbonate and outer-detrital belts. This model is adopted here. The Colville Basin, which hosts the Mount Clark and Mount Cap formations, was situated near the eastern edge of the paleonorth coast of Laurentia (Pyle, 2012; Sommers et al., 2020). Syn-sedimentary, extensional tectonism has been documented along this coast (Aitken, 1971; Dilliard et al., 2010), as well as in the Colville Basin itself (MacLean, 2011). The Colville Basin was a semi-enclosed, epicontinental sea, bordered to the modern-day east where it onlaps the paleoshoreline of the Canadian Shield, to the north by the Aklavik Arch Complex and Coppermine Arch and to the west by the Mackenzie, Redstone and Peel arches (Dixon and Stasiuk, 1998; MacLean, 2011; Pyle, 2012; Sommers et al., 2020). These arches are cored by deformed Neoproterozoic strata (Aitken et al., 1973). The southern Colville Basin is poorly understood, though the occurrence of Devonian strata overlying Precambrian strata south of 62° N suggests either that this was the Cambrian depositional limit, or the limit of post-Cambrian erosion (Sommers et al., 2020). Similar facies patterns observed in the lower and middle Cambrian units of Victoria Island suggests the Colville Basin may have connected with the Arctic Islands Basin (Durbano et al., 2015). Thinning of Cambrian strata in the subsurface delineates smaller paleotopographic highs, which subdivided the Colville Basin into various depocenters (Dixon and Stasiuk, 1998; MacLean, 2011; Sommers et al., 2020). This region was flooded several times throughout the early and middle Paleozoic, though the definition of the Colville Basin is restricted to Cambrian Series 2 to Miaolingian formations (Sommers et al., 2020). Subsequent Paleozoic formations were deposited along a stable carbonate platform, termed the Mackenzie Platform (Pyle, 2012).

1.2.2 Stratigraphy

The Mount Clark and Mount Cap formations are present in the subsurface of the Mackenzie Plain and northern Interior Plain, and are uplifted and exposed in the eastern Mackenzie Mountains and Franklin Mountains (Williams, 1922; 1923; Aitken et al., 1973; Aitken and Cook, 1974; Dixon and Stasiuk, 1998; ; Serié et al., 2009; 2013; MacLean, 2011; Fallas and MacNaughton, 2012; MacNaughton et al., 2013). The basal Cambrian formation in the eastern Mackenzie Mountains is tectonically controlled: proximal to the Mackenzie Arch, the basal formation is the Mount Clark Formation, whereas distal to the arch, the heterolithic,

sandstone-rich interval is treated as the basal Mount Cap Formation (Aitken et al., 1973; Aitken and Cook, 1974; Fallas and MacNaughton, 2012; MacNaughton et al., 2013). The Mount Clark Formation is composed of cross-bedded, rippled and bioturbated quartz arenite and argillaceous sandstone, with minor siltstone. The lower Mount Cap Formation is composed of sandstone, siltstone and carbonate with minor mudstone. Conformably overlying both formations is the upper Mount Cap Formation, sometimes called the mudstone-dominated Mount Cap Formation, which is composed of mudstone and fine-grained limestone (Aitken et al., 1973; Aitken and Cook, 1974; MacNaughton et al., 2013).

Both formations generally thicken eastward into the Mackenzie Trough (Dixon and Stasiuk, 1998; Serié et al., 2009; 2013; MacLean, 2011; Herbers et al., 2016; Sommers et al., 2020). The lithostratigraphic nomenclature used in this study was sourced from MacNaughton et al. (2013), although it should be noted that the same terminology used in the subsurface refers to different lithostratigraphic units. The Mount Clark and lower Mount Cap formations in the eastern Mackenzie Mountains are equivalent lithostratigraphically to the Mount Clark Formation in the Colville Hills (Herbers et al., 2016; Sommers et al., 2020). Similarly, the upper Mount Cap Formation in the eastern Mackenzie Mountains is equivalent to the lower and upper Mount Cap Formation in the subsurface (Sommers et al., 2020). The Mount Clark Formation has been interpreted as recording a shallow-marine setting elsewhere, while the Mount Cap Formation records a deeper water setting (Herbers et al., 2016; Sommers et al., 2020). The conformable contact between the basal units and the upper Mount Cap Formation is regarded as a flooding surface (MacNaughton et al., 2013; Sommers et al., 2020). The *Bonnia–Olenellus*, *Albertella* and *Glossopleura* zones have previously been documented in the lower and upper Mount Cap formations, although fossiliferous strata were sparse and the apparent absence of the *Plagiura–Poliella* Zone was interpreted as evidence of a possible unconformity (Fig. 1.3) (Fritz, 1969; Aitken et al., 1973). The *Plagiura–Poliella* Zone has been documented in the Great Basin extensively (Lochman-Balk and Wilson, 1958; Palmer and Halley, 1979).

Locally, basal Cambrian units overly the Mackenzie Arch; this is cored by Neoproterozoic strata of the Mackenzie Mountain Supergroup and specifically the Katherine and Little Dal groups (Aitken et al., 1973; Aitken and Cook, 1974; Turner and Long, 2012; Long and Turner, 2014). The Katherine Group consists of seven formations of alternating lithological character:

four sandstone-dominated formations alternating with three mudstone-rich formations (Aitken et al., 1978; Long and Turner, 2014). The overlying Little Dal Group is also composed of seven formations, mainly of limestone and dolostone packages, with minor fine-grained siliciclastic and evaporite packages (Aitken, 1981; Turner and Long, 2012). Unconformably overlying the upper Mount Cap Formation is the Saline River Formation, composed of mudstone, dolostone and evaporites (Aitken and Cook, 1974; Bouchard and Turner, 2017). The presence of an erosional unconformity at the base of the Saline River Formation, as well as its lithology, suggests that shallowing of the basin occurred following the deposition of the Mount Cap Formation (Aitken and Cook, 1974; Dixon and Stasiuk, 1998; MacNaughton et al., 2013).

On the other side of the Mackenzie Arch, in the open-ocean facing Selwyn Basin, equivalent units are the upper Sekwi and lower Rockslide formations. The Sekwi Formation is composed of coarse- and fine-grained carbonate and is interpreted as a shallow- to deep-water platform deposit (Dilliard et al, 2010), dated to the *Fallotaspis* to *Olenellus* zones (Fritz, 1972). The overlying Rockslide Formation consists of mudstone, fine-grained carbonate and debris-flow conglomerate, regarded as a deep-water, ramp-style slope succession with interspersed mud mounds (Fritz, 1979; Pratt, 1989). Trilobites of the Rockslide Formation indicate the *Plagiura–Poliella* through *Bolaspidella* zones. The contact between these Formations is likely equivalent to the flooding surface in the Colville Basin (Fig. 1.3). In the Arctic Islands Basin, equivalent formations are the, as of now informal, Quyuq, Uvauuluk and Mount Phayre formations in ascending order. The sandstone with minor mudstone of the Quyuq formation is interpreted as nearshore and offshore facies deposited along a tide-dominated shoreline (Durbano et al., 2015). The overlying Uvauuluk formation consists of mudstone and carbonate with minor thrombolites, while the Mount Phayre formation is composed of mudstone and dolomudstone (Dewing et al., 2014). Trilobite biostratigraphy from the Mount Phayre formation is under investigation by B.R. Pratt. Correlation of these equivalent formations is presented in Fig. (1.3).

1.2.3 Early and Middle Cambrian Trilobite Biostratigraphy

The early Cambrian in Laurentia is composed of three genus-based zones: in ascending order, they are the *Fallotaspis*, *Nevadella* and *Olenellus* zones (Fritz, 1972), with a species-based biozonation developed for the *Olenellus* Zone (Webster, 2011b). Delamaran, species-based biozones are better constrained than Dyeran ones. Above the *Olenellus* Zone, trilobites of the

Great Basin record the *Eokochoaspis nodosa* Zone and *Amecephalus arrojensis* Zone, respectively (Sundberg and McCollum, 2000; 2003b), whereas in the Precordillera of Argentina, these zones occur in reverse order suggesting they are not mutually exclusive (Pratt and Bordonaro, 2014). In younger strata, Delamarian biozones are facies-controlled in the Great Basin (McCollum and Sundberg, 2007). In the inner-detrital belt sections, the biozonation consists of, in ascending order, the *Poliella denticulata*, *Mexicella mexicana* and *Glossopleura walcottii* zones (Eddy and McCollum, 1998; Sundberg and McCollum, 2003a; Sundberg, 2005), whereas in the outer-detrital belt sections, it consists of the *Oryctocephalus indicus* and *Ptychagnostus praecurrens* zones (Fig. 1.4) (Sundberg and McCollum, 1997; 2003b; Sundberg, 2018). Facies controls on biostratigraphy reflects the distribution of shallow and deep-water (inferred to be warm- and cold-water) faunas (Robison, 1976). The use of these two frameworks has been extrapolated to the southern Canadian Rocky Mountains (McCollum and Sundberg, 2007) and northern Mexico (Noriega-Ruiz et al., 2020). Zones of the outer-detrital belt are partly recognizable in western Newfoundland (Lochman-Balk and Wilson, 1958; Young and Ludvigsen, 1989).

1.2.4 Previous Work

The first descriptions of the Mount Clark and Mount Cap formations was by Williams (1922; 1923), who defined them in the Franklin Mountains. Subsequent work mostly focused around the regional stratigraphy following the discovery of the Norman Wells oil fields (Hume, 1923; 1954; Bell, 1959). The first examination of Cambrian trilobites from the region was by Kobayashi (1936). Large-scale, reconnaissance mapping by the Geological Survey of Canada (GSC) in the late 1960's to early 1970's focused on the sparsely documented areas of the northern Northwest Territories and Yukon. This occurred under operations Norman, Mackenzie and Porcupine, the first of which included the eastern Mackenzie Mountains (Aitken et al., 1973; Aitken and Cook, 1974). Detailed study of the lower Paleozoic stratigraphy for Operation Norman was undertaken by R.W. Macqueen, J. Usher and J. Aitken, and examination of the Cambrian paleontology and trilobite biostratigraphy was conducted by Fritz (1969; Aitken et al., 1973). The Mount Cap Formation was recognized in the eastern Mackenzie Mountains, though not the Mount Clark Formation. Biostratigraphy was based on the biozonation developed by Lochman-Balk and Wilson (1958). Following Operation Norman, work on the Mount Clark and

Mount Cap formations was primarily focused on the subsurface by Meijer-Drees (1975), Pugh (1983), Williams (1987), Hamblin (1990) and Dixon and Stasiuk (1998).

More recently, large parts of the Northwest Territories were remapped/restudied by the GSC as part of the Geomapping for Energy and Minerals (GEM) Program. The Mackenzie Valley and adjacent mountains were the sites of work during phases 1 (2008–2012) and 2 (2013–2020) of the program, with the present study being part of phase 2. The goal was to reinvestigate the geology of northern Canada and update previous work with modern techniques. Hannigan et al. (2011) discussed the potential of petroleum exploration in the Mount Clark and Mount Cap formations. MacLean (2011) conducted an analysis of the Colville Basin using seismic lines, characterizing the tectonics and geometry of the formations. Fallas and MacNaughton (2012) documented the Mount Clark Formation in the eastern Mackenzie Mountains, and recognized that the basal Cambrian formations there are tectonically controlled. Serié et al. (2009; 2013), measured many new and previously studied sections of the Cambrian strata in the eastern Mackenzie and Franklin mountains, reporting the existence of the Mount Clark Formation there. Serié et al. (2009; 2013) theorized that the contact between the Mount Clark and Mount Cap formation is diachronous in the eastern Mackenzie Mountains, which had already been hypothesized by Dixon and Stasiuk (1998) in the subsurface of the Mackenzie Plain. This led MacNaughton et al. (2013) to speculate the possibility of buried Cambrian shorelines beneath the Mackenzie and northern Interior Plains as potential petroleum reservoirs, and comment on the need for high-resolution biostratigraphy of the formations. A preliminary study by Herbers et al. (2016) characterized the sedimentology of four industry cores of the Mount Clark Formation in the subsurface of the Colville Hills, and produced the first detailed ichnological description for the unit. Sommers et al. (2020) incorporated all available cores and wireline logs of the Mount Clark and Mount Cap formations in the Colville Basin, proposing a transgressive-regressive, sequence stratigraphic model for the basin's evolution. Trilobite biostratigraphy of some of the cores from Sommers et al. (2020) was interpreted by Morgan (2019) to calibrate the sequence stratigraphy. Preliminary trilobite collections by B.R. Pratt (*in* MacNaughton et al., 2013) identified an unusual fauna with endemic taxa in the upper Mount Cap Formation of the eastern Mackenzie Mountains.

1.2.5 Research Goals and Outline of Thesis

The goals of this project are threefold: (1) document the sedimentary facies and internal stratigraphy of the Mount Clark and Mount Cap formations, (2) develop a species-based trilobite biostratigraphy for these formations that can constrain the timing of sedimentological and sequence stratigraphic changes, as well as allow for temporal correlation with other localities in Laurentia, and (3) describe and investigate the trilobite systematics, their faunas and the paleoecology of the associations, with possible implications for the evolution of the endemic species. To complete this, fieldwork was carried out at five sites in the Canyon Ranges of the eastern Mackenzie Mountains (Fig. 1.5) to measure stratigraphic sections and generate large trilobite collections. Following fieldwork, preparation and photography of specimens was conducted for taxonomic identification.

Chapter 2 of this thesis will take the form of a manuscript submitted as a memoir in the *Journal of Paleontology*. The abstract to this thesis is the same as that in the manuscript, which is not included in Chapter 2. In general, trilobite-based taxonomic and biostratigraphic manuscripts will lay out the results and interpretations section of the biostratigraphy and/or paleoecology prior to the systematic paleontology (taxonomy) section. However, it is important to note that the taxonomy is determined prior to the interpretation of any biostratigraphy or paleoecology. Names for new genera and species will not be used here in an unpublished thesis, but will be present in the submitted manuscript. Chapter 3 will provide a more in-depth discussion of the results and interpretations made in Chapter 2, as well as any recommended work to be done in the future. Appendices A–E will tabulate the measured section data from the field season and denote trilobite collection horizons.

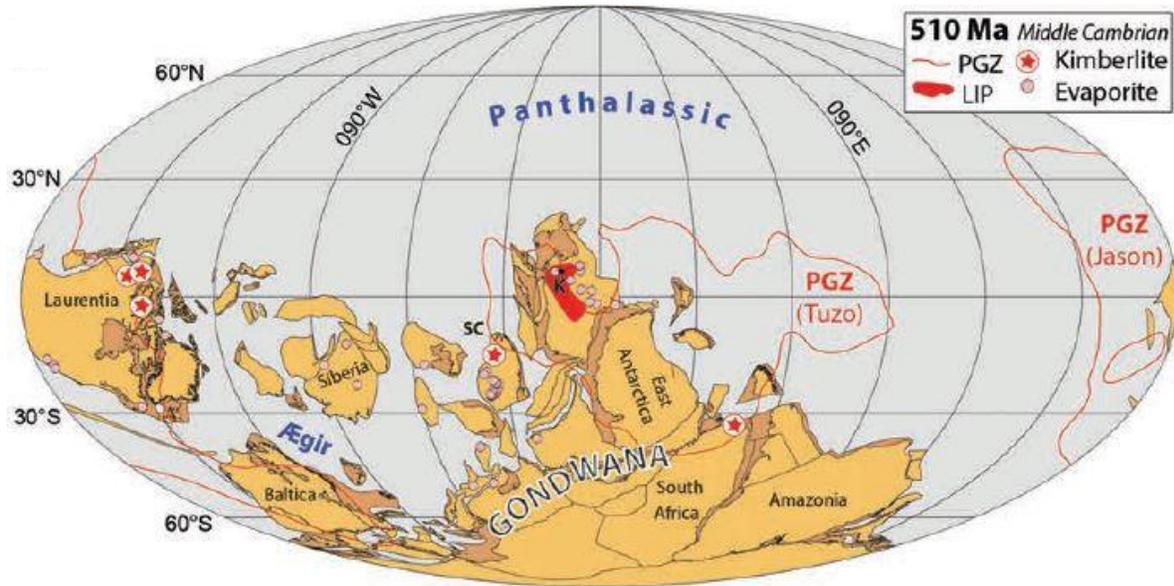


Figure 1.1. Middle Cambrian paleogeography. SC=South China, PGZ=Plume generation zone. From Torsvik and Cocks (2017).

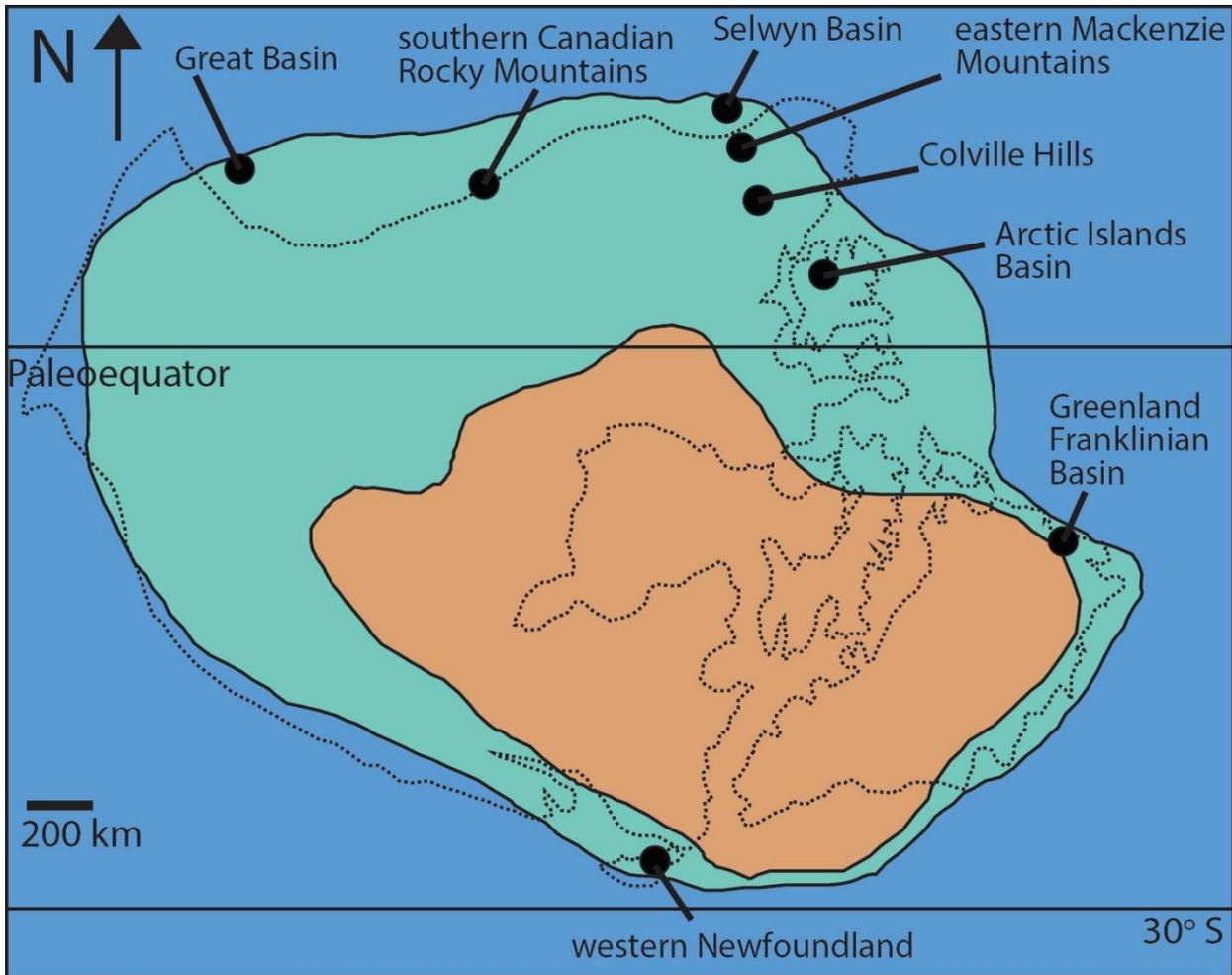


Figure 1.2. Paleogeographic reconstruction of Laurentia during the early Cambrian. Dashed line delineates the edge of the continent; the north coast is bordered at the extent of Laramide deformation. Brown-shaded area=exposed land; teal-shaded area=approximation of the continental shelf; and dark blue-shaded area=deep-sea. Modified from Cocks and Torsvik (2011).

Global chron.		Laurentian chronostratigraphy			Selwyn Basin	Arctic Islands Basin	Colville Basin
Series	Stage	Series	Stage	Biozones			
Miaolingian	Wuliuan	Lincolnian	Delamaran	Glossopleura Zone/ Glossopluera walcotti Zone	Rockslide Formation		Saline River ? Formation ?
				Albertella Zone/ Mexicella mexicana Zone		Mount Phayre formation	upper Mount Cap Formation
				Plagiura-Poliella Zone		Poliella denticulata Zone	Uvayualuk formation
Amecephalus arjosensis Zone	Mount Clark and lower Mount Cap formations						
Eokochaspis nodosa Zone							
Series 2	Stage 4	Waucoban	Dyeran	Olenellus Zone	Sekwi Formation	Quyuk formation	
	Stage 3		Monte-zuman	Nevadella Zone			

Figure 1.3. Lithostratigraphic and biostratigraphic correlations of formations from the Selwyn Basin, Arctic Islands Basin and Colville Basin. Data from Fritz (1969; 1972; 1979), Pratt (1989), Durbano et al. (2015) and Morgan (2019), with modifications from Eddy and McCollum (1998), Palmer (1998), Sundberg and McCollum (2000; 2003a), McCollum and Sundberg (2007), Geyer (2019) and Sundberg et al. (2020). Color indicates the dominant lithology. Yellow=dominantly coarse clastics; grey=dominantly fine clastics; blue=dominantly carbonates; and brown=mixed mudstone, dolostone and evaporite. Question marks=poorly constrained boundaries. Vertical lines=unconformities.

Stages	Genus-based zones	Inner-detrital species-based zones	Outer-detrital species-based zones
Delamaran	<i>Glossopleura</i> Zone	<i>Glossopleura walcotti</i> Zone	<i>Ptychagnostus preacurrens</i> Zone
	<i>Albertella</i> Zone	<i>Mexicella mexicana</i> Zone	<i>Oryctocephalus indicus</i> Zone
	<i>Plagiura-Poliella</i> Zone	<i>Poliella denticulata</i> Zone	
		<i>Amecephalus arjosensis</i> Zone	
		<i>Eokochaspis nodosa</i> Zone	
Dyeran	<i>Olenellus</i> Zone	<i>Nephrolenellus multinodus</i> Zone	
		<i>Bolbolenellus euryparia</i> Zone	

Figure 1.4. Correlation chart for the genus- and species-based biostratigraphy of Laurentia. Modified from McCollum and Sundberg (2007) with additions from Webster (2011b).

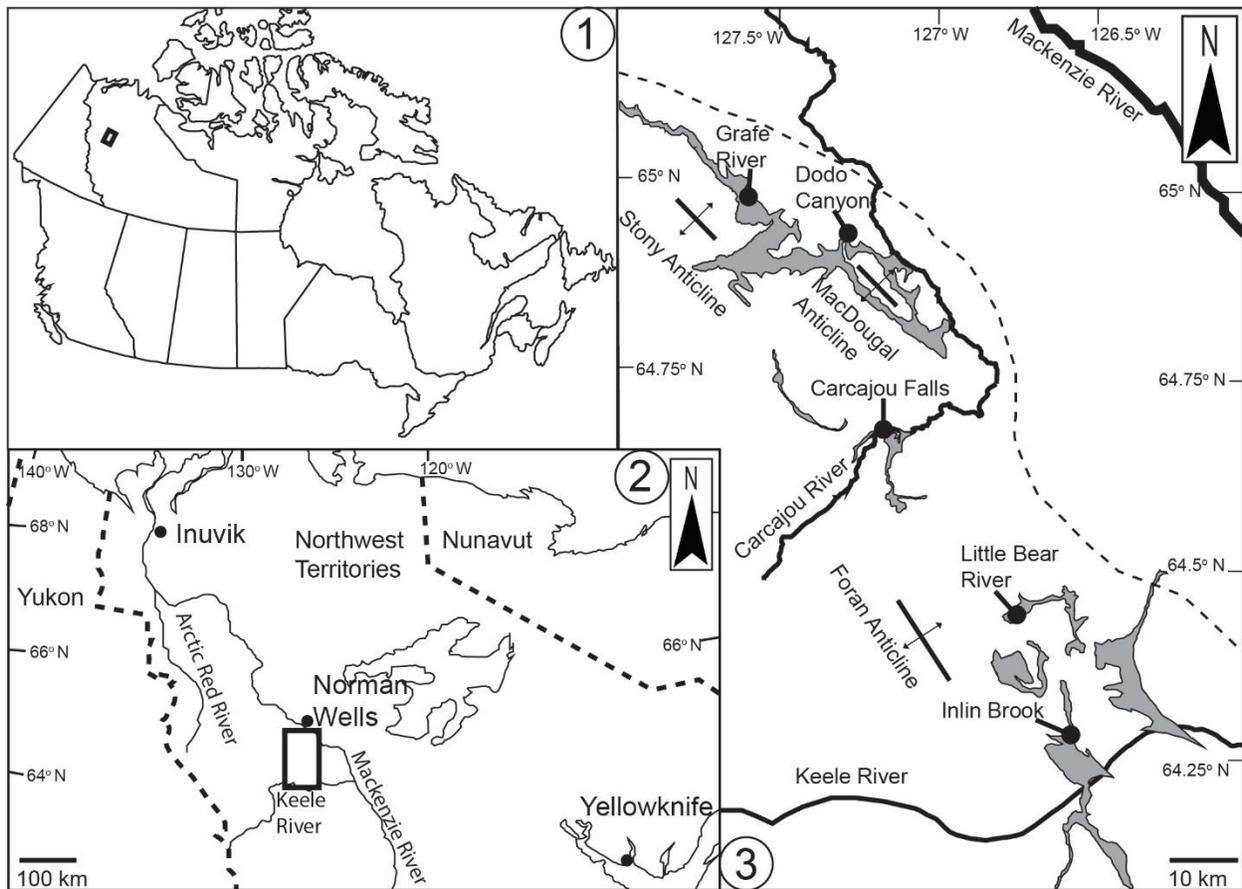


Figure 1.5. Locality of study area in the eastern Mackenzie Mountains, Northwest Territories: (1) National map; (2) Location in the Northwest Territories; (3) Location in the eastern Mackenzie Mountains. Outcrop belts of the Mount Clark, Mount Cap, and Saline River formations are shaded in grey. Outcrops visited are indicated by black dots. The dashed line roughly delineates the Mackenzie Arch. Major Laramide anticlines indicated by crosses with arrows.

CHAPTER 2

BIOSTRATIGRAPHY AND PALEOECOLOGY OF A UNIQUE TRILOBITE FAUNA FROM THE MOUNT CLARK AND MOUNT CAP FORMATIONS (EARLY AND MIDDLE CAMBRIAN), EASTERN MACKENZIE MOUNTAINS, NORTHWESTERN CANADA

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2.1 Introduction

Cambrian trilobites of Laurentia have been studied extensively for over a century and a half (Walcott, 1886; 1890; 1916a; b; 1917a; b). However, there are many gaps in the geographic coverage, especially in northern Canada. Due to the remoteness of this region, with a few exceptions (Fritz, 1972; Pratt, 1992), most biostratigraphic information is at a reconnaissance level (Fritz, 1968; 1979; Dewing and Nowlan; 2012; Pyle, 2012) organized around the Laurentian, genus-based biozonation. Now that more-refined, species-based biozones are being erected in a number of localities (Sundberg, 1994; McCollum and Sundberg, 2007), a higher resolution biostratigraphy is needed in support of local basin modelling and long-distance correlation. The fossiliferous, well-exposed, lower and middle Cambrian formations of the eastern Mackenzie Mountains provide a good opportunity to develop a biozonation within the region (MacNaughton et al., 2013).

The Mount Clark and Mount Cap formations of the northern Canadian Cordillera record sedimentation in a shallow, epicontinental sea, one of several which rimmed Laurentia during the

early and middle Cambrian (Aitken et al., 1973; Pyle, 2012). This basin, termed the Colville Basin by Sommers et al. (2020), is thought to have been partially isolated from the open-ocean by a series of uplifted, Precambrian-cored arches (Dixon and Stasiuk, 1998; MacLean, 2011). Regional stratigraphic study suggests that the contact between the Mount Clark and Mount Cap formations is diachronous (Serié et al., 2013). Early reports on reconnaissance collections of trilobites (Kobayashi, 1936; Fritz, 1969; Aitken et al., 1973) identified taxa indicating an age range from the *Bonnia–Olenellus* through *Glossopleura* zones (Cambrian Stage 4 and Wuliuan). Preliminary biostratigraphy by Pratt (*in* MacNaughton et al., 2013) showed that trilobites occurred sporadically in the Mount Clark Formation in offshore facies, though more or less throughout the entire Mount Cap Formation. The purpose of this study is to provide a detailed taxonomic, biostratigraphic and paleoecological account of the trilobite fauna from a series of sections cropping out in the eastern Mackenzie Mountains.

2.2 Geological Setting

Cambrian strata of the Colville Basin are present in the subsurface of the Mackenzie Plain and northern Interior Plains (Dixon and Stasiuk, 1998; MacLean, 2011; Herbers et al., 2016; Sommers et al., 2020) and are uplifted and exposed in the Franklin Mountains and the Canyon Ranges of the eastern Mackenzie Mountains (Aitken et al., 1973; Aitken and Cook, 1974). The Colville Basin was flanked to the modern-day west by the Mackenzie, Redstone and Peel arches, the northwest by the Aklavik Arch Complex and the east by the paleoshoreline with the Canadian Shield (Aitken et al., 1973; Dixon and Stasiuk, 1998). Convergent orientations of the Aklavik Arch Complex and Coppermine Arch indicates that they may have connected to isolate the Colville Basin to the north (Dixon and Stasiuk, 1998), though similar depositional sequences on Victoria Island suggests a connection with basins in the Arctic Islands (Durbano et al., 2015; Sommers et al., 2020). The southern extent of the Colville Basin is poorly understood (Aitken and Cook, 1974; Sommers et al., 2020). Subsurface data indicate the Colville Basin was subdivided into depocenters by paleotopographic highs composed of Precambrian strata (Dixon and Stasiuk, 1998, MacLean, 2011; Sommers et al., 2020).

Outcrops in the eastern Mackenzie Mountains represent the westernmost occurrences of the Mount Clark and Mount Cap formations. Strata onlap the eastern flank of the Mackenzie

Arch, which is composed of deformed Neoproterozoic strata of the Mackenzie Mountain Supergroup (Aitken et al., 1973; Aitken and Cook, 1974; MacNaughton et al., 2013). The basal Cambrian formation at each locality is controlled by the geographic position relative to the arch: at proximal sections in the Stony and Foran anticlines the basal formation is the Mount Clark Formation, composed of variably burrowed quartz arenite and argillaceous sandstone; whereas at distal sections in the MacDougal Anticline the basal formation is the lower (heterolithic) Mount Cap Formation, composed of burrowed sandstone and siltstone, silty mudstone and limestone (Williams, 1922; 1923; Aitken et al., 1973; Aitken and Cook, 1974; Fallas and MacNaughton, 2012; MacNaughton et al., 2013; Serié et al., 2013). Both formations are conformably overlain by the upper (mudstone-dominated) Mount Cap Formation, consisting of mudstone and lime mudstone with minor siltstone (Williams, 1923; Aitken et al., 1973; Aitken and Cook, 1974; MacNaughton et al., 2013). Unconformably overlying the Mount Cap Formation is the Saline River Formation, composed of mudstone, dolostone and gypsum (Aitken et al., 1973; Aitken and Cook, 1974; Dixon and Stasiuk, 1998; Serié et al., 2013; Bouchard and Turner, 2017). The westward truncation of the Mount Cap Formation by the Saline River Formation indicates the Mackenzie Arch was variably tectonically active at this time (Aitken et al., 1973; Aitken and Cook, 1974).

In the Mackenzie Plain to the northeast, the Mount Clark and Mount Cap formations are thicker, and the contact between the two formations is in the *Olenellus* Zone (Morgan, 2019; Sommers et al., 2020) (Fig. 2.1). On the western flank of the Mackenzie Arch, lower and middle Cambrian formations of the Selwyn Basin record a carbonate platform to slope setting on the passive continental margin (Pratt, 1989, Dilliard et al., 2010; Kimmig and Pratt, 2016). Limestone of the Sekwi Formation contain trilobites which indicate the *Fallotaspis* through *Olenellus* zones (Cambrian stages 3 and 4; Fritz, 1972), suggesting that the initial Cambrian transgression had flooded the western continental margin prior to the Colville Basin. Conformably overlying the Sekwi Formation is the Rockslide Formation, which belongs to the *Plagiura–Poliella* through *Bolaspidella* zones (Fritz, 1979).

2.3 Materials and Methods

Fieldwork was carried out at five sites in the Canyon Ranges, roughly 50 km southwest of Norman Wells (NTS 96D; see Appendices A–E for longitude and latitude of sections) (Fig. 1.5): Dodo Canyon, Little Bear River, Inlin Brook, Carcajou Falls and Grafe River (Fig. 2.2) (Handkamer, 2020). Additional material was collected by MacNaughton in 2012 from three outcrops northeast of the Little Bear River locality (unpublished GSC measured sections 12-MWB-04, -05 and -06). All specimens were coated with sublimated ammonium chloride and photographed, mainly with a macro lens, and in the case of small specimens, with a bellows attachment. Photographs were assembled using Adobe Photoshop and Adobe Illustrator, and brightness and contrast were altered to increase photo quality.

All figured specimens are deposited in the type collection of the Geological Survey of Canada Ottawa. Specimens not illustrated are housed at Geological Survey of Canada Calgary. Institutional abbreviations are: GSC= Geological Survey of Canada; USNM= U.S. National Museum of Natural History, Smithsonian Institution, Washington DC; DMNH= Denver Museum of Natural History; and MGUH= Natural History Museum, Copenhagen Denmark.

2.4 Results and Discussion

2.4.1 Sedimentology

The Mount Clark and Mount Cap formations record the evolution from a nearshore to deeper water environment (MacNaughton et al., 2013; Herbers et al., 2016; Handkamer, 2020; Sommers et al., 2020). Here, the formations are summarized and their sedimentology is interpreted; detailed descriptions of these unit can be found in the Appendices. Low-angle cross-bedded, wavy bedded and wave-rippled sandstone with minor glauconite of the Mount Clark Formation indicate a nearshore setting. The dominance of storm-induced features, with rare sand bars, suggest a storm-dominated shoreline with weak tidal influence. Interbedded sandstone and siltstone with wave ripples, gutter casts, local hummocky cross-stratification and minor unidirectional ripples record fluctuating conditions produced by storms in the offshore setting. Interbedded, rippled sandy grainstone and argillaceous lime mudstone were also produced by fluctuating conditions in the offshore area, albeit during times of localized carbonate production.

Sediments of the Mount Clark and lower Mount Cap formations are dominated by a deposit-feeding ichnofauna. The scarcity of burrows cast by storm beds in the offshore setting is attributed to relatively deeper scouring during deposition. A vertical, suspension-feeding ichnofauna is dominant in strata representing upper shoreface sediments, which indicates organic productivity in the water column.

The greater proportion of carbonate strata in the eastern Mackenzie Mountains compared to the Colville Hills (Sommers et al., 2020) indicates that there was a more productive but geographically localized carbonate factory in this region. The Colville Hills were closer to the eastern paleoshoreline and may have been provided with a more continuous supply of siliciclastic mud compared to the intermittently tectonically active Mackenzie Arch. Carbonate lithologies include (1) thin-bedded, rippled sandy grainstone; (2) wavy-bedded and rippled, argillaceous or sandy dolostone; (3) thin- to medium-bedded, bioclastic and peloidal wackestone; (4) variably burrowed, wavy-bedded lime mudstone; and (5) interbedded mudstone and burrowed lime mudstone with minor bioclastic grainstone lenses and bioclastic wackestone. These are interpreted as, respectively, (1 and 2) higher energy, shallow-subtidal ramp sediments, (3 and 4) deeper subtidal ramp sediments, and (5) intercalated deeper subtidal lime mud and siliciclastic mud, punctuated by rare low-energy tempestites. Thick carbonate accumulations at Dodo Canyon and Carcajou Falls and less carbonate strata at Little Bear River, Inlin Brook and Grafe River are regarded as localized carbonate production in a well-oxygenated setting conducive to a deposit-feeding ichnofauna. By contrast, variably calcareous and fossiliferous silty mudstones, mudstones and minor siltstones are interpreted as deeper water hemipelagites. Horizontal, deposit-feeding burrows are rare, either preserved by pyrite or on the surfaces of carbonate concretions. Thoroughly bioturbated concretion surfaces in silty mudstones indicate well-oxygenated sediments, whereas apparent absence of burrows in mudstone is regarded as taphonomic. Trilobites, hyoliths and linguliformean brachiopods can be numerous, supporting the interpretation that conditions were favourable to the development of a benthic, shelly biota.

2.4.2 Biostratigraphy

Trilobites from the Mount Clark and Mount Cap formations indicate an age spanning the Laurentian Waucoban, Dyeran–Lincolnian, Delamaran boundary and the global Cambrian Series 2, Stage 4–Miaolingian, Wuliuan boundary. Recognizable in part are some traditional Laurentian

biozones (Rasetti, 1951; Lochman-Balk and Wilson, 1958; Robison, 1976; Palmer and Halley, 1979; Palmer, 1998a; b; Sundberg and McCollum, 2000; 2003a; 2003b; McCollum and Sundberg, 2007; Pratt and Bordonaro, 2014; Sundberg et al., 2020). However, two new biozones are established in the middle Mount Cap Formation. These zones are, in ascending order, the *Olenellus*, *Amecephalus arrojensis–Eokochaspis nodosa*, Zacanthoidid n. gen. 1, n. sp. 1, *Albertelloides mischi*, and *Glossopleura walcotti* zones (Fig. 2.3 and 2.4).

The *Olenellus* Zone of the Dyeran (Palmer, 1998a) is recorded at the base by the first appearance datum (FAD) of *Olenellus*. The last appearance datum (LAD) of *Olenellus* was previously interpreted as synchronous with the LAD of redlichiids and FAD of *Oryctocephalus indicus* in south China (Zhao et al., 2019). Sundberg et al. (2020) constrained the LAD of *Olenellus* with zircon crystal ages in the Tapeats Sandstone and found that the extinction of *Olenellus* is slightly earlier (~0.5 Ma) than the extinction of *Redlichia*, indicating that the end of the Dyeran is slightly older than the Stage 4–Wuliuan boundary. Two species from the Mount Cap Formation, *Olenellus gilberti* and *O. terminatus*, have documented biostratigraphic distributions in the Great Basin. Both species span the two youngest zones of the Dyeran, the *Bolbolenellus euryparia* Zone and overlying *Nephrolenellus multinodus* Zone (Webster, 2011b). Delineation between these two zones is not possible with the fossil collections of this study, hence the adoption of the genus-based zone here. The interpretation that the *N. multinodus* is represented is favored as there is a lack of any regional unconformities between strata of this zone and those of the overlying zone.

The overlying biozone is the undifferentiated *Amecephalus arrojensis–Eokochaspis nodosa* Zone. The first recording of this zone originally separated into the older *Eokochaspis nodosa* Zone and the younger *Amecephalus arrojensis* Zone (Sundberg and McCollum, 2000). In La Laja Formation of the Precordillera of western Argentina, *A. arrojensis* and *E. nodosa* are present in reverse order, suggesting these two taxa co-existed and are not temporally exclusive (Pratt and Bordonaro, 2014). In the upper Mount Cap Formation at Little Bear River, *A. arrojensis* and *E. nodosa* occur in the same bed. The base of the *A. arrojensis–E. nodosa* Zone in the Mount Cap Formation is probably synchronous with the base of the *E. nodosa* Zone in the Pioche, Emigrant and Monola formations (Sundberg and McCollum, 2000; 2003b), and the *Plagiura–Poliella* Zone in general (Lochman-Balk and Wilson, 1958; Robison, 1976). It is at

this time when simple ptychoparioids, referable as ‘kochaspids’, become dominant (Sundberg and McCollum, 2000).

The succeeding zone in the Mount Cap Formation is the *Zacanthoidid* n. gen. 1, n. sp. 1 Zone, established herein. The base of this zone is therefore inferred to be equivalent to the base of the *Poliella denticulata* Zone in restricted-shelf settings (Sundberg and McCollum, 2003a) and the *Oryctocephalus indicus* Zone in open-shelf settings in the Great Basin (Robison, 1976; Sundberg and McCollum, 2003b). The time-relationships of the *Zacanthoidid* n. gen. 1, n. sp. 1 Zone relative to the *Wenkchemnia–Stephenaspis* and *Plagiura–Kochaspis* zones of the Mount Whyte Formation of Alberta and British Columbia (Rasetti, 1951), or the upper *Amecephalus arrojosensis–Eokochaspis nodosa* and the overlying *Mexicella mexicana* zones of La Laja Formation are not well constrained. The *Zacanthoidid* n. gen. 1, n. sp. 1 and equivalent zones are when dolichometopids and zacanthoidids become significant components of Laurentian faunas.

The new *Albertelloides mischi* Zone overlies the *Zacanthoidid* n. gen. 1, n. sp. 1 Zone in the upper Mount Cap Formation, indicated by the FADs of *Albertelloides mischi*, *A. pandispinata*, and *A. n. sp.* In the Great Basin, *A. pandispinata* occurs close to the base of the *Albertellina aspinosa* Subzone of the *Albertella/Mexicella mexicana* Zone, while *Albertelloides mischi* likely occurs higher up in the *Albertella highlandensis* Subzone (Fritz, 1968; Eddy and McCollum, 1998; McCollum and Sundberg, 2007). These two species co-occur in the upper Mount Cap Formation, so the age relationship of the base of the *Albertelloides mischi* Zone with respect to that of the *Albertella/Mexicella mexicana* Zone is uncertain. The presence of *Euarthrocephalus nevadensis* (Sundberg and McCollum, 1997) co-occurring with *Albertelloides* n. sp. in the upper Mount Cap Formation at Little Bear River may suggest the base is partially equivalent to the *Oryctocephalus indicus* and *Poliella denticulata* zones (Sundberg and McCollum, 1997; 2003a). Two biofacies comprise the *Albertelloides mischi* Zone here: the higher diversity and abundance *Albertelloides* biofacies present at Carcajou Falls, Little Bear River and Grafe River in variably calcareous silty mudstone and lime mudstone; and the sparse biofacies present at Dodo Canyon in organic- and clay-rich mudstone. The diversity and abundance trend between biofacies correlates with shoreline trajectory.

The youngest zone in the upper Mount Cap Formation is the *Glossopleura walcotti* Zone, the base indicated by the FADs of *Glossopleura boccar* and *Glossopleura* n. sp. In the southern

Canadian Rocky Mountains, the oldest species of *Glossopleura* is *G. skokiensis* (*G. walcotti*? McCollum and Sundberg, 2007), indicating the base of the *Glossopleura walcotti* Zone is near the top of the Cathedral Formation (Rasetti, 1951; McCollum and Sundberg, 2007). The basal beds of the overlying Stephen Formation contain *G. boccar*, suggesting this species occurs slightly above the base of the *Glossopleura walcotti* Zone. Therefore, the base of the *Glossopleura walcotti* Zone in the upper Mount Cap Formation is considered slightly younger than that in the Carrara Formation, Lyndon Limestone, Chisholm Formation, upper Emigrant Formation and possibly the Bright Angel Shale of the Great Basin (Palmer and Halley, 1979; Eddy and McCollum, 1998; Sundberg, 2005; Foster, 2011; Sundberg, 2018); younger than the *Glossopleura* Zone of the Cathedral Formation (Rasetti, 1951) and equivalent to the *Glossopleura* Zone of the Stephen and Snake Indian formations of the Canadian Rocky Mountains (Rasetti, 1951; Mountjoy and Aitken, 1978; Fletcher and Collins, 1998); younger than the *G. walcotti* Zone of Cape Wood Formation of Greenland (Poulsen, 1927); and younger than the *G. walcotti* Zone of the upper La Laja Formation of the Precordillera (Foglia and Vaccari, 2010).

Biostratigraphic zonation of the Mount Clark and Mount Cap formations indicates that: (1) the formations are partly time-equivalent; and (2) that the contact between the Mount Clark Formation/lower Mount Cap Formation and upper Mount Cap Formation, interpreted as a flooding event, is diachronous. Flooding occurred during the *Olenellus* Zone in the southeastern part of the basin and during the *Albertelloides mischi* Zone in the northwestern part of the basin.

2.4.3 Paleoecology

Trilobites co-occur with linguliformean brachiopods in siltstone, limestone and mudstone, and co-occur with hyoliths in mudstone. Soft-bodied faunal elements are present at Little Bear River, which include anomalocarids, bivalved arthropods, chancelloriids and small carbonaceous fossils of planktonic acritarchs, crustaceans and lophotrochozoans (Butterfield and Nicholas, 1996; Harvey and Butterfield, 2011). The rare occurrence of protaspids and meraspids of Dolichometopid n. gen. 2, n. sp. 1 and Dolichometopid n. gen. 1, n. sp. 1 in mudstone and lime mudstone, respectively, indicates that these species were able to reproduce in these environments.

2.4.3.1 Trilobite faunas

Trilobite faunas of the Mount Cap Formation are less diverse than in many other middle Cambrian formations in Laurentia, particularly at the family level in the *Albertelloides mischi* and *Glossopleura walcotti* zones. The taxa present are typical of a restricted-shelf setting (Robison, 1976; Palmer and Halley, 1979; Eddy and McCollum, 1998). As the Mount Cap Formation is inboard of the continental slope setting of the Rockslide Formation, and lacks thick, cliff-forming, shallow-water carbonate intervals, the closest faunal analogues are those present in the inner-detrital belt facies of the Great Basin. Faunas of the *Albertella/Mexicella mexicana* and *Glossopleura walcotti* zones of the Pioche, Chisholm and inner-shelf Carrara formations are comparable (Fritz, 1968; Palmer and Halley, 1979; Eddy and McCollum, 1998; Sundberg, 2005). Rarefaction of trilobite collection data from all formations indicates that they represent a reasonable approximation of the original communities.

Dolichometopids and zacanthoidids are relatively diverse and abundant in the Mount Cap Formation, whereas ptychoparioids and oryctocephalids are rare, and agnostoids, eodiscoids, dorypygids and ogygopsidids are absent (Fig. 2.5). The dominance of dolichometopids and zacanthoidids increases in younger zones, and ptychoparioids virtually disappear. The absence of agnostoids, eodiscoids and oryctocephalids is to be expected within a semi-enclosed basin far from the open shelf and continental slope where these taxa tend to be common (Robison, 1976; Whittington, 1995; Sundberg and McCollum, 1997). The lack of dorypygids and ogygopsidids in the *Albertelloides mischi* and *Glossopleura walcotti* zones contrasts with other areas where these families are represented, such as in the southern Canadian Rocky Mountains (Rasetti, 1951), Alaska (Palmer, 1968), the Great Basin (Fritz, 1968; Robison, 1976; Palmer and Halley, 1979; Eddy and McCollum, 1998; Sundberg, 2005; Foster, 2011; Robison and Babcock, 2011; Sundberg, 2018), the Precordillera (Bordonaro et al., 2008) and Greenland (Poulsen, 1927; Babcock, 1994). Environmental conditions were favourable, or tolerable, to zacanthoidids and dolichometopids while less so with ptychoparioids, and not so for dorypygids and ogygopsidids. Facies broadly similar to those of the Mount Cap Formation in the Pioche (Fritz, 1968; Eddy and McCollum, 1998) and Chisholm formations (Sundberg, 2005) suggest environmental preference was independent of substrate type or physical sedimentary processes, such as bottom turbulence. Three possible paleoecological stressors include variation in water temperature, salinity or

bottom-water oxygen conditions. Variations in any of these could be expected within a semi-enclosed basin, but to single them out specifically is not yet possible.

2.4.3.2 Paedomorphic trilobites

Several taxa unique to the upper Mount Cap Formation of the eastern Mackenzie Mountains have paedomorphic anatomical features, interpreted as arising due to heterochronic changes during ontogeny (McNamara, 1986a; b). These species are *Zacanthoidid* n. gen. 2, n. sp. 1 and *Dolichometopid* n. gen. 2, n. sp. 1 in the *Albertelloides mischi* Zone of Dodo Canyon, and *Dolichometopid* n. gen. 2, n. sp. 1, *Zacanthoidid* n. gen. 3, n. sp. 1 and *Zacanthoidid* n. gen. 3, n. sp. 2 in the *Glossopleura walcotti* Zone of Carcajou Falls. Non-paedomorphic relatives of all four species are known: *Albertella levis*, *Dolichometopid* n. gen. 1, n. sp. 1 and *Albertelloides* n. sp. or *A. mischi*, respectively, which are regarded as ancestral due to their similar morphologies with typical zacanthoidids and dolichometopids of Laurentia (McNamara, 1982). Identification of the ancestral form is a criterion for recognizing the occurrence of paedomorphosis (McNamara, 1986a). Compared to the ancestral apaedomorphs in the upper Mount Cap Formation, paedomorphic species have: (1) a lower number of thoracic segments; (2) a larger pygidium composed of a greater amount of segments; and (3) shorter thoracic spines. The sizes of complete exoskeletons of paedomorphic trilobites, inferred to be fully mature specimens, are comparable to that of apaedomorphic relatives. Morphological differences indicate that only the development of the thorax is retarded. Paedomorphosis occurs in three separate lineages (each paedomorph-apaedomorph couple) indicating that it was likely environmentally provoked, rather than from random mutation or genetic drift.

2.5 Systematic Paleontology

Class Trilobita Walch, 1771

Order Redlichiida Richter, 1932

Suborder Olenellina Walcott, 1890

Superfamily Olenelloidea Walcott, 1890

Family Olenellidae Walcott, 1890

Subfamily Olenellinae Walcott, 1890

Genus *Olenellus* Hall, 1861

Type species.— *Olenus thompsoni* Hall, 1859 from the *Olenellus* Zone of an argillaceous shale, Georgia.

Remarks.— Palmer and Repina's (1993) and Palmer's (1998) generic classification is followed. Observations on the ontogeny and intraspecific variation of *Olenellus gilberti* Meek, 1874 have raised doubt about this classification (Webster, 2015). Because of this uncertainty, subgenera proposed by Palmer (1998) are not adopted here.

Olenellus gilberti Meek, 1874

Figure 2.6.1–2.6.4, 2.6.6 and 2.6.10

1874 *Olenellus gilberti* Meek in White, p. 7.

1877 *Olenellus gilberti*, White, p. 44, pl. 2, fig. 3a–3c.

?1936 *Olenellus mackenziensis* Kobayashi, p. 162, pl. 21, fig. 32.

2015 *Olenellus gilberti*, Webster, p. 11, figs. 6A–6D, 7A–7F, 8A–8F, 9A–9F, 10A–10G, 11A–11G, 12A–12D, 13A–13D, 14A–14D, 19A–19T, 20A–20R, 21A–21O, 25A–25W, 26A–26R, 27A–27D, 28A–28S, 29A–29V, 31A–31E, 32A–32F, 33A–33E, 36A–36W. [see for synonymy]

Holotype.— Cephalon (USNM 15411a) from the *Olenellus* Zone of the C-shale Member, Pioche Formation, Nevada (White, 1877, pl. 2, fig. 3a; Walcott, 1910, pl. 36, fig. 3).

Occurrence.— Sandstone, Mount Clark Formation, 12-MWB-05; carbonate, upper Mount Cap Formation, 12-MWB-06; sandy limestone, lower Mount Cap Formation, Dodo Canyon; silty mudstone, upper Mount Cap Formation, Little Bear River and Inlin Brook, Northwest Territories, *Olenellus* Zone; Buelna Formation, Sonora, Mexico (Cooper et al., 1952); Carrara Formation, Nevada, *Olenellus* Zone (Palmer and Halley, 1979); C-shale Member, Pioche

Formation, Utah and Nevada, *Olenellus* Zone (Palmer, 1998b); and Cadiz Formation, California, *Olenellus* Zone (Webster, 2015).

Material.— 20 cephalata and one hypostome.

Remarks.— *Olenellus gilberti* is characterized by a long cephalic border which is the same length or slightly shorter than the preglabellar field, a moderately long ocular lobe which has the posterior tip opposite the occipital furrow and an advanced genal spine. Specimens from the Mount Cap Formation are identical to the holotype from the Pioche Formation. One specimen (Fig. 2.6.10) from the Mount Clark Formation appears to have a shorter ocular ridge, though this is attributed to compaction.

Olenellus terminatus Palmer, 1998b

Figure 2.6.5, 2.6.7 and 2.6.9

1979 *Olenellus clarki* (Resser); Palmer and Halley, p. 68, pl. 3, figs. 1, 2, 5.

1998 *Olenellus terminatus* Palmer, p. 670, fig. 12.1–12.8.

Holotype.— Cephalon (DMNH 16085) from the *Olenellus* Zone of the C-shale Member, Pioche Formation, Nevada (Palmer, 1998b, fig. 12.3).

Occurrence.— Sandy limestone, lower Mount Cap Formation, Dodo Canyon; silty mudstone, upper Mount Cap, Little Bear River and Inlin Brook, Northwest Territories, *Olenellus* Zone; Carrara Formation, Nevada and California, *Olenellus* Zone (Palmer and Halley, 1979) and C-shale Member, Pioche Formation, Nevada, *Olenellus* Zone (Palmer, 1998b).

Material.— 27 cephalata, two thoracic segments and one possible hypostome.

Remarks.— *Olenellus terminatus* differs from *O. gilberti* by the shorter cephalic border and less-advanced genal spine. *Olenellus terminatus* differs from *O. clarki* by having a longer ocular lobe which terminates opposite the anterior part of the occipital ring.

Genus *Bolbolenellus* Palmer and Repina, 1993

Type species.— *Olenellus euryparia* Palmer in Palmer and Halley, 1979 from the *Olenellus* Zone of the Carrara Formation, Nevada.

Remarks.— This genus was originally classified in subfamily Bristoliinae by Palmer and Repina (1993), but was later reclassified within Olenellinae due to the presence of a macropleural thoracic segment (Palmer, 1998b). The most distinctive feature is the absence of a preglabellar field, where the anterior glabellar lobe abuts or overlaps the cephalic border (Palmer and Repina, 1993).

Bolbolenellus new species 1

Figure 2.7.1–2.7.4

Holotype.— Cephalon (GSC 142289) from the *Olenellus* Zone of the lower Mount Cap Formation, Northwest Territories (Fig. 2.7.1, 2.7.2).

Diagnosis.— A species of *Bolbolenellus* with the anterior glabellar lobe intersecting or overlapping the anterior cephalic border furrow, ocular lobe long, posterior cephalic border nearly transverse, genal spine slightly advanced and moderately long.

Occurrence.— Sandy limestone, lower Mount Cap Formation, Dodo Canyon, silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Olenellus* Zone.

Description.— Cephalon is semicircular in outline, the length equal to half the width. Anterior cephalic border ranges in length from half to slightly less than that of the occipital ring. Cephalic

border furrow is moderately to well defined. Preglabellar field is absent, with the anterior edge of the glabella either intersecting or overlapping the anterior border furrow. Strongly convex glabella with a well-defined axial furrow, narrowing from the occipital ring to 2L and expanding from 2L to the rounded anterior lobe. 1S and 2S are well defined and oriented obliquely backwards, 2S does not intersect the axial furrow and 3S is moderately defined and oriented transverse. 3L expands posterolaterally to envelope the lateral side of 2L. Occipital furrow is well defined, occipital ring with a medial tubercle. Strongly convex ocular lobe is crescent-shaped, narrows posteriorly, with the anterior tip intersecting the posterior part of the anterior glabellar lobe and the posterior tip opposite the occipital furrow. Length of the ocular lobe is half that of the glabella. Interocular cheek at the widest point is in width one-third that of the occipital ring. Width of the moderately convex extraocular area at the widest point one and one-third times that of the occipital ring. Posterior border oriented nearly transverse and is in width one and one-half times that of the occipital ring. Genal spine is slightly advanced, the length is five-sixths that of the glabella.

Hypostome, thorax and pygidium are unknown.

Material.—11 cephalia.

Remarks.— Specimens of *Bolbolenellus* n. sp. from the Mount Cap Formation show variation in the length of the anterior cephalic border and position of the anterior lobe of the glabella with respect to the cephalic border. The border length and position of the anterior glabellar lobe with respect to the anterior cephalic border varies in *Olenellus gilberti* (Webster, 2015, figs. 4F, 5A). These features are considered to represent intraspecific variation in *Bolbolenellus* n. sp. as well.

Olenellid genus and species indet.

Figure 2.6.8

Occurrence.— Dolomitic limestone of the upper Mount Cap Formation, Little Bear River, Northwest Territories, *Olenellus* Zone.

Material.— 1 partial cephalon.

Remarks.— The fragmentary cephalon shows the ocular lobe intersecting the posterior edge of 4L, and 3L expanding posterolaterally to envelope the side of 2L. This separates 2S from the axial furrow.

Order Corynexochida Kobayashi, 1935
Family Dolichometopidae Walcott, 1916b

Genus *Bathyuriscus* Meek, 1873

Type species.— *Bathyurus* (?) *haydeni* Meek, 1873 from the Meagher Limestone of southwestern Montana (Diess, 1936).

Remarks.— The generic diagnosis by Robison (1964) is followed here. See Young and Ludvigsen (1989) for the history of the discussion on the generic name.

Bathyuriscus rotundatus (Rominger, 1887)

Figures 2.8.1–2.8.10, 2.9.1–2.9.6

1887 *Embolimus rotundata* Rominger, p. 16, pl. 1, figs. 4, 5.

1908a *Bathyuriscus rotundatus*, Walcott, pl. 4, fig. 2.

1916b *Bathyuriscus rotundatus*, Walcott, p. 346, pl. 47, figs. 2, 2a, b.

1951 *Bathyuriscus rotundatus*, Rasetti, p. 158, pl. 28, figs. 2, 3.

1985 *Bathyuriscus rotundatus*, Hu, pl. 6, figs. 18, 21, 25.

Holotype.— *Embolimus rotundata* (specimen appears to be lost) from the Stephen Formation, British Columbia (Rominger, 1887, pl. 1, fig. 4).

Diagnosis.— A species of *Bathyriscus* with the anterior facial suture divergent, interocular area narrow, posterior border moderately wide; pygidium subisopygous, five to six axial rings, border spines absent.

Occurrence.— Mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, Zacanthoidid n. gen. 1, n. sp. 1 Zone; Stephen Formation, British Columbia, *Bathyriscus-Elrathina* Zone (Rominger, 1887; Walcott, 1908a; 1916b; Rasetti, 1951; Hu, 1985).

Material.— Six complete exoskeletons, 23 incomplete exoskeletons or complete exoskeletons lacking free cheeks, two early holaspid exoskeletons, 10 cranidia, 15 free cheeks, 3 thoracic segments and 27 pygidia.

Remarks.— Pygidia from the Mount Cap Formation vary in the length to width ratio (Figs. 2.9.1, 2.9.4 and 5.4.6), similar to Walcott's material (1916b, pl. 47, figs. 2, 2a) from the Stephen Formation. As the ratio does not correlate to the overall size or number of pygidial segments, this is interpreted as intraspecific variation. The length of the terminal spines of the thoracic segments seem to vary slightly in *B. rotundatus*. Free cheeks from the Mount Cap Formation appear to have a slightly longer genal spine than those in the Stephen Formation. The occurrence of *B. rotundatus* is older than previously reported collections.

Two early holaspids of *Bathyriscus rotundatus* were collected (Fig. 2.9.1, 2.9.2). These differ from late holaspid exoskeletons by the narrower posterior cranial border, narrower thoracic pleura, smaller, triangular-shaped pygidium with an axis that is nearer the border furrow, which is composed of one-less axial ring and a faintly denticulated pygidial margin. Except for the denticulated margin, these differences are similar to those between early and late holaspids of *B. fimbriatus* Robison, 1964 (Robison, 1967).

Genus Dolichometopid new genus 1

Type species.— Dolichometopid n. gen. 1, n. sp. 1 from the *Albertelloides mischi* and *Glossopleura walcotti* zones of the upper Mount Cap Formation, Northwest Territories.

Diagnosis.— Dolichometopid with glabella expanding anteriorly, anterior border short to absent, palpebral lobe short, interocular area wide to moderately wide; free cheek moderately wide, genal spine long; eight or nine thoracic segments; subisopygous, four or five axial rings, pleural field moderately narrow, pleural furrows poorly to moderately defined, border furrow well-defined, border short.

Remarks.— Dolichometopid n. gen. 1 is similar to *Bathyuriscus*, *Poliella* Walcott, 1916b, *Parkaspis* Rasetti, 1951 and *Wenkchemnia* Rasetti, 1951. Dolichometopid n. gen. 1 differs from *Bathyuriscus* by having a usually wider interocular area, smaller pygidium composed of fewer axial rings and less well-defined pygidial pleural furrows. Dolichometopid n. gen. 1 differs from *Poliella* in having a usually shorter palpebral lobe, larger pygidium composed of more axial rings and narrower pygidial border. It differs from *Parkaspis* by having a shorter palpebral lobe, wider interocular area, fewer thoracic segments and larger pygidium. Dolichometopid n. gen. 1 differs from *Wenkchemnia* in having a wider interocular area and larger pygidium.

Dolichometopid n. gen. 1 is intermediate in form between *Wenkchemnia* and *Bathyuriscus*. The length of the palpebral lobe is like that of *Wenkchemnia* and some species of *Bathyuriscus*, such as *B. terranovensis* Young and Ludvigsen, 1989. The size of the pygidium and number of axial rings in Dolichometopid n. gen. 1 is intermediate between the other two genera. Some specimens of *B. rotundatus* have the same number of axial rings, although the pygidium is proportionally larger and has better defined pleural furrows than Dolichometopid n. gen. 1 (Fig. 2.9.6; Walcott, 1916b, pl. 47, figs. 2, 2a).

Dolichometopid new genus 1, new species 1

Figures 2.10.1–2.10.9, 2.11.1–2.11.11

Holotype.— Dolichometopid n. gen. 1, n. sp. 1 (GSC 142301) from the *Glossopleura walcotti* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.10.1).

Diagnosis.— Dolichometopid n. gen. 1 with interocular area wide; free cheek narrow, genal spine short; eight or nine thoracic segments, thoracic spines short; four or five pygidial axial

rings, pleural field narrow, border short, variably with shallow medial indentation and very short border spines.

Occurrence.— Mudstone, siltstone, lime mudstone and wackestone, upper Mount Cap Formation, Little Bear River, Carcajou Falls and Dodo Canyon, Northwest Territories, Zacanthoidid n. gen. 1, n. sp. 1, *Albertelloides mischi* and *Glossopleura walcotti* zones.

Description.— Exoskeleton is subelliptical in outline. Exoskeleton length 14–25 mm.

Cranidium is subtrapezoidal in outline. Axial furrow is well defined. Glabella extends to anterior border furrow or margin if anterior border is absent. Four pairs of lateral glabellar furrows are present. Glabella narrows gently from the occipital ring to 1S and widens from 1S to the anterior lobe. 1S is well defined and oriented obliquely backwards; 2S is moderately defined and oriented obliquely backwards; and 3S and 4S are poorly defined and oriented obliquely forward. Occipital furrow is well defined, the occipital ring variably bearing a median tubercle. Anterior course of the facial suture is slightly divergent. Interocular area at the widest point is two-thirds to half the width of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite 4S and the posterior tip opposite 1S. Length of the palpebral lobe is half that of the glabella. Posterior course of the facial suture is oriented obliquely backward. Posterior border is equal in width to the occipital ring, with a moderately defined border furrow.

Free cheek is equal in width to the occipital ring; flat lateral border is in width one-fifth that of the total free cheek at the widest point. Genal spine is non-advanced and is one-third the length of the total free cheek.

Hypostome is conterminant, widening anteriorly and narrowing posteriorly. Length of the posterior lobe is equal to one-fifth of the total length.

Thorax consists of eight, rarely nine segments. Axial furrow is well defined; each axial ring has a medial tubercle. Pleura is slightly wider than the axis, with well-defined pleural and interpleural furrows. Pleural spines moderately short to moderately long and narrow.

Pygidium subisopygous, semicircular in outline and the length is equal to two-thirds the width. Pygidial axis tapers gently posteriorly; the posterior tip is slightly anterior of the border furrow and is composed of four or five rings and a terminal piece. Pleural field is equal in width

to the axis, with four or five pairs of pleural furrows. The two or three anterior furrows are moderately to poorly defined and intersect the border furrow, and the two posterior furrows are poorly defined or effaced and do not intersect the border furrow. The border is in length one-tenth or less that of the pygidium. One pair of short border spines is variably present, opposite the anteriormost pleural furrow. The posterior edge of the border may have a medial indentation.

Material.— 29 complete and incomplete exoskeletons, 93 exoskeletons lacking free cheeks, 78 holaspid cranidia, three meraspid cranidia, four isolated thoracic segments and 87 pygidia.

Remarks.— Specimens of Dolichometopid n. gen. 1, n. sp. 1 show variation in the width of the interocular area, number of thoracic segments, length and width of the border of the free cheek and pygidium, number of pygidial axial rings and furrows, presence of a medial indentation in the pygidial margin and presence of border spines. The width of the interocular area correlates to the size of the cranidium in that it is narrower in larger specimens (Fig. 2.10.1, 2.10.7 and 2.11.8). Larger pygidia have five rather than four axial rings and pleural furrows, and border spines are present only on the smaller pygidia (Figs. 2.11.4–2.11.6, 2.12.2). These features are interpreted as growth related. Variation in border length, number of thoracic segments and presence of a medial indentation do not correlate with exoskeleton size and are regarded as intraspecific variation.

Dolichometopid new genus 1, new species 2

Figure 2.12.1–2.12.12

Holotype.— Dolichometopid n. gen. 1, n. sp. 2 (GSC 142320) from the *Glossopleura walcotti* Zone of the upper Mount Cap Formation, Northwest Territories (Figs. 2.13.1–2.13.3).

Diagnosis.— Dolichometopid n. gen. 1 with an interocular area narrow; free cheek wide, genal spine long; nine thoracic segments, thoracic spines long; five or six pygidial axial rings, pleural field wide, border long, medial indentation and border spines absent.

Occurrence.— Lime mudstone and rarely wackestone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Glossopleura walcotti* Zone.

Description.— Exoskeleton is subquadrate in outline. Exoskeleton length 40 mm.

Cranidium is subtrapezoidal in outline. Axial furrow is well defined. Glabella extends to anterior border furrow or margin if anterior border is absent. Four pairs of lateral glabellar furrows are present. Glabella narrows gently from the occipital ring to 1S and widens from 1S to the anterior lobe. 1S is well defined and oriented obliquely backwards; 2S is poorly defined or effaced and oriented obliquely backwards; and 3S and 4S are poorly defined or effaced and oriented obliquely forward. Occipital furrow is well defined, the occipital ring variably bearing a medial tubercle. Anterior course of the facial suture is divergent. Moderately convex interocular area at the widest point is equal to half the width of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite 4S and the posterior tip opposite the middle of 1L. Length of the palpebral lobe is equal to half that of the glabella. Posterior course of the facial suture is oriented obliquely backwards. Weakly convex posterior border is equal in width to the occipital ring, with a well-defined border furrow.

Free cheek is slightly narrower than the occipital ring, moderately convex and the border is in width one-third that of the total free cheek at the widest point. Genal spine is non-advanced and less than half to almost double the length of the total free cheek.

Hypostome is conterminant.

Thorax consists of nine segments. Moderately convex axis with a well-defined axial furrow; each axial ring has a medial tubercle. Gently convex pleura is slightly wider than the axis, with well-defined pleural and interpleural furrows. Pleural spines are moderately long and narrow.

Pygidium subsopygous, semicircular in outline and the length is equal to half to two-thirds the width. Moderately convex axis narrows posteriorly, the posterior tip is slightly anterior of the border furrow and is composed of five or six rings and a terminal piece. Axial ring furrows are well defined. Gently convex pleural field is slightly wider than the axis, with five pairs of pleural furrows which intersect the border furrow. The three anterior furrows are well defined, and the two posterior furrows are poorly defined. The flat border is one-eighth the length of the pygidium. Border spines are absent.

Material.— One complete exoskeleton, one incomplete exoskeleton, six crania and seven pygidia.

Remarks.— *Dolichometopid* n. gen. 1, n. sp. 2 differs from *Dolichometopid* n. gen. 1, n. sp. 1 in its larger size, narrower interocular area, wider free cheek, longer genal spine, slightly longer thoracic spines, occasional additional axial ring, wider pleural field, better defined pleural furrows, slightly longer border and lack of short border spines. *Dolichometopid* n. gen. 1, n. sp. 2 was only collected in limestone, whereas *Dolichometopid* n. gen. 1, n. sp. 1 was collected in mudstones as well.

Genus *Glossopleura* Poulsen, 1927

Type species.— *Dolichometopus boccar* Walcott, 1916b from the *Glossopleura* Zone of the Stephen Formation, British Columbia.

Remarks.— *Glossopleura* Poulsen, 1927 has over 50 species and is in need of review, as most species are likely synonymous (Sundberg, 2005; Robison and Babcock, 2011) and features used to discern species of this genus can overlap significantly (Sundberg, 2005). Hitherto, *Glossopleura* species for which the thorax is known had seven or eight segments. *Glossopleura* n. sp. bears six thoracic segments, and this is not regarded as taxonomically important at the generic level.

Glossopleura boccar (Walcott, 1916b)

Figure 2.13.1–2.13.6

1916b *Dolichometopus boccar* Walcott, p.363, pl. 52, figs. 1, 1a–f.

2005 *Glossopleura boccar*, Sundberg, p. 65, fig. 6.10–6.14. [see for synonymy]

2011 *Glossopleura boccar*, Foster, p. 105, fig. 4.1–4.3.

Holotype.— *Dolichometopus boccar* (USNM 62702) from the *Glossopleura* Zone of the Stephen Formation, British Columbia (Walcott, 1916b, pl. 52, fig. 1).

Diagnosis.— *Glossopleura* with anterior glabellar lobe moderately wide to wide, 1S well defined, 2S, 3S and 4S poorly defined or effaced, palpebral lobe long and narrow; posterior border wide; thorax with seven segments; pygidial length two-thirds the width, axis long, intersecting the border furrow, ring furrows moderately defined, pleural furrows and border furrow moderately to poorly defined, border moderately long. [modified from Sundberg, 2005]

Material.— 11 incomplete exoskeletons, 28 cranidia, eight free cheeks, 13 thoracic segments and 52 pygidia.

Occurrence.— Mudstone, lime mudstone and wackestone, upper Mount Cap Formation, Dodo Canyon and 12-MWB-04, Northwest Territories, *Glossopleura walcottii* Zone; Stephen Formation, Alberta and British Columbia, *Glossopleura* Zone (Walcott, 1916b; Rasetti, 1951); Chisholm Formation, Utah, *Glossopleura walcottii* Zone (Sundberg, 2005); Bright Angel Shale, Arizona, *Glossopleura walcottii* Zone (Foster, 2011).

Remarks.— *Glossopleura boccar* from the Mount Cap Formation varies in the width of the anterior glabellar lobe (Fig. 2.13.1–2.13.3) and the depth of the pygidial border and pleural furrows (Fig. 2.13.4–2.13.6), similar to *G. boccar* in the Chisholm Formation (Sundberg, 2005, fig 6.10–6.14). This species has been tentatively reported from the Mount Cap Formation of the Colville Hills as well (Morgan, 2019; Sommers et al., 2020).

Glossopleura new species

Figure 2.14.1–2.14.11

Holotype.— *Glossopleura* n. sp. (GSC 142332) from the *Glossopleura walcottii* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.14.1).

Diagnosis.— *Glossopleura* with anterior glabellar lobe moderately wide, lateral glabellar furrows poorly defined to effaced, palpebral lobe long and wide, posterior border narrow; thorax with six segments; pygidial length half to three-fifths the width, axis short, anterior of border furrow, ring furrows poorly defined or effaced, pleural furrows poorly defined or effaced, border furrow well defined, border long.

Occurrence.— Mudstone and grainstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Glossopleura walcotti* Zone.

Description.— Exoskeleton is subelliptical in outline. Exoskeleton length 18–28 mm.

Cranidium is subquadrate in outline. Axial furrow is moderately defined. Glabella is subrectangular in shape and extends to anterior border. One pair of lateral glabellar furrows is present. Glabella widens gently from 1S to the anterior lobe. 1S is poorly defined and oriented obliquely backwards. Occipital furrow is poorly to moderately defined. Length of the anterior border is less than one-tenth that of the occipital ring. Anterior course of the facial suture is slightly divergent. Width of the interocular area at the widest point is one-third that of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite what is likely the anterior lobe and the posterior tip opposite the occipital furrow. Length of the palpebral lobe is three-fifths that of the glabella, and the width is slightly narrower than that of the interocular area. Posterior course of the facial suture is transverse. Width of the posterior border is two-thirds that of the occipital ring, with a moderately defined border furrow.

Free cheek width is unknown. Free cheek border is at least one-sixth the width of the total free cheek. Genal spine is short.

Hypostome is unknown.

Thorax consists of six segments. Axial furrow is well defined. Pleural width is equal to or slightly wider than that of the axis, pleura with moderately defined pleural and interpleural furrows. Pleural spines are very short.

Pygidium isopygous, semicircular in outline and the length is half to three-fifths the width. Moderately convex axis narrows gently posteriorly, with the posterior tip slightly anterior of the border furrow and is composed of at least three rings. Axial ring furrows are poorly defined or

effaced. Gently convex pleural field is slightly narrower than the axis, with two poorly defined or effaced pleural furrows. Flat border is one-quarter to one-fifth the length of the pygidium. Border is covered in terrace lines. Border spines are absent.

Material.— One complete exoskeleton, 21 incomplete exoskeletons or complete exoskeletons lacking free cheeks, 10 cranidia and 19 pygidia.

Remarks.— *Glossopleura* n. sp. has one fewer thoracic segment than in other species of *Glossopleura* for which the thorax is known. *Glossopleura* varies in having either seven or eight thoracic segments, but the number is stable within individual species. Apart from the number of thoracic segments, *Glossopleura* n. sp. is similar to *G. boccar* and *G. producta* (Walcott, 1916b), differing from the former by having an effaced glabella, a longer and wider palpebral lobe, a narrower posterior border, a slightly shorter pygidial axis, a less well-defined axial furrow, a near absence of pleural furrows and a longer border; and differing from the latter by having an effaced glabella, a slightly shorter pygidial axis and a longer pygidial border.

Genus *Polypleuraspis* Poulsen, 1927

Type species.— *Polypleuraspis solitaria* Poulsen, 1927 from the *Glossopleura* Zone of the lower Cape Wood Formation, Greenland.

Remarks.— Peel's (2020) generic diagnosis is followed herein. *Polypleuraspis* currently contains three species: *P. solitaria*, *P. insignis* Rasetti, 1951 and *P. glacialis* Peel, 2020, all from the *Glossopleura* Zone. Peel (2020) allowed for some intraspecific variation in the pygidium of *P. glacialis*, in outline, convexity and shape of the median indentation of the posterior margin.

Polypleuraspis solitaria Poulsen, 1927

Figure 2.13.7, 2.13.8

1927 *Polypleuraspis solitaria* Poulsen, p. 270, pl. 16, figs. 37, 38

2020 *Polypleuraspis solitaria*, Peel, p. 20, figs. 2D, 2K, 2L, 2N, 2P, 2Q, 2S, 2T, 4A–4U. [see for synonymy]

Holotype.— Pygidium (MGUH 2292) from the *Glossopleura walcotti* Zone of the lower Cape Wood Formation, northwestern Greenland (Poulsen, 1927, pl. 16, figs. 37, 38; Peel, 2020 fig. 2I, 2K, 2N).

Occurrence.— Lime mudstone, upper Mount Cap Formation, 12-MWB-04, Northwest Territories, *Glossopleura walcotti* Zone; Cap Wood Formation, Kap Kent, Greenland, *Glossopleura walcotti* Zone (Poulsen, 1927; Peel, 2020).

Material.— Two pygidia.

Remarks.— The maximum pygidial width is at the midlength, which is consistent with *P. solitaria*. The two pygidia in the Mount Cap Formation are wider than most specimens from northwestern Greenland. The axial nodes are preserved only on one specimen.

Genus Dolichometopid new genus 2

Type species.— Dolichometopid n. gen. 2, n. sp. 1 from the *Glossopleura walcotti* Zone of the upper Mount Cap Formation, Northwest Territories.

Diagnosis.— As for species.

Remarks.— The glabellar shape, size and orientation of the palpebral lobe, size and shape of the postocular fixed cheek, narrow pygidial border and lack of border spines indicate that Dolichometopid n. gen. 2 belongs to Dolichometopidae and is closely related to *Bathyriscus* and Dolichometopid n. gen. 1. Dolichometopid n. gen. 2, compared to other dolichometopids, has fewer thoracic segments and a larger pygidium. At present the genus is monospecific.

Dolichometopid new genus 2, new species 1

Figures 2.15.1–2.15.9, 2.16.1–2.16.12

Holotype. — Dolichometopid n. gen. 2, n. sp. 1 (GSC 142342) from the *Glossopleura walcotti* Zone of the Mount Cap Formation, Northwest Territories (Fig. 2.16.1).

Diagnosis.— Dolichometopid with glabella anteriorly wide, palpebral lobe short, postocular fixed cheek long and wide; four thoracic segments; macropygous, eight or nine axial rings, eight or nine pleural furrows well defined, border short, pygidial spines absent.

Occurrence.— Mudstone, lime mudstone, wackestone and grainstone, upper Mount Cap Formation, Dodo Canyon, upper *Albertelloides mischi* Zone, Carcajou Falls, *Glossopleura walcotti* Zone, Northwest Territories.

Description. — Exoskeleton is subelliptical in outline. Exoskeleton length 8–33 mm

Cranidium is subtrapezoidal in outline. Axial furrow is well defined. Strongly convex glabella is subrectangular in outline, extending anteriorly to the border. Glabella narrows gently from the occipital ring to 1S and widens from 1S to the anterior lobe. Four pairs of lateral glabellar furrows are present. 1S and 2S are well defined and oriented obliquely backward, and 3S and 4S are poorly defined or effaced and oriented obliquely forward. Occipital furrow is well defined, the occipital ring bearing a medial tubercle. Length of the anterior border is one-sixth that of the occipital ring. Anterior course of the facial suture is parallel or slightly divergent. Moderately convex interocular area at the widest point is three-fifths the width of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite 4S and the posterior tip opposite the anterior-half to middle of 1L. Length of the palpebral lobe is equal to half that of the glabella. Posterior course of the facial suture is oriented obliquely backwards. Posterior border is equal in width to that of the occipital ring, with a well-defined posterior border furrow.

Free cheek is slightly wider than the occipital ring and the border is in width one-fifth to one-sixth that of the total free cheek at the widest point. Genal spine is slightly advanced and is

slightly less than half the length of the total free cheek. Free cheek is variably caecate. Terrace lines are present on the border.

Hypostome is conterminant, widening anteriorly and narrowing gently posteriorly. Medial lobe is covered in terrace lines. Length of the posterior lobe is equal to one-quarter of the total length and is covered in terrace lines.

Thorax consists of four segments. Axial furrow is well defined; each ring bearing a medial tubercle. Pleural width is one and one-half times that of the axis, pleura with well-defined pleural and interpleural furrows. Pleural spine is short.

Pygidium is macropygous, subelliptical in outline and the length is equal to four-fifths the width. Strongly convex axis narrows gently posteriorly, the posterior tip intersecting the border furrow and is composed of eight or nine rings, each bearing a medial tubercle, and a terminal piece. Axial ring furrows are well to moderately defined. Moderately convex pleural field is slightly wider than the axis, with eight or nine pleural and seven interpleural furrows. The seven anterior pleural and interpleural furrows are well defined and intersect the border furrow. The one or two posterior pleural furrows are poorly defined and do not intersect the border furrow. Flat border is one-tenth to slightly less than one-tenth the length of the pygidium. Border spines are absent. Interpleural areas are caecate.

Material.— 14 complete exoskeletons, 52 exoskeletons lacking free cheeks, 17 holaspid crania, two meraspid crania, one protaspid, three free cheeks and 30 pygidia.

Remarks. — Dolichometopid n. gen. 2, n. sp. 1 is distinguished by the large size of the pygidium yet reduced number of thoracic segments in holaspids. The unrelated zacanthoidids Zacanthoidid n. gen. 3, n. sp. 1 and Zacanthoidid n. gen. 2, n. sp. 1 also both have four thoracic segments and a large pygidium.

Family Oryctocephalidae Beecher, 1897

Subfamily Oryctocarinae Hupé, 1953

Genus *Euarthricocephalus* Ju, 1983

Type species.— *Euarthrocephalus laterilobatus* Ju, 1983 from the *Arthrocephalus*–*Probowmanops* Zone of the Dachenling Formation, Zhejiang, China.

Remarks.— This genus has an expanded glabella, wider fixed cheek, five thoracic segments and is smaller. Originally a subgenus of *Arthrocephalus*, it is now recognized a separate genus (Jell and Adrain, 2002). *Microrhyctocara* Sundberg and McCollum, 1997 is now considered synonymous with *Euarthrocephalus* Ju, 1983.

Euarthrocephalus nevadensis (Sundberg and McCollum, 1997)

Figure 2.18.7–2.18.10

1997 *Microrhyctocara nevadensis* Sundberg and McCollum, p.1085, fig. 15.1–15.10.

2003a *Microrhyctocara nevadensis*, Sundberg and McCollum, p. 345, fig. 9.10, 9.11.

2003b *Microrhyctocara nevadensis*, Sundberg and McCollum, p. 964, pl. 8, figs. 4–6.

2018 *Euarthrocephalus nevadensis*, Peng et al., p. 325.

Holotype.— Cranidium (USNM 488938) from the *Oryctocephalus indicus* Zone of the Emigrant Formation, Nevada (Sundberg and McCollum, 1997, fig. 15.1).

Occurrence.— Mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Albertelloides mischi* Zone; Monola and Emigrant formations, California and Nevada, *Oryctocephalus indicus* Zone; Emigrant Formation, Nevada, *Amecephalus arrosensis* Zone (Sundberg and McCollum, 1997; Sundberg and McCollum, 2003b); Pyramid Shale Member, Carrara Formation, *Poliella denticulata* Zone (Sundberg and McCollum, 2003a).

Material.— 10 cranidia and nine pygidia.

Remarks.— This species is present at Little Bear River but is absent at time-equivalent strata at Dodo Canyon, Carcajou Falls and Grafe River. In the Mackenzie Mountains, it occurs in younger strata than in the Great Basin.

Family Zacanthoididae Swinnerton, 1915

Remarks.— Review of the literature has revealed that *Mexicaspis* has already been assigned as a genus name. *Mexicaspis* Lochman, 1948 (type species *Mexicaspis stenopyge* Lochman, 1948) is preoccupied by *Mexicaspis* Spaeth, 1936 (*Coptocyclus azteca*, Champion, 1894) a tortoise beetle. The replacement name *Mexicaspidella* is proposed herein.

Genus Zacanthoidid new genus 1

Type species.— Zacanthoidid n. gen. 1, n. sp. 1 from the Zacanthoidid n. gen. 1, n. sp. 1 Zone of the Mount Cap Formation, Northwest Territories.

Diagnosis.— As for species.

Remarks.— Zacanthoidid n. gen. 1 resembles *Fieldaspis* Rasetti, 1951 and *Stephenaspis* Rasetti, 1951. Cranidia of *Fieldaspis* and *Stephenaspis* differ by the distance from the posterior tips of the palpebral lobe to the axial furrow (Rasetti, 1951). This distance in the type species of *Stephenaspis*, *S. bispinosa* Rasetti, 1951, is one-quarter of the width of the occipital ring, whereas in the type species of *Fieldaspis*, *F. furcata* Rasetti, 1951, the distance is one-sixth of the width of the occipital ring. In Zacanthoidid n. gen. 1, n. sp. 1 this distance is the same as in *F. furcata*. The pygidium of Zacanthoidid n. gen. 1 lacks the border spines or median indentation in the posterior margin present in species of *Fieldaspis* and *Stephenaspis*, though the well-defined border furrow of Zacanthoidid n. gen. 1 is within the interspecific variation of *Stephenaspis*. Thus, Zacanthoidid n. gen. 1 is intermediary between *Fieldaspis* and *Stephenaspis*. At present the genus is monospecific.

Zacanthoidid new genus 1, new species 1

Figures 2.17.1–2.17.10, 2.18.1–2.18.6

?1996 *Zacanthoides* sp. Butterfield and Nicholas, fig. 2.5.

Holotype.— *Zacanthoidid* n. gen. 1, n. sp. 1 (GSC 142361) from the *Zacanthoidid* n. gen. 1, n. sp. 1 Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.17.1).

Diagnosis.— *Zacanthoidid* with glabella anteriorly wide, palpebral lobe long; genal spine non-advanced; nine thoracic segments, pleural spines long, macropleural spines on the fifth and ninth segment; oval-shaped pygidium subisopygous, four axial rings, four pleural furrows, border furrow well defined, border spines absent.

Occurrence.— Silty mudstone and siltstone, lower Mount Cap Formation, Dodo Canyon, mudstone and silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Zacanthoidid* n. gen. 1, n. sp. 1 Zone.

Description.— Exoskeleton is subelliptical in outline. Exoskeleton length 10–20 mm.

Cranidium is subquadrate in outline. Axial furrow is well defined. Glabella is subquadrate in outline, extending anteriorly to the border. Glabella narrows gently from the occipital ring to 1S and widens from 1S to the anterior lobe. Four pairs of lateral glabellar furrows are present. 1S is well defined and oriented obliquely backward; 2S is poorly defined and nearly transverse; and 3S and 4S are poorly defined and oriented obliquely forward. Occipital furrow is well defined, the occipital ring bearing a medial tubercle. Length of the anterior border is one-sixth that of the occipital ring. Anterior course of the facial suture is divergent. Interocular area at the widest point is one-third to half the width of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite 3S and the posterior tip opposite the occipital furrow. Length of the palpebral lobe is two-thirds that of the glabella. Posterior course of the facial suture is transverse. Posterior border is equal in width to the occipital ring, with a poorly defined posterior border furrow.

Free cheek is slightly wider than the occipital ring and the border is in width one-fifth that of the total free cheek at the widest point. Genal spine is non-advanced and in length is half that of the total free cheek.

Hypostome is conterminant, widening anteriorly and narrowing gently posteriorly. Anterior lobe is covered in terrace lines. Length of the posterior lobe is one-sixth the total length.

Thorax consists of nine segments. Axial furrow is well defined; each axial ring bearing a medial tubercle. Pleura is in width one and one-half to twice that of the axis, with well-defined pleural and interpleural furrows. Thoracic spines are moderately long; posteriorly directed macropleural spines are present on segments five and nine, with the latter extending just past to well beyond the posterior border of the pygidium.

Pygidium subisopygous, oval in outline and the length is equal to two-thirds the width. Axis narrows posteriorly, with the posterior tip anterior of the border furrow and is composed of four rings, each bearing a medial tubercle, and a terminal piece. Ring furrows are moderately defined. Pleural field is in width two-thirds that of the axis and has four pleural furrows, which are poorly to well defined and do not intersect the well-defined border furrow. Border is one-eighth the length of the pygidium. Border spines are absent. Terrace lines are variably present on the border.

Material.— Two complete exoskeletons, 13 exoskeletons lacking free cheeks, 46 cranidia, 12 free cheeks, 13 thoracic segments, 27 pygidia and one hypostome.

Remarks.— *Zacanthoides* sp. in Butterfield and Nicholas (1996) has a nearly identical cephalon and thorax to that of *Zacanthoidid* n. gen. 1, n. sp. 1. The pygidium of this specimen is partially covered by matrix and can not be compared to the pygidium of *Zacanthoidid* n. gen. 1, n. sp. 1.

Genus *Albertella* Walcott, 1908b

Type species.— *Albertella helena* Walcott, 1908b from the *Albertella* Zone of the Gordon Shale, Montana.

Remarks.— *Albertella* Walcott, 1908b has a subrectangular-shaped glabella, a moderately long cranidial border, a moderately short palpebral lobe with the posterior tip opposite 1S, a wide interocular area, a narrow free cheek, a macropleural third thoracic segment, a pygidium that is wider than long, a pygidial axis composed of four rings and a terminal piece and a

posterolaterally oriented pygidial border spine (Rasetti, 1951; Palmer and Halley, 1979). This species has been recognized in the Mount Cap Formation of the Colville Hills (Morgan, 2019; Sommers et al., 2020).

Albertella levis Walcott, 1917a

Figure 2.19.1–2.19.6

1917a *Albertella levis* Walcott, p. 39, pl. 7, figs. 1, 1a.

Holotype.—Cranidium (USNM 63758) from the *Albertella* Zone of the Chetang Formation, Alberta (Walcott, 1917a, pl. 7, fig. 1).

Occurrence.—Silty mudstone and mudstone, upper Mount Cap Formation, Dodo Canyon, *Albertelloides mischi* Zone, Carcajou Falls, *Glossopleura walcotti* Zone, Northwest Territories; Chetang Formation, Alberta, *Albertella* Zone (Walcott, 1917a).

Material.—12 cranidia and 14 pygidia.

Remarks.—This species is intermediate between *Albertella* and *Paralbertella* Palmer in Palmer and Halley, 1979. Features shared with *Albertella* include a moderately short palpebral lobe, a pygidium that is wider than long, poorly defined pleural furrows and a pair of posterolaterally oriented border spines. Features shared with *Paralbertella* include an anteriorly wide glabella and a pygidial axis composed of five rings. The pygidium of *Albertelloides* n. sp. is broadly similar to *Albertella levis*, but *Albertelloides* n. sp. is distinguished by having a longer palpebral lobe, well-defined pygidial furrows and shorter pygidial axis. Pygidia from the Mount Cap Formation differ from those from the Chetang Formation by having a slightly shorter pygidial axis which is slightly anterior to the border furrow.

Genus *Albertelloides* Fritz, 1968

Type species.— *Albertelloides mischi* Fritz, 1968, from the *Albertella* Zone of the Pioche Formation, Nevada.

Remarks.— *Albertelloides* Fritz, 1968 differs from *Albertella* by having a wider anterior glabellar lobe, a longer palpebral lobe, a shorter postocular fixed cheek, a narrower, less-convex interocular fixed cheek, a wider free cheek, a non-advanced genal spine, wider thoracic pleura and a more posteriorly located pygidial border spine. *Albertelloides* differs from *Paralbertella* by having a wider anterior glabellar lobe, a non-advanced genal spine, a thorax composed of eight instead of seven segments, four to five instead of five to seven pygidial axial rings, less well-defined pleural furrows, a shallower border furrow and a more posteriorly located border spine.

Fritz (1968) described three species, *Albertelloides mischi*, *A. pandispinata* and *A. sp. indet.* Campbell (1974, unpublished) recognized an additional species. *Albertelloides rectimarginatus* Palmer in Palmer and Halley, 1979 and more complete material belonging to *A. mischi* were described from the Carrara Formation (Palmer and Halley, 1979) and *A. kitai* Eddy and McCollum, 1998 was described from the Pioche Formation, all from Nevada. Fritz (1968) proposed that the pygidia of *Kochaspis maladensis* Resser, 1939b and *K. dispar* Resser, 1939b (Resser, 1939b, pl. 13, figs. 9–12, 13–15) belong to *Albertelloides*. Sundberg and McCollum (2003a) argued that these pygidia belong to a corynexochid, but not *Albertelloides* due to the fewer axial rings. The species described by Campbell (1974, pl. 15, figs. 1, 2, 6 and 7) probably also does not belong to *Albertelloides* for the same reason.

Albertelloides mischi, *A. kitai*, *A. pandispinata* and *A. rectimarginatus* all have four to five pygidial axial rings. These species are distinguished by the variable length, width and orientation of the pygidial border spine. *Albertelloides mischi* and *A. pandispinata* have long and narrow border spines, but differ in the orientation: subparallel in *A. mischi* and divergent in *A. pandispinata*. *Albertelloides rectimarginatus* and *A. kitai*, by contrast, have short and wide border spines: parallel and sharp-tipped in *A. rectimarginatus*, whereas they are blunt-tipped in *A. kitai* (Eddy and McCollum, 1998). The interocular area is wider in *A. rectimarginatus* and *A. kitai* and narrower in *A. mischi*. The cranidium of *A. pandispinata* is unknown.

Albertelloides new species

Figure 2.20.4–2.20.13

Holotype.— Pygidium (GSC 142396) from the *Albertelloides mischi* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.20.6).

Diagnosis.— *Albertelloides* with cranidial border short, posterior border oriented gently posterolaterally; free cheek wide, border of free cheek narrow; thoracic segments with moderately long pleural spines; pygidial pleural field wide, three pleural furrows well defined, border short, bearing one pair of moderately short, narrow and subparallel-oriented spines.

Occurrence.— Calcareous siltstone and silty mudstone, upper Mount Cap Formation, Carcajou Falls and Little Bear River, Northwest Territories, *Albertelloides mischi* Zone.

Description.— Cranidium is subtriangular in outline. Axial furrow is well defined. Glabella is subparallel, extending anteriorly to the border. Glabella narrows from the occipital ring to 1S and widens from 1S to the anterior lobe. Four pairs of lateral glabellar furrows are present. 1S is well defined and oriented obliquely backwards; 2S is poorly defined and transverse; and 3S and 4S are poorly defined and oriented obliquely forward. Occipital furrow is well defined. Length of the anterior border is one-quarter that of the occipital ring. Anterior course of the facial suture is parallel to slightly divergent. Interocular area at the widest point is half to two-thirds the width of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow opposite 4L and the posterior tip opposite the occipital furrow. Length of the palpebral lobe is two-thirds that of the glabella. Posterior course of the facial suture is oriented gently posterolaterally. Posterior border is in width equal to the occipital ring, with a moderately defined border furrow.

Border of the free cheek is in width one-fifth that of the total free cheek, bearing terrace lines. Genal spine is non-advanced and is one-third the length of the total free cheek.

Hypostome is unknown.

Thorax consists of at least five segments. Axial furrow is well defined. Pleura is in width one and one-half times that of the axis, with well-defined pleural and interpleural furrows. Thoracic spines are moderately long.

Pygidium is semicircular in outline and in length equal to two-thirds the width. Axis is parallel-sided, with the posterior end anterior to or intersecting the border furrow and is composed of four to five rings and a terminal piece. Axial ring furrows are moderately to poorly defined. Pleural field is in width equal to that of the axis, with four pleural furrows and three interpleural furrows. The three anterior pleural and interpleural furrows are well defined and intersect the border furrow. The posterior pleural furrow is poorly defined and does not intersect the border furrow. Border is one-tenth the length of the pygidium. Border spine is opposite the fourth pygidial pleural furrow, oriented subparallel and is slightly shorter than half the length of the pygidial axis.

Material.— Three incomplete exoskeletons, 28 crania, 10 free cheeks and 13 pygidia.

Remarks.— *Albertelloides* n. sp. differs from other species of *Albertelloides* by having shorter cranial and pygidial borders, a slightly obliquely backwards oriented posterior cranial border, a wider pygidial pleural field and a short and narrow border spine. Variation in the number of pygidial axial rings and orientation of the border spine are interpreted as intraspecific variation (Fig. 2.20.6, 2.20.7 and 2.20.10).

Albertelloides mischi Fritz, 1968

Figures 2.19.7–2.19.11, 2.20.1–2.20.3

1968 *Albertelloides mischi* Fritz, p. 215, pl. 38, figs. 1–7.

1979 *Albertelloides mischi*, Palmer and Halley, p. 90, pl. 10, figs. 7–13.

Holotype.— Pygidium (USNM 153568) from the *Albertella* Zone of the Pioche Formation, Nevada (Fritz, 1968, pl. 38, figs. 5, 7).

Occurrence.— Calcareous siltstone and silty mudstone, upper Mount Cap Formation, Carcajou Falls and Grafe River, Northwest Territories, *Albertelloides mischi* Zone; upper member, Pioche

Formation, Nevada, *Albertella* Zone (Fritz, 1968); Carrara Formation, Nevada, Zacanthoidid Zonule, *Albertella* Zone (Palmer and Halley, 1979).

Material.— 35 cranidia, six free cheeks and 21 pygidia.

Remarks.— Specimens from the Mount Cap Formation differ from those of the Pioche and Carrara formations by having a slightly shorter anterior cranial border which is interpreted as intraspecific variation (Fritz, 1968, pl. 38, figs. 1–3, 6; Palmer and Halley, 1979, pl. 10, figs. 8, 9 and 13). *Albertelloides rectimarginatus* also exhibits minor variation in the length of the anterior border (Palmer and Halley, 1979, pl. 10, figs. 16, 17). The less well-defined pygidial border furrow and presence of a longitudinal groove on the border spines are attributed to compaction.

Albertelloides pandispinata Fritz, 1968

Figure 2.19.12

1968 *Albertelloides pandispinata* Fritz, p. 216, pl. 39, figs. 31, 32.

Holotype.— Pygidium (USNM 153597) from the *Albertella* Zone of the Pioche Formation, Nevada (Fritz, 1968, pl. 39, figs. 31, 32).

Occurrence.— Calcareous siltstone and silty mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Albertelloides mischi* Zone; upper member, Pioche Formation, Nevada, *Albertella* Zone (Fritz, 1968).

Material.— Nine pygidia.

Remarks.— *Albertelloides pandispinata* from the Mount Cap Formation is nearly identical to the two pygidia illustrated by Fritz (1968), although some pygidia differ by having five axial rings as opposed to four. This is interpreted as intraspecific variation by analogy with *A. mischi*, as this species from both the Pioche and Mount Cap formations ranges from five to six axial rings (Figs.

5.14.9, 5.15.3). Because the cranidium of *A. pandispinata* is unknown, it is possible that some cranidia assigned here to *A. mischi* belong instead to *A. pandispinata*.

Genus Zacanthoidid new genus 2

Type species.— Zacanthoidid n. gen. 2, n. sp. 1 from the *Albertelloides mischi* Zone of the upper Mount Cap Formation, Northwest Territories.

Diagnosis.— As for species.

Remarks.— This genus is currently monospecific, and the most diagnostic feature is the thorax consisting of four segments. The presence of a short palpebral lobe, anteriorly widened and effaced glabella, effaced pygidial axis and pleural field and long pygidial border spines indicate that this species belongs to Zacanthoididae and is closely related to *Mexicaspidella* n. gen. (replacement name for preoccupied *Mexicaspis*) and less so to *Albertella*. *Mexicaspidella radiatus* (Palmer in Palmer and Halley, 1979) has twice as many segments as the type species, Zacanthoidid n. gen. 2, n. sp. 1.

Zacanthoidid new genus 2, new species 1

Figure 2.22.2, 2.22.5

Holotype.— Zacanthoidid n. gen. 2, n. sp. 1 (GSC 142414) from the *Albertelloides mischi* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.22.2).

Diagnosis.— Zacanthoidid with axial furrow moderately defined, two pairs of lateral glabellar furrows poorly defined, palpebral lobe short, posterior border long and narrow; genal spine oriented obliquely backwards; four thoracic segments; macropygous, ring furrows effaced, pleural field narrow, pleural furrows poorly defined or effaced, one pair of border spines oriented obliquely backwards.

Occurrence.— Mudstone and siltstone, upper Mount Cap Formation, Dodo Canyon, Northwest Territories, *Albertelloides mischi* Zone.

Description.— Exoskeleton is subelliptical in outline. Exoskeleton length 16 mm.

Cranidium is subtrapezoidal in outline. Axial furrow is moderately defined. Glabella is subrectangular in outline, extending anteriorly to the border. The glabella widens gently from 1S to the anterior lobe. One pair of lateral glabellar furrows is present. 1S is poorly defined and oriented obliquely backwards. Occipital furrow is well defined. Anterior border is unknown. Anterior course of the facial suture is slightly divergent. Interocular area at the widest point is in width three-quarters that of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow one-third of the glabellar length from the anterior end and the posterior tip opposite 1L. Length of the palpebral lobe is half that of the glabella. Posterior course of the facial suture is oriented obliquely backwards. Posterior border is slightly narrower than the occipital ring, with a well-defined border furrow.

Free cheek is slightly narrower than the occipital ring; the border is in width one-fourth the total free cheek. Genal spine is slightly advanced, oriented obliquely backwards and is three fifths the length of the total free cheek.

Hypostome is unknown.

Thorax consists of four segments. Axial furrow is moderately defined. Pleura is equal in width to the axis, with a moderately defined pleural furrow. Thoracic segments terminate in a short spine.

Pygidium macropygous, semicircular in outline and the length is equal to five-sevenths the width. Moderately convex axis narrows gently posteriorly, with the posterior tip intersecting the border furrow. If the isolated pygidium belongs to this species, the posterior end of the axis may also be anterior to the border furrow. Ring furrows are effaced. Gently convex pleural field is slightly narrower than the axis, with one or two pairs of poorly defined pleural furrows that intersect the border furrow. Flat border is less than one-tenth the length of the pygidium. Flat, narrow border spines are oriented obliquely backwards and in length are slightly shorter than the pygidial axis. If the isolated pygidium belongs to this species, then the border spine may also be oriented subparallel and slightly curve medially.

Material.— One nearly complete exoskeleton lacking a free cheek; one probable pygidium.

Remarks.— One isolated pygidium is tentatively assigned to this species. It has a slightly shorter axis that does not intersect the border furrow and more strongly curved and subparallel rather than divergent, border spines. This is interpreted as intraspecific variation, because similar variation is observed in other species such as *Paralbertella bosworthi* (Walcott, 1908b) (Walcott, 1917a, pl. 7, figs. 3, 3a; Rasetti, 1951, pl. 17, figs. 1–4, 9) and *Albertella microps* Rasetti, 1951 (Rasetti, 1951, pl. 19, figs. 1, 3 and 7).

Genus Zacanthoidid new genus 3

Type species.— Zacanthoidid n. gen. 3, n. sp. 1 from the *Glossopleura walcottii* Zone of the upper Mount Cap Formation, Northwest Territories.

Diagnosis.— Zacanthoidid with a glabella subrectangular, palpebral lobe long; advanced genal spines long; two or four thoracic segments, axis and pleura equal in width; macropygous, six or eight axial rings, three to five pleural furrows well defined, one pair of posteriorly located border spines.

Remarks.— Zacanthoidid n. gen. 3 is regarded as a zacanthoidid because it has a long, subrectangular glabella, a long palpebral lobe and an advanced and long genal spine. This is supported by the presence of moderately long thoracic and pygidial border spines, in common with many other zacanthoidids. This genus includes two new species that have relatively few thoracic segments and larger pygidia compared to other zacanthoidids. The cephalon of Zacanthoidid n. gen. 3, n. sp. 1 is most-similar to that of *Paralbertella* and *Albertelloides*.

Zacanthoidid new genus 3, new species 1

Figures 2.21.1–2.21.9, 2.22.3, 2.22.4 and 2.22.6–2.22.11

Holotype.—Zacanthoidid n. gen. 3, n. sp. 1 (GSC 142404) from the *Glossopleura walcottii* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.22.1).

Diagnosis.—Zacanthoidid n. gen. 3 with palpebral lobe long; free cheek border narrow, genal spine short to moderately long, advanced and directed posteriorly; four thoracic segments; macropygous, pygidium semicircular in outline, eight axial rings, pleural field wide, four or five pleural furrows, parallel border spines moderately long.

Occurrence.—Mudstone, lime mudstone and grainstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Glossopleura walcottii* Zone.

Description.—Exoskeleton is subelliptical in outline. Exoskeleton length 10–31 mm.

Cranidium is subquadrate in outline. Axial furrow is well defined. Strongly convex glabella is subrectangular in outline, extending anteriorly to the border. Four pairs of lateral glabellar furrows are present. 1S and 2S are moderately defined and oriented obliquely backward; 3S is poorly defined or effaced and transverse; and 4S is poorly defined or effaced and oriented obliquely forwards. The occipital furrow is moderately defined; the occipital ring bears a medial tubercle. Length of the anterior border is equal to one-quarter that of the occipital ring. Anterior course of the facial suture is parallel. Moderately convex interocular area at the widest point is slightly narrower than the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow at 4S and the posterior tip opposite the occipital furrow. Length of the palpebral lobe is two-thirds that of the glabella. Posterior course of the facial suture is transverse. Posterior border is in width four-fifths that of the occipital ring, with a moderately defined border furrow.

Free cheek is slightly wider than the occipital ring and the border is in width one-seventh the total free cheek at widest point. Genal spine is advanced, oriented posteriorly and half to three-fifths the length of the total free cheek.

Hypostome is conterminant, widening anteriorly and narrowing gently posteriorly. Anterior and medial lobes bear terrace lines. Length of the posterior lobe is one-seventh the total length.

Thorax consists of four segments. Axial furrow is well defined; each ring bearing a medial tubercle. Pleura is in width equal to the axis, with well-defined pleural and interpleural furrows. Thoracic spines are moderately long.

Pygidium macropygous, semicircular in outline and in length is equal to two-thirds the width. Axis narrows gently posteriorly, the posterior end intersecting the border furrow and is composed of eight rings, each with a medial tubercle, and a terminal piece. Axial ring furrows are well to moderately defined. Pleural field is slightly wider than the axis, with four or five pleural furrows and three interpleural furrows. The three anterior pleural and interpleural furrows are well defined and intersect the border furrow. The one or two posterior pleural furrows are moderately to poorly defined and do not intersect the border furrow. Border is in length one-tenth that of the pygidium. One pair of border spines is present opposite the fourth pleural furrow. Border spines are subparallel and half to one and one-half times the length of the pygidial axis.

Material.—12 complete exoskeletons, 25 exoskeletons lacking free cheeks, 26 cranidia, eight free cheeks and 44 pygidia.

Remarks.—Zacanthoidid n. gen. 3, n. sp. 1 differs from Zacanthoidid n. gen. 3, n. sp. 2 by having a more advanced and slightly longer palpebral lobe, advanced and parallel genal spines and a semicircular pygidium with more axial rings, a wider pleural field, more pleural furrows and parallel border spines.

Zacanthoidid new genus 3, new species 2

Figure 2.22.1

Holotype.—Zacanthoidid n. gen. 3, n. sp. 2 (GSC 142413) from the *Glossopleura walcottii* Zone of the upper Mount Cap Formation, Northwest Territories (Fig. 2.22.1).

Diagnosis.—Zacanthoidid n. gen. 3 with palpebral lobe short; free cheek border wide, genal spine long, non-advanced and oriented obliquely backward; at least two thoracic segments;

isopygous, pygidium subtriangular in outline, six axial rings, pleural field narrow, three pleural furrows, border spines extending from pleural field, oriented posterolaterally.

Occurrence.— Mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Glossopleura walcotti* Zone.

Description.— Complete exoskeleton is unknown.

Cranidium is subquadrate in outline. Axial furrow is well defined. Glabella is subrectangular in outline, extending anteriorly to the border. At least one pair of lateral glabellar furrows are present. 1S is poorly defined and oriented obliquely backwards. 2S, 3S and 4S are not preserved. Occipital furrow is well defined. Length of the anterior border is equal to one-quarter that of the occipital ring. Anterior course of the facial suture is parallel. Interocular area at the widest point is in width half that of the occipital ring. Palpebral lobe is crescent-shaped, with the anterior tip intersecting the axial furrow one-third the glabellar length from the anterior end and the posterior tip opposite the middle of 1L. Length of the palpebral lobe is half that of the glabella. Posterior course of the facial suture is transverse. Posterior border is slightly narrower than the occipital ring, with a well-defined border furrow.

Free cheek is in width equal to that of the occipital ring and the border is in width one-fifth of the total free cheek at the widest point. Genal spine is non-advanced, oriented posterolaterally and two-thirds the length of the total free cheek.

Hypostome is unknown.

Thorax consists of at least two segments. Axial furrow is well defined. Pleura is equal in width to the axis, with a well-defined pleural furrow. Tips of segments are unknown.

Pygidium isopygous, subtriangular in outline and the length is equal to four-fifths the width. Axis narrows gently posteriorly; the posterior end intersecting the border furrow and is composed of at least six axial rings. Ring furrows are poorly defined. Pleural field is equal in width to the axis, with three pleural furrows. The two anterior pleural furrows are well defined and intersect the border furrow. The posterior pleural furrow is moderately defined and does not intersect the border furrow. Length of the border is unknown. One pair of spines extends from the pleural field posterior of the third pleural furrow, are oriented posterolaterally and are twice the length of the axis.

Material.— One nearly complete exoskeleton.

Remarks.— Aside from the distinctively low number of thoracic segments, the pair of strongly divergent pygidial spines that extends from the pleural field of Zacanthoidid n. gen. 3, n. sp. 2 is unusual, but similar to spines present in *Albertella longwelli* Palmer in Palmer and Halley, 1979.

Corynexochid genus and species indet.

Figures 2.24.13, 2.24.14

Occurrence.— Silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Amecephalus arrojosis*–*Eokochaspis nodosa* Zone.

Material.— Nine cranidia, three free cheeks and one partial thorax consisting of five segment.

Remarks.— The lack of a pygidium limits identification because early middle Cambrian corynexochids have morphologically conservative cranidia, such as in species of *Poliella*, *Fieldaspis*, *Stephenaspis* and Zacanthoidid n. gen. 1.

Order Ptychopariida Swinnerton, 1915

Suborder Ptychopariina Richter, 1932

Superfamily Ptychoparioidea Matthew, 1887

Family Alokistocaridae Resser, 1939b

Subfamily Altioculinae Sundberg, 1994

Genus *Altiocculus* Sundberg, 1994

Type species.— *Altiocculus drumensis* Sundberg, 1994 from the *Altiocculus* Subzone, *Ehmaniella* Zone of the Swasey Limestone, Utah.

Remarks.— Sundberg (1994) differentiated this genus from *Alokistocare* Lorenz, 1906 on the basis of a more-convex preocular fixed cheek, a shorter palpebral lobe and a subelliptical pygidium with better defined pleural and interpleural furrows (Sundberg, 1999).

Altiocculus americanus (Walcott, 1916a)

Figures 2.23.16, 2.23.17

1916a *Acrocephalites americanus* Walcott, p. 177, pl. 24, fig. 2.

1989 *Alokistocare americanum*, Schwimmer, p. 486, fig. 2.11, 2.13–2.15.

Holotype.— Cranidium (USNM 61557) from the *Bolaspidella* Zone of the Conasauga Formation, Georgia (Walcott, 1916a, pl. 24, fig. 2).

Occurrence.— Mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Glossopleura walcotti* Zone; Conasauga Formation, Georgia, *Bolaspidella* Zone (Walcott, 1916a; Schwimmer, 1989).

Description.— Exoskeleton is subelliptical in outline. Exoskeleton length 20 mm.

Cranidium is subtrapezoidal in outline. Axial furrow is moderately defined. Glabella is subtrapezoidal in outline. Three pairs of lateral glabellar furrows are present. 1S and 2S are poorly defined and oriented obliquely backward, and 3S is nearly effaced and transverse. Occipital furrow is moderately defined. Anterior border is slightly longer than the preglabellar field. Border furrow is moderately defined, shallowing at a poorly defined preglabellar swelling that extends into the border. Anterior course of the facial suture is convergent. Interocular area is equal in width to the occipital ring. Ocular ridge is well defined and nearly transverse; slightly bowed anteriorly. Mid-point of palpebral lobe is opposite 2S, with the anterior tip opposite 3L and posterior tip opposite 2L. Length of the palpebral lobe is one-quarter that of the glabella. Posterior course of the facial suture is oriented obliquely backwards. Posterior border is in width twice that of the occipital ring, with a well-defined border furrow.

Free cheek and hypostome are unknown.

Thorax consists of 18 segments. Axial furrow is moderately defined. Pleura is in width one and one-third times that of the axis, with well-defined pleural and interpleural furrows. Pleural spines blunt.

Pygidium micropygous, elliptical in outline and the length is equal to one-third the width. Axis tapers gently posteriorly, with the posterior tip slightly anterior to the posterior edge of the pygidium and is composed of two axial rings and a terminal piece. Pleural field is in width twice that of the axis, with two pairs of poorly defined pleural furrows that intersect the margin of the pygidium. Border and border spines are absent

Material.— One complete exoskeleton lacking free cheeks.

Remarks.— Sundberg (1994; 1999) placed this species in *Altiocculus*. *Altiocculus americanus* (Walcott, 1916a) from the Mount Cap Formation is older than the material from the Conasauga Formation.

Family Ptychopariidae Matthew, 1887

Subfamily uncertain

Genus *Amecephalus* Walcott, 1924

Type species.— *Ptychoparia piochensis* Walcott, 1886 from the *Amecephalus arrojensis* Zone of the Pioche Formation, Nevada.

Remarks.— The concept of this genus as outlined by Pratt and Bordonaro (2014) is followed here. The relationship with other ptychopariids is uncertain because many species are based on insufficient material (Sundberg, 2004).

Amecephalus arrojensis (Lochman, 1952)

Figure 2.23.1–2.23.7

1952 *Strotocephalus arrojensis* Lochman in Cooper et al., p. 157, pl. 21, figs. 29–34.
2000 *Amecephalus arrojensis*, Sundberg and McCollum, p. 607, fig. 5.1–5.13.
2003b *Amecephalus arrojensis*, Sundberg and McCollum, p. 966, pl. 3, fig. 12.
2014 *Amecephalus arrojensis*, Pratt and Bordonaro, p. 911, figs. 5.1–5.13, 6.1–6.20.

Holotype.—Cranidium (USNM 115753) from the Arrojos Formation of Sonora, (Cooper et al., 1952, pl. 21, figs. 31–33).

Occurrence.—Silty mudstone, upper Mount Cap Formation, Little Bear River, siltstone and silty mudstone, lower Mount Cap Formation, Dodo Canyon, Northwest Territories, *Amecephalus arrojensis*–*Eokochaspis nodosa* and Zacanthoidid n. gen. 1, n. sp. 1 zones; Arrojos Formation, Sonora (Cooper et al., 1952); Comet Shale and Susan Duster Limestone, Pioche Formation, Nevada, *Amecephalus arrojensis* Zone (Sundberg and McCollum, 2000); Emigrant Formation, Nevada and Monola Formation, California, *Amecephalus arrojensis* Zone (Sundberg and McCollum, 2003b); Soldano Member, La Laja Formation, San Juan, Argentina, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone (Pratt and Bordonaro, 2014).

Material.—Two nearly complete exoskeletons, 30 cranidia, three free cheeks and one pygidium.

Remarks.—*Amecephalus arrojensis* has also been questionably reported from the Cerro Prieto Formation of Sonora (Noriega-Ruiz et al., 2020).

Amecephalus agnesensis (Walcott, 1912)

Figure 2.23.9–2.23.11

1912 *Olenopsis? agnesensis* Walcott, p. 242, pl. 36, fig. 2.
1917b *Olenopsis? agnesensis*, Walcott, pl. 13, figs. 5, 5a–5c.
1951 *Amecephalus agnesensis*, Rasetti, p. 207, pl. 10, figs, 11–14.

Holotype.— *Olenopsis? agnesensis* (USNM 58364) from the Mount Whyte Formation of Alberta (Walcott, 1912, pl. 36, fig. 2; 1917b, pl. 13, fig. 5).

Occurrence.— Silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; Mount Whyte Formation, Alberta and British Columbia, *Wenkchemnia*–*Stephenaspis* Zone (Walcott, 1912; 1917b; Rasetti, 1951).

Material.— 13 cranidia.

Remarks.— Compared to cranidia in the Mount Whyte Formation, those in the Mount Cap Formation have the ocular ridge oriented slightly more obliquely backwards. This is regarded as intraspecific variation which also has been noted in *Eokochaspis nodosa* Sundberg and McCollum, 2000 (Webster, 2011a).

Genus *Caborcella* Lochman, 1948

Type species.— *Caborcella arrojensis* Lochman, 1948 from the Arroj Formation, Sonora, Mexico.

Remarks.— *Caborcella* Lochman, 1948 is characterized by a concave prelabellar field with a well-defined border furrow (Lochman, 1948; Palmer and Halley, 1979). *Nyella* Palmer in Palmer and Halley, 1979 is similar, but differs by having a convex prelabellar field.

Caborcella collaris (Rasetti, 1951)

Figures 2.23.14, 2.23.15, 2.24.2 and 2.24.3

1951 *Schistometopus collaris* Rasetti, p. 239, pl. 14, figs. 1–3.

Holotype.— Cranidium (USNM 116123) from the *Plagiura–Kochaspis* Zone of the Mount Whyte Formation, Alberta (Rasetti, 1951, pl.14, figs. 1–3).

Occurrence.— Siltstone and silty mudstone, lower Mount Cap Formation, Dodo Canyon, Northwest Territories, *Amecephalus arrosensis–Eokochaspis nodosa* and *Zacanthoidid* n. gen. 1, n. sp. 1 zones; Mount Whyte Formation, Alberta and British Columbia, *Plagiura–Kochaspis* Zone (Rasetti, 1951).

Material.— Five cranidia.

Remarks.— Owing to the poor quality of the holotype of *Schistometopus typicalis* Resser, 1938, the type species, Sundberg (2004) advocated for the reassignment of existing species to other genera. Sundberg (2004) suggested that *S. collaris* belongs in *Caborcella*. Compared to the holotype cranidium, the cranidia from the Mount Cap Formation have a slightly longer anterior border. The presence of the occipital spine is uncertain because of poor preservation.

Genus *Chancia* Walcott, 1924

Type species.— *Chancia ebdome* Walcott, 1924 from the *Glossopleura* Zone of the Spence Shale, Langston Formation, Idaho (Maxey, 1958; Oriel and Armstrong, 1971).

Remarks.— The diagnosis in Palmer and Halley, 1979 of *Chancia* Walcott, 1924 is followed here. Walcott (1924, 1925) assigned two species to *Chancia*: *C. ebdome* Walcott, 1924 and *C. evax* Walcott, 1925. Resser (1939a) added *C. angusta* Resser, 1939a. Four species were added by Rasetti (1951): *C. latigena* Rasetti, 1951; *C. bigranulosa* Rasetti, 1951; *C. odarayensis* Rasetti, 1951; and *C. stenometopa* Rasetti, 1951. The re-assignment to *Chancia* of *Ptychoparia palliseri* Walcott, 1908a by Rasetti (1951), *Kochina venusta* Resser, 1939b by Fritz (1968) and *Ehmaniella maladensis* Resser, 1939b by Palmer (in Palmer and Halley, 1979) brings the number of species to ten. In addition, Fritz (in Oriel and Armstrong, 1971) listed *C. coriacea* (Resser, 1939a). Hu (1985) added *C. conica* Hu, 1985.

Chancia ebdome, *C. evax*, *C. venusta*, *C. bigranulosa* and *C. stenometopa* have a frontal area that is four-tenths of the total cranial length (Walcott, 1925, pl. 17, figs. 26; 27; Resser, 1939b, pl. 6, figs. 9, 10; Rasetti, 1951, pl. 8, fig. 20, pl. 22, figs. 1–3). *Chancia evax* has a border that is one-fifth the length of the frontal area and 24 thoracic segments. *Chancia ebdome* has a border that is one-third the length of the frontal area and 20 thoracic segments. *Chancia venusta*, *C. bigranulosa* and *C. stenometopa* all have a border that is slightly less than half the length of the frontal area, as well as granular or finely pustulose prosopon on the cranidium. The posterior cranial border is slightly narrower in *C. venusta* and slightly wider in *C. bigranulosa* and *C. stenometopa*. Also, *C. venusta* has a palpebral lobe that is one-third the glabellar length, whereas *C. bigranulosa* and *C. stenometopa* have a shorter palpebral lobe that is one-fifth the glabellar length. The similarities in cranial dimensions between *C. stenometopa* and *C. bigranulosa* indicate that the former may be synonymous with the later.

Chancia latigena, *C. palliseri* and *C. angusta* have a frontal area that is one-third of the total cranial length (Walcott, 1908a, pl. 3, fig. 6; Resser, 1939a, pl. 5, fig. 14; Rasetti, 1951, pl. 21, fig. 15). *Chancia palliseri* has an anterior border that is one-third the length of the frontal area, a palpebral lobe that is one-quarter the glabellar length and 20–23 thoracic segments (Rasetti, 1951). *Chancia latigena* and *C. angusta* have a border nearly half the length of the frontal area and a palpebral lobe that is one-fifth the glabellar length. *Chancia latigena* has a narrower posterior border. *Chancia angusta* has a distinctly tapering glabella, a wider posterior border and 18 thoracic segments (Resser, 1939a). *Chancia maladensis* has a frontal area that ranges from slightly less to slightly more than one-third of the total cranial length, as well as an anterior border that is less than half the length of the frontal area, a palpebral lobe that is one-quarter the glabellar length, an interocular area slightly wider than the glabella and 18 thoracic segments (Resser, 1939b, pl. 12, figs. 20, 21; Sundberg, 2018, figs. 24.1–24.6, 25.1–25.12). *Chancia odarayensis* has a frontal area that is one-fifth of the total cranial length, as well as a border that is nearly half the length of the frontal area, a palpebral lobe that is one-quarter the glabellar length, an interocular area that is equal in width to the glabella and at least 22 thoracic segments (Rasetti, 1951, pl. 33, fig. 16).

Chancia maladensis (Resser, 1939b)

Figure 2.24.1

1939b *Ehmaniella maladensis* Resser, p. 98, pl. 12, figs. 17–23.

2018 *Chancia maladensis*, Sundberg, p. 31, figs. 24.1–24.6, 25.1–25.12.

Holotype.—Cranidium (USNM 98563a) from the Spence Shale, Idaho (Resser, 1939b, pl. 12, figs. 20, 21).

Occurrence.—Mudstone, upper Mount Cap Formation, Dodo Canyon, Northwest Territories, *Glossopleura walcotti* Zone; Spence Shale, Idaho (Resser, 1939b); Rachel Limestone and Emigrant Formation, Nevada, *Glossopleura walcotti/Ptychagnostus praecurrens* Zone (Sundberg, 2018).

Material.—Two partially complete exoskeletons lacking free cheeks and one cranidium.

Remarks.—*Chancia maladensis* from the Mount Cap Formation resembles specimens from the Spence Shale, Emigrant Formation and Rachel Limestone, but differs in having a slightly shorter anterior cranial border. It shares a palpebral lobe which is slightly longer than that in other species.

Genus *Eokochaspis* Sundberg and McCollum, 2000

Type species.—*Eokochaspis nodosa* Sundberg and McCollum, 2000 from the *Eokochaspis nodosa* Zone of the Comet Shale Member, Pioche Formation, Nevada.

Remarks.—The diagnosis by Sundberg and McCollum (2000) with amendments in Webster (2011) is followed. Features used to distinguish species of *Eokochaspis* include the relative lengths of the prelabellar field and anterior border, presence of a plectrum, depth of axial and lateral glabellar furrows, width of the free cheek, length of the genal spine, number of pygidial axial rings and presence of a medial indentation on the pygidial border. Sundberg (2004) suggested that *Eokochaspis* is polyphyletic.

Eokochaspis nodosa Sundberg and McCollum, 2000

Figure 2.23.8, 2.23.12 and 2.23.13

2000 *Eokochaspis nodosa* Sundberg and McCollum, p. 611, fig. 7.1–7.20.

2003b *Eokochaspis nodosa*, Sundberg and McCollum, p. 967, pl. 2, figs. 1, 2 and 4.

2011 *Eokochaspis nodosa*, Webster, p. 218, figs. 7.1–7.20, 28.1–28.29 and 29.1–29.31.

2011 *Eokochaspis nodosa*, Webster and Zelditch, fig. 1C, 1D.

2014 *Eokochaspis nodosa*, Pratt and Bordonaro, p. 916, fig. 8.1–8.10.

Holotype.— Cranidium (USNM 497818) from the *Eokochaspis nodosa* Zone of the Comet Shale Member, Pioche Formation, Nevada (Sundberg and McCollum, 2000, fig. 7.1–7.3)

Occurrence.— Silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Amecephalus arjosensis*–*Eokochaspis nodosa* Zone; Comet Shale Member, Pioche Formation, Nevada, *Eokochaspis nodosa* Zone (Sundberg and McCollum, 2000; Webster, 2011a; Webster and Zelditch, 2011); Emigrant Formation, Nevada, *Eokochaspis nodosa* Zone (Sundberg and McCollum, 2003b); Soldano Member, La Laja Formation, San Juan, Argentina, *Amecephalus arjosensis*–*Eokochaspis nodosa* Zone (Pratt and Bordonaro, 2014).

Material.— One nearly complete exoskeleton, one cranidium and two pygidia.

Remarks.— The cranidium and free cheek differ slightly from the holotype by the more curved anterior cranial border, shorter prelabellar field, less well-defined ocular ridge and palpebral lobe and narrower genal spine. The cranial differences record earlier holaspid stages of *Eokochaspis nodosa* (Webster, 2011a) and variation in the width of the genal spine is regarded as intraspecific variation (Webster, 2011a).

Eokochaspis species indet.

Figure 2.24.4, 2.24.7

Occurrence.— Mudstone and silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, Zacanthoidid n. gen. 1, n. sp. 1 Zone.

Material.— One nearly complete exoskeleton and three cranidia.

Remarks.— *Eokochaspis* sp. indet. is most similar to *E. piochensis* (Palmer in Palmer and Halley, 1979), but differs by having a shorter glabella, slightly longer palpebral lobe and less well-defined axial and lateral glabellar furrows. However, the available cranidia are small.

Genus *Tonopahella* Sundberg and McCollum, 2003b

Type species.— *Tonopahella goldfieldensis* Sundberg and McCollum, 2003b from the *Amecephalus arrojensis* Zone of the Emigrant Formation, Nevada.

Remarks.— Sundberg and McCollum (2003b) proposed this genus to account for two species classified in *Kochina* Resser, 1935 which are somewhat similar to *Amecephalus*. The cranidium of *Tonopahella* differs from that of *Amecephalus* by the constriction of the axial furrow at 2S, moderately defined 1S and 2S and an absence of the interborder furrow in the anterior border. *Tonopahella goldfieldensis* differs from *T. walcotti* (Sundberg and McCollum, 2000) by having a transverse anterior border and a less well-defined border furrow.

Tonopahella goldfieldensis Sundberg and McCollum, 2003b

Figure 2.24.6, 2.24.8

2003b *Tonopahella goldfieldensis* Sundberg and McCollum, p. 981, pl. 7, figs. 1–6.

Holotype.— *Tonopahella goldfieldensis* (USNM 517665) from the *Amecephalus arrojensis* Zone of the Emigrant Formation, Nevada (Sundberg and McCollum, 2003b, pl. 7, figs. 1, 3).

Occurrence.— Silty mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories, *Amecephalus arrojosisensis–Eokochaspis nodosa* Zone; Emigrant Formation, Nevada, *Amecephalus arrojosisensis* Zone; Monola Formation, California, *Amecephalus arrojosisensis* Zone (Sundberg and McCollum, 2003b).

Material.— Three cranidia.

Remarks.— Cranidia from the Mount Cap Formation differ from the holotype in having a slightly curving anterior margin. As this is intermediate between *T. goldfieldensis* and *T. walcotti*, it may suggest that the two species are synonymous.

Ptychoparioid genus and species indet. 1

Figure 2.24.11, 2.24.12

Occurrence.— Siltstone, lower Mount Cap Formation, Dodo Canyon, Northwest Territories, Zacanthoidid n. gen. 1, n. sp. 1 Zone.

Material.— One cranidium.

Remarks.— This cranidium has a tapered glabella with two lateral glabellar furrows that curve obliquely backwards, a shallow anterior border furrow, a wide fixed cheek and an effaced ocular ridge. It bears a resemblance to *Solenopleura conifrons* Westergård, 1952, although this taxon is from Baltic and Avalonian strata of the younger *Solenopleura? brachymetopa* and *Paradoxides forchhammeri* zones (Guzhangian Stage).

Ptychoparioid genus and species indet. 2

Figures 2.24.5, 2.24.9 and 2.24.10

Occurrence.— Silty mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories, *Albertelloides mischi* Zone.

Description.— Cranium is subtriangular in outline. Axial furrow is well defined. Glabella is subrectangular in outline and with the axial furrow outwardly bowed slightly. Three pairs of lateral glabellar furrows are present. 1S and 2S are well defined and oriented obliquely backwards and 3S is poorly defined and nearly transverse. Occipital furrow is well defined, the occipital ring bearing a medial tubercle. Length of the anterior border is one-quarter that of the preglabellar field. Border furrow is moderately defined and shallows medially. Anterior course of the facial suture is convergent. Interocular area is in width three-quarters that of the glabella at the mid-point. Ocular ridge is well defined and is oriented transverse to obliquely backwards. Mid-point of the palpebral lobe opposite 2S, with the anterior tip opposite 3L and the posterior tip opposite 1L. Length of the palpebral lobe is nearly half that of the glabella. Posterior course of the facial suture is nearly transverse. Posterior border is slightly wider than the occipital ring, with a well-defined border furrow.

Free cheek is equal in width to the occipital ring, the border is in width one-fifth of the total free cheek at the widest point. Genal spine is slightly advanced and in length is one-third of the total free cheek.

Hypostome, thorax and pygidium are unknown.

Material.— One cephalon and 16 cranidia.

Remarks.— This species is distinct among ptychoparioids in that it has a unique combination of a short anterior cranial border, a convergent anterior facial suture, a long palpebral lobe and a wide fixed cheek. Typically, genera with convergent facial sutures, such as *Plagiura* Resser, 1935 and *Onchocephalus* Resser, 1937 have a short palpebral lobe located anteriorly and a narrow fixed cheek.

Global chron.		Laurentian chronostratigraphy			Mackenzie Mountains	Victoria Island	Colville Hills	eastern Mackenzie Mountains	eastern Mackenzie Mountains biozones
Series	Stage	Series	Stage	Biozones					
Miaolingian	Wuliuan	Lincolnian	Delamaran	Glossopleura Zone/ Glossopluera walcotti Zone	Rockslide Formation	Mount Phayre formation	upper Mount Cap Formation	Glossopleura walcotti Zone	
				Albertella Zone/ Mexicella mexicana Zone				Albertelloides mischi Zone	
				Plagiura- Poliella Zone				Poliella denticulata Zone	? ? ? ? Zacanthoidid n. gen. 1, n. sp. 1 Zone
Amecephalus arrojosensis Zone	Amecephalus arrojosensis-Eokochaspis nodosa Zone								
Eokochaspis nodosa Zone									
Series 2	Stage 4	Waucoban	Dyeran	Bonnia-Olenellus Zone	Sekwi Formation	Uvayualuk formation	lower Mount Cap Formation	Olenellus Zone	
						Quyuk formation		Mount Clark Formation	

Figure 2.1. Lithostratigraphic correlation chart and biostratigraphic ages of Cambrian formations of the Mackenzie Mountains, Interior Plains, Franklin Mountains, and Arctic Islands. Color of formations indicates the dominant lithology: brown=dominantly coarse clastics, grey=dominantly fine clastics, and blue=dominantly carbonate. Biostratigraphic and lithostratigraphic data from Pratt, 1989; Palmer, 1998a; Durbano et al., 2015; Kimmig and Pratt; 2016; Morgan, 2019; Sommers et al., 2020; and Sundberg et al., 2020. Biostratigraphic framework of the eastern Mackenzie Mountains based on Aitken et al. (1973) and this work.

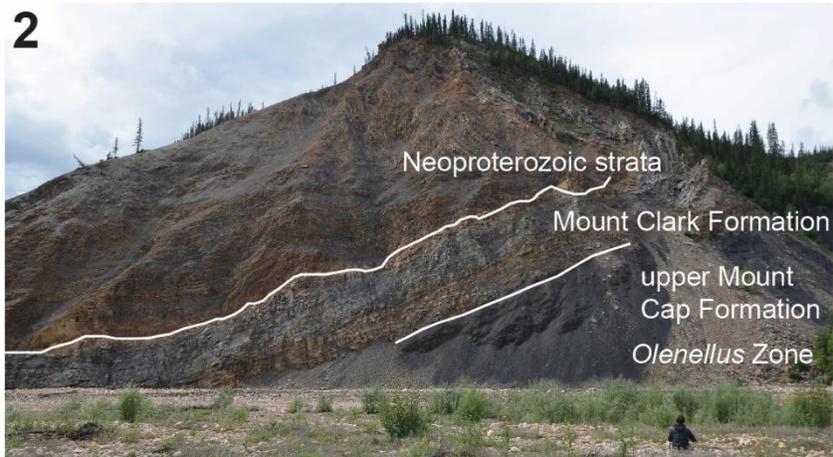
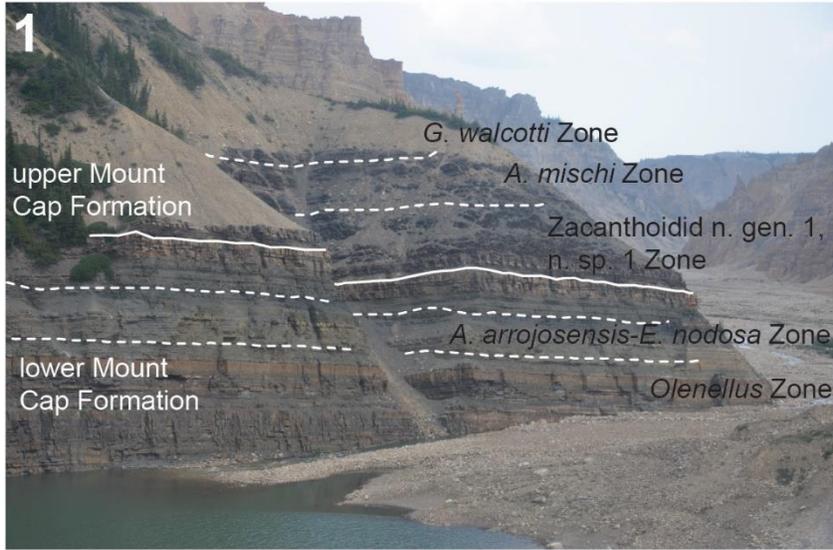


Figure 2.2. Outcrop views of the Mount Clark, Mount Cap, and Neoproterozoic formations of the Canyon Ranges, Northwest Territories. Solid lines indicate lithostratigraphic boundaries and dashed lines indicate biostratigraphic boundaries. **(1)** Section at Dodo Canyon of the lower and upper Mount Cap Formation. Stratal thickness=73.9 m. The Mount Cap Formation-Saline River Formation contact is exposed further downriver (towards the photo). Central talus cone covers normal faults. **(2)** Section at Inlin Brook of the Mount Clark and upper Mount Cap formations exposed in an overturned anticline. Stratal thickness of Cambrian formations=18.3 m. The top of the section is marked where debris covers the Mount Cap Formation. **(3)** Upper Mount Cap Formation exposed at Carcajou Falls. Stratal thickness=28.2 m. The section was measured further upriver where there is better access (away from the photo).

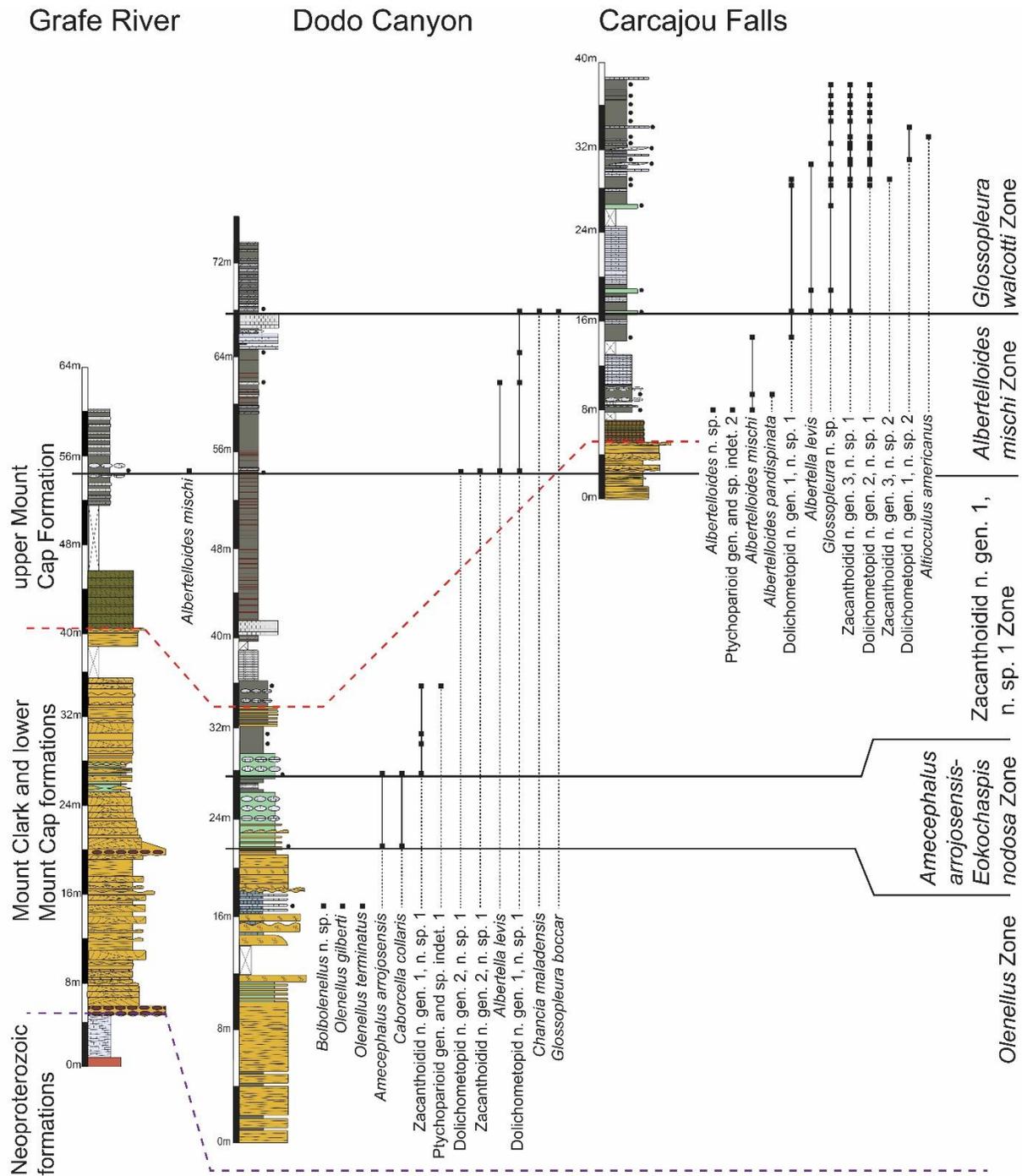


Figure 2.3. Measured sections of the Mount Clark, lower and upper Mount Cap formations exposed at Dodo Canyon, Carcajou Falls, and Grafe River. Black dots beside stratigraphic sections denote sampling horizons. The legend for the stratigraphic columns is in Fig. 2.4.

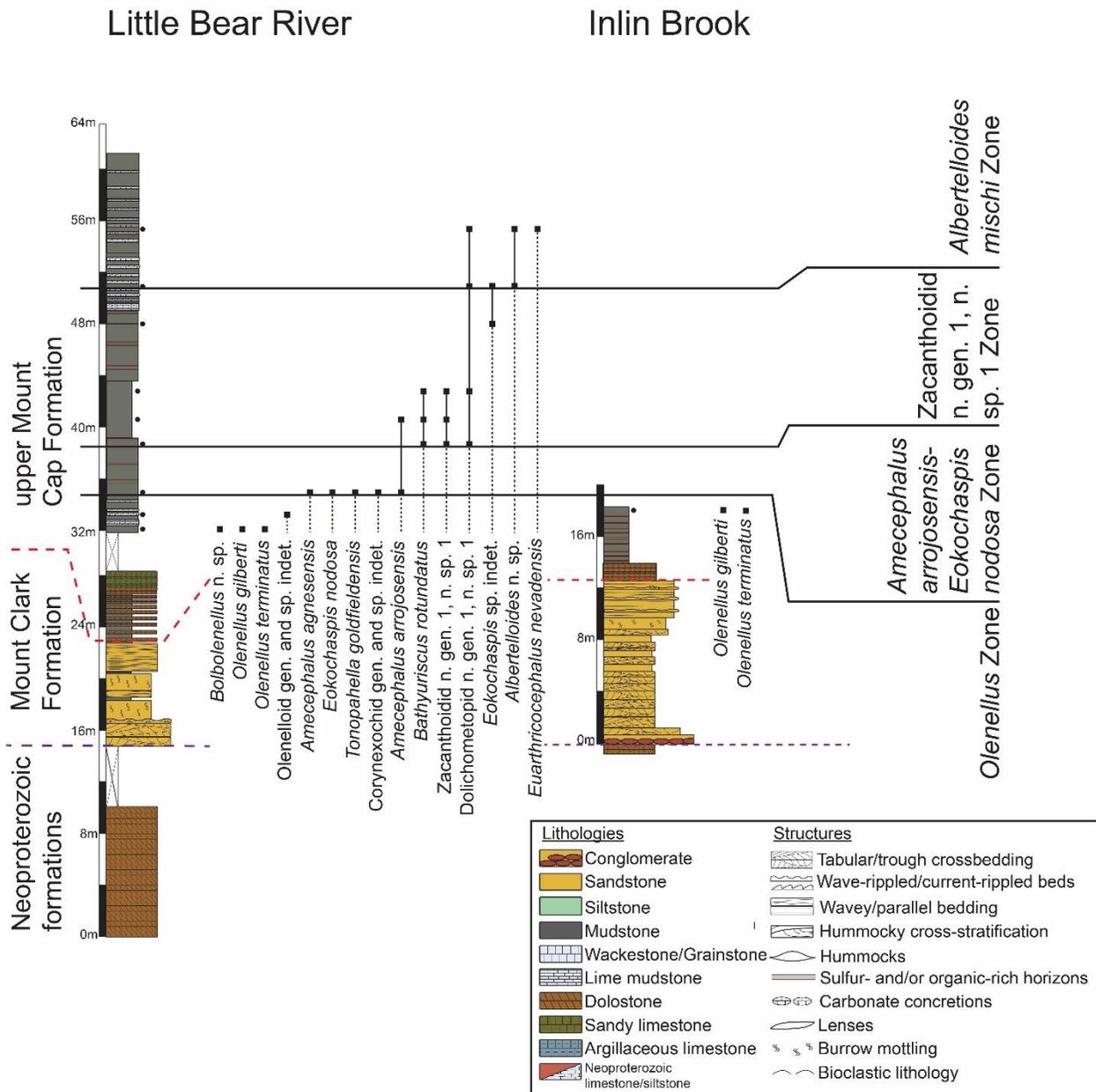


Figure 2.4. Measured sections of the Mount Clark and upper Mount Cap formations exposed at Little Bear River and Inlin Brook. Black dots beside stratigraphic sections denotes sampling horizons.

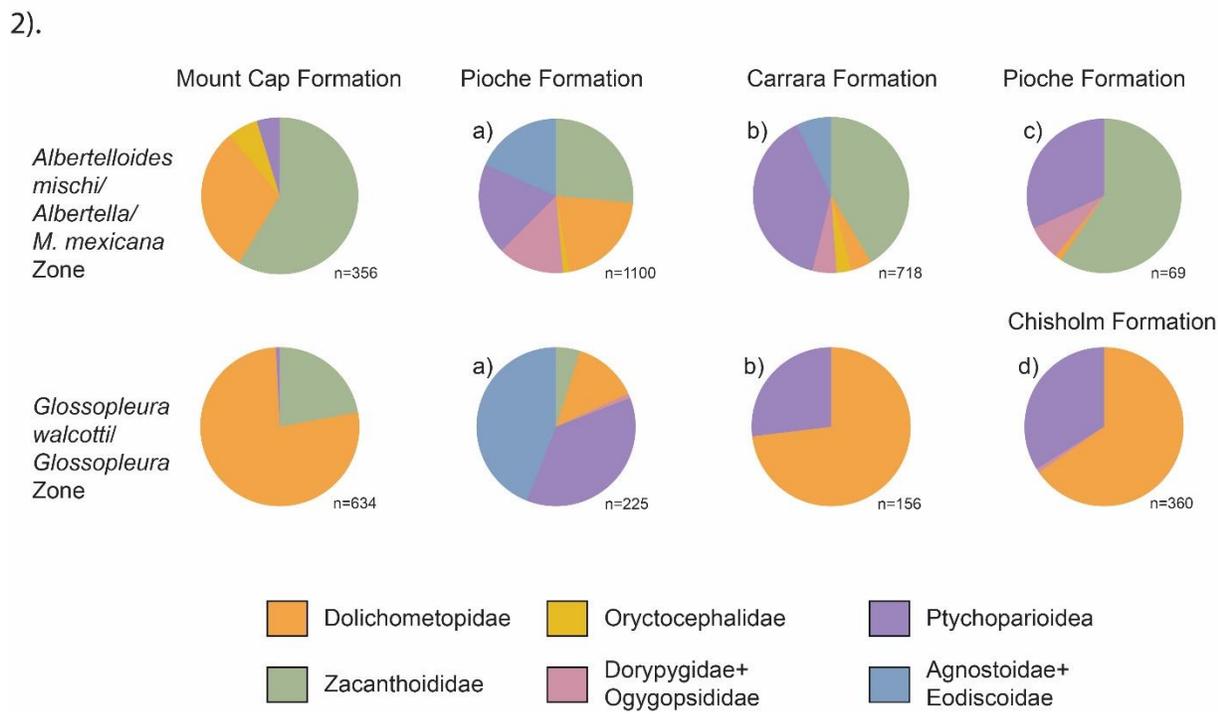
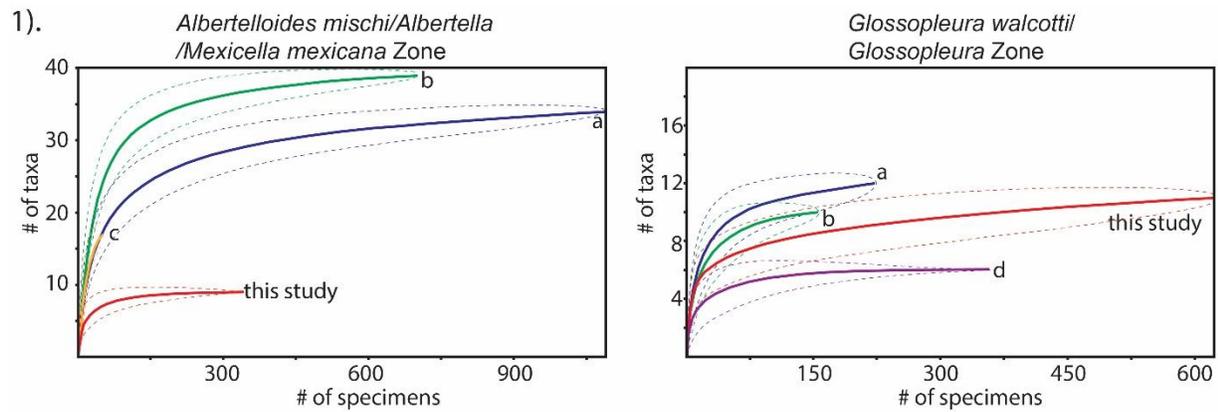


Figure 2.5. Quantified paleoecology of the trilobite faunas from the *Albertelloides mischi/Albertella/Mexicella mexicana* and *Glossopleura walcottii/Glossopleura* zones of the upper Mount Cap, Pioche, Chisholm, and Carrara formations. (1) Simple rarefaction curves of collections. Dashed lines denote 95% confidence intervals. (2) Abundance of trilobite groups. Individual cranidia and pygidia, partially complete specimens, and complete specimens were all given equal value in the abundance count. Counts from the Great Basin are compiled from (a) Fritz, 1968; (b) Palmer and Halley, 1979; (c) Eddy and McCollum, 1998; and (d) Sundberg, 2005.

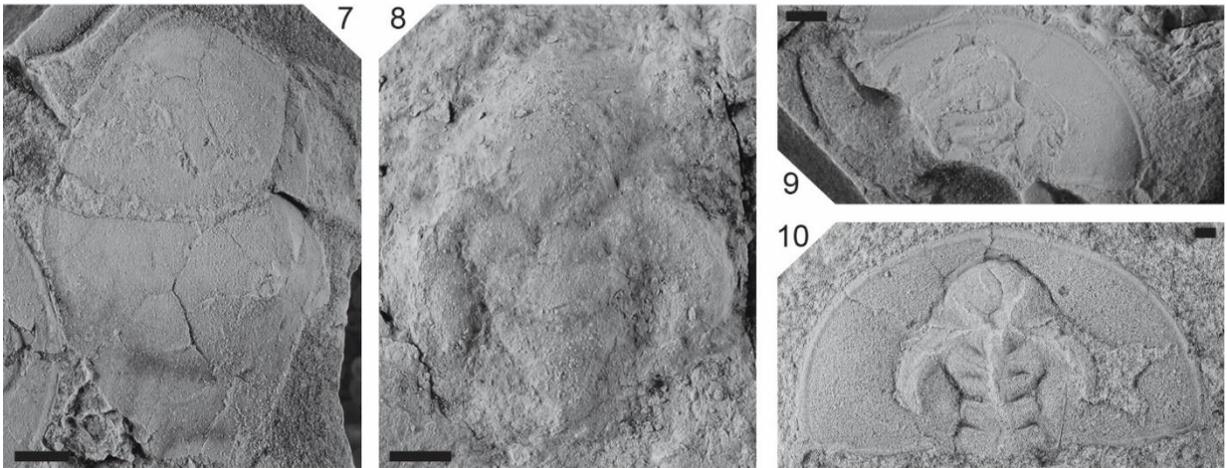
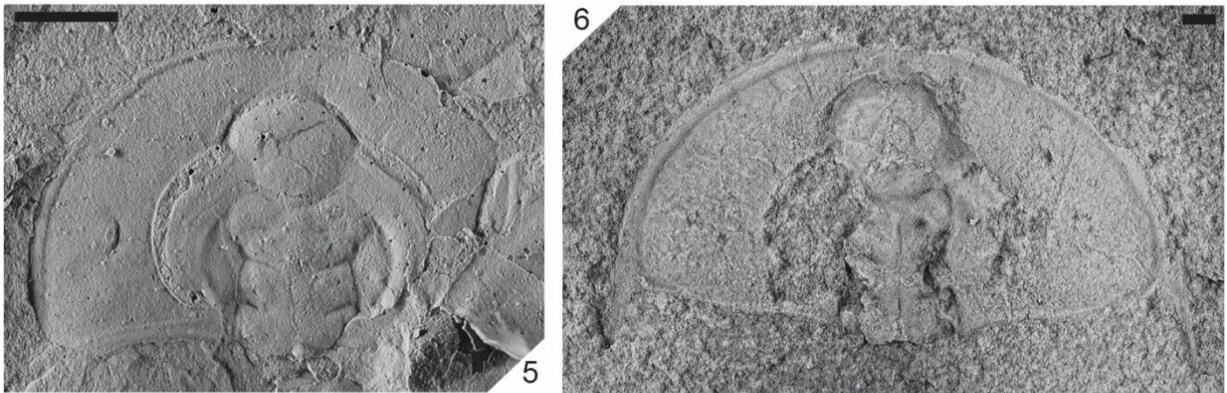
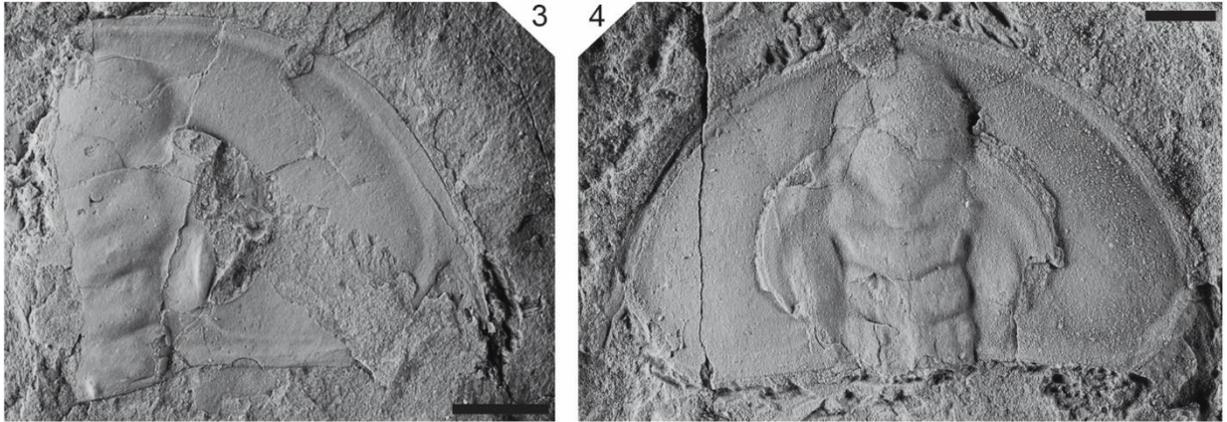
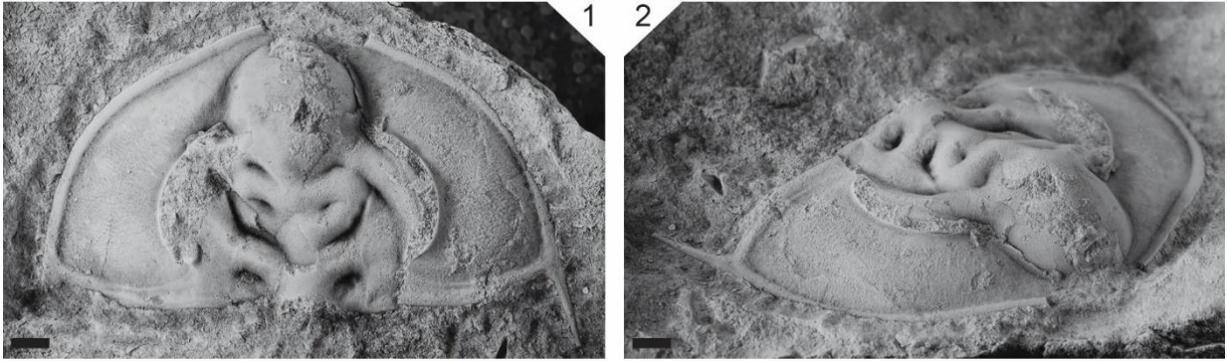


Figure 2.6. Species of *Olenellus* Hall, 1861 from the *Olenellus* Zone, Northwest Territories: (1–4, 6 and 10) *Olenellus gilberti* Meek, 1874; (1, 2) cephalon (dorsal, oblique) GSC 142281, sandy limestone, lower Mount Cap Formation, Dodo Canyon; (3) partially complete cephalon (dorsal) GSC 142282, silty mudstone, upper Mount Cap Formation, Inlin Brook; (4) fractured cephalon (dorsal) GSC 142283, silty mudstone, upper Mount Cap Formation, Inlin Brook; (6) cephalon (dorsal) GSC 142284, sandstone, Mount Clark Formation, 12-MWB-05; (10) cephalon (dorsal) GSC 142285, carbonate, upper Mount Cap Formation, 12-MWB-06; (5, 7 and 9) *O. terminatus* Palmer, 1998b; (5) cephalon (dorsal, latex cast) GSC 142286, silty mudstone, upper Mount Cap Formation, Little Bear River; (7) possible fractured hypostome (dorsal) GSC 142287, silty mudstone, upper Mount Cap Formation, Inlin Brook; (9) partially complete cephalon (dorsal) GSC 142287, silty mudstone, upper Mount Cap Formation, Inlin Brook; (8) olenellid gen. and sp. indet., partially complete cephalon (dorsal) GSC 142288, lime mudstone, upper Mount Cap Formation, Little Bear River. All scale bars=2 mm.

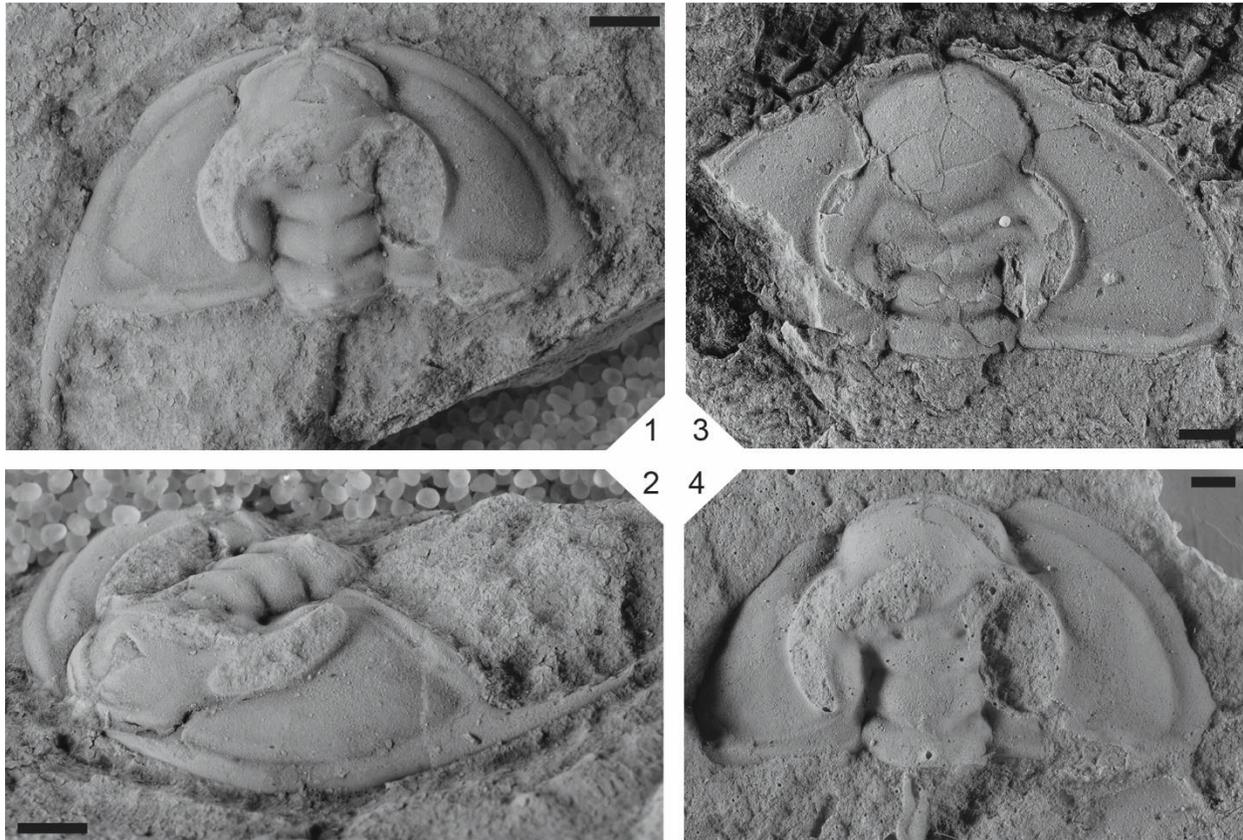


Figure 2.7. *Bolbolenellus* n. sp. from the *Olenellus* Zone, Northwest Territories: (1, 2) holotype cephalon (dorsal, oblique) GSC 142289, sandy limestone, lower Mount Cap Formation, Dodo Canyon; (3) partially complete paratype cephalon (dorsal) GSC 142290, silty mudstone, upper Mount Cap Formation, Little Bear River; (4) paratype cephalon (dorsal, latex mold) GSC 142291, sandy limestone, lower Mount Cap Formation, Dodo Canyon. All scale bars=2 mm.

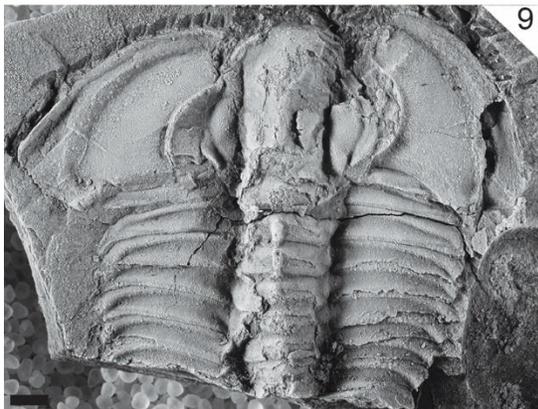
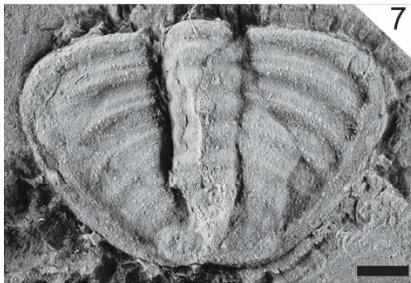
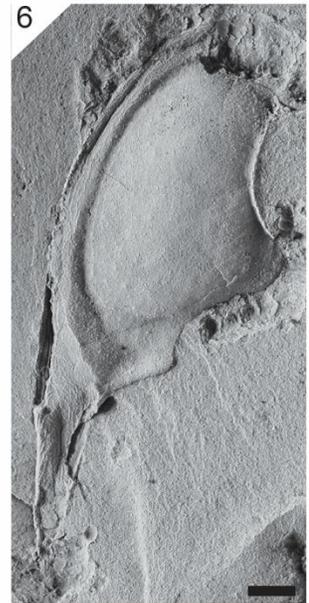
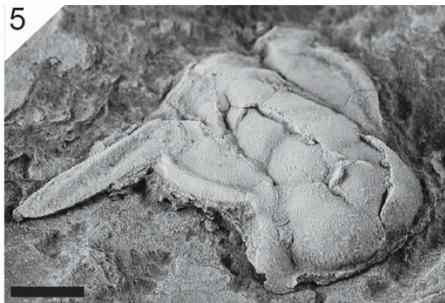
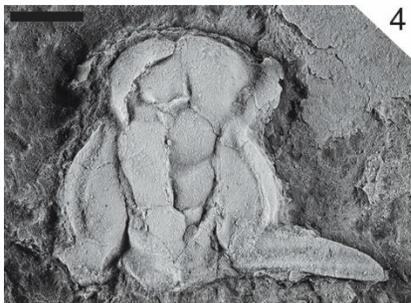


Figure 2.8. *Bathyriscus rotundatus* (Rominger, 1887) from the Zacanthoidid n. gen. 1, n. sp. 1 Zone, mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories: **(1–3)** nearly complete exoskeleton (dorsal, lateral, oblique) GSC 142292; **(4, 5)** cranidium (dorsal, oblique) GSC 142293; **(6)** free cheek, (dorsal) GSC 142294; **(7, 8)** pygidium (dorsal, oblique) GSC 142295; **(9, 10)** nearly complete exoskeleton, (dorsal, oblique) GSC 142296. All scale bars=2 mm.

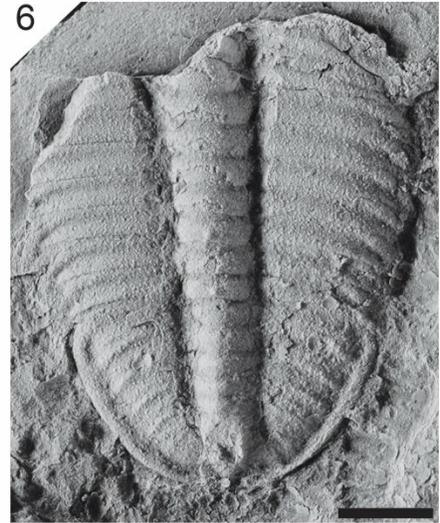
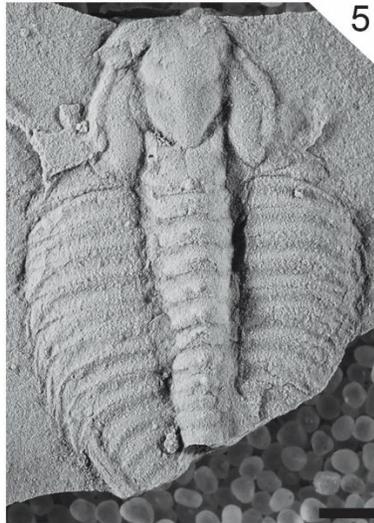
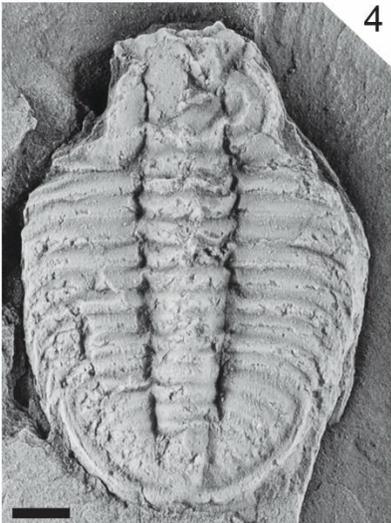
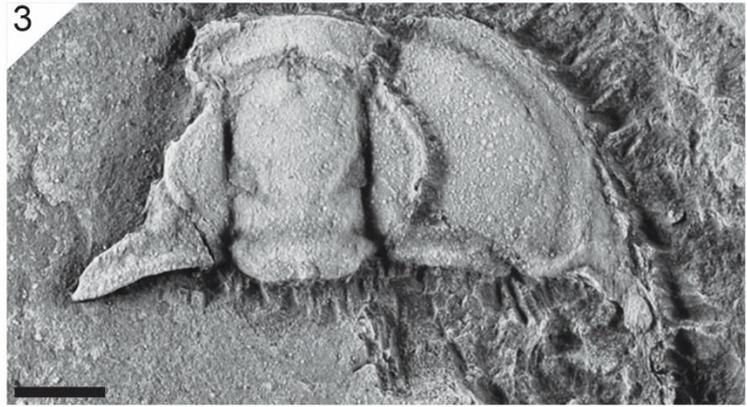
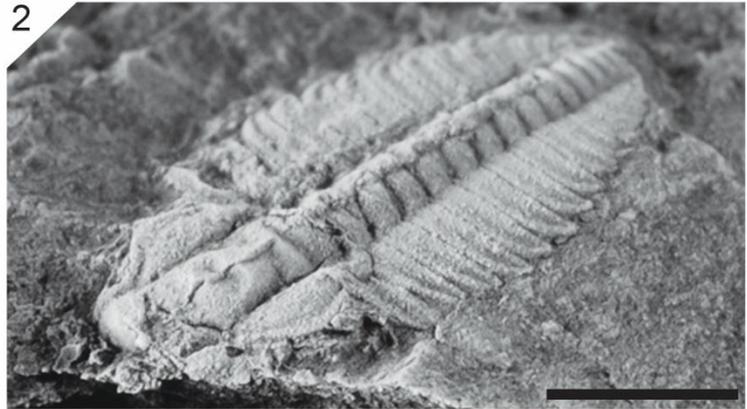
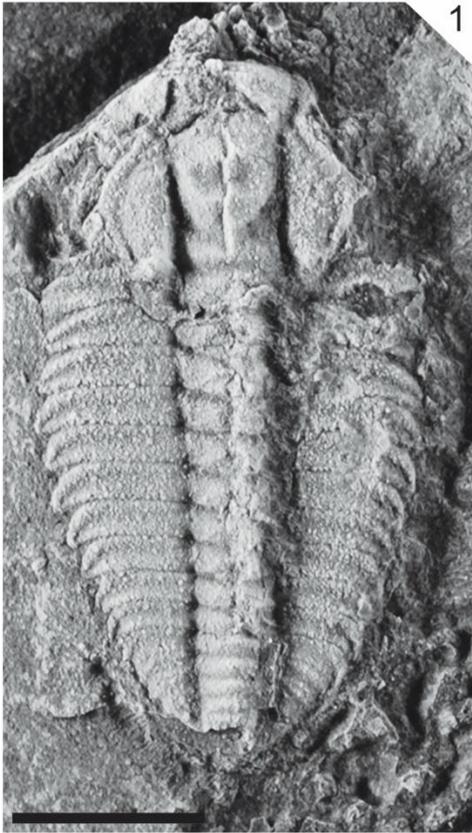


Figure 2.9. *Bathyriscus rotundatus* (Rominger, 1887) from the Zacanthoidid n. gen. 1, n. sp. 1 Zone, mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories: **(1, 2)** early holaspid exoskeleton lacking free cheeks (dorsal, oblique) GSC 142297; **(3)** cranidium with one free cheek (dorsal) GSC 142298; **(4)** exoskeleton lacking free cheeks (dorsal) GSC 142299; **(5)** exoskeleton lacking free cheeks (dorsal) GSC 142300; **(6)** articulated thorax and pygidium (dorsal) GSC 142294. All scale bars= 2 mm.

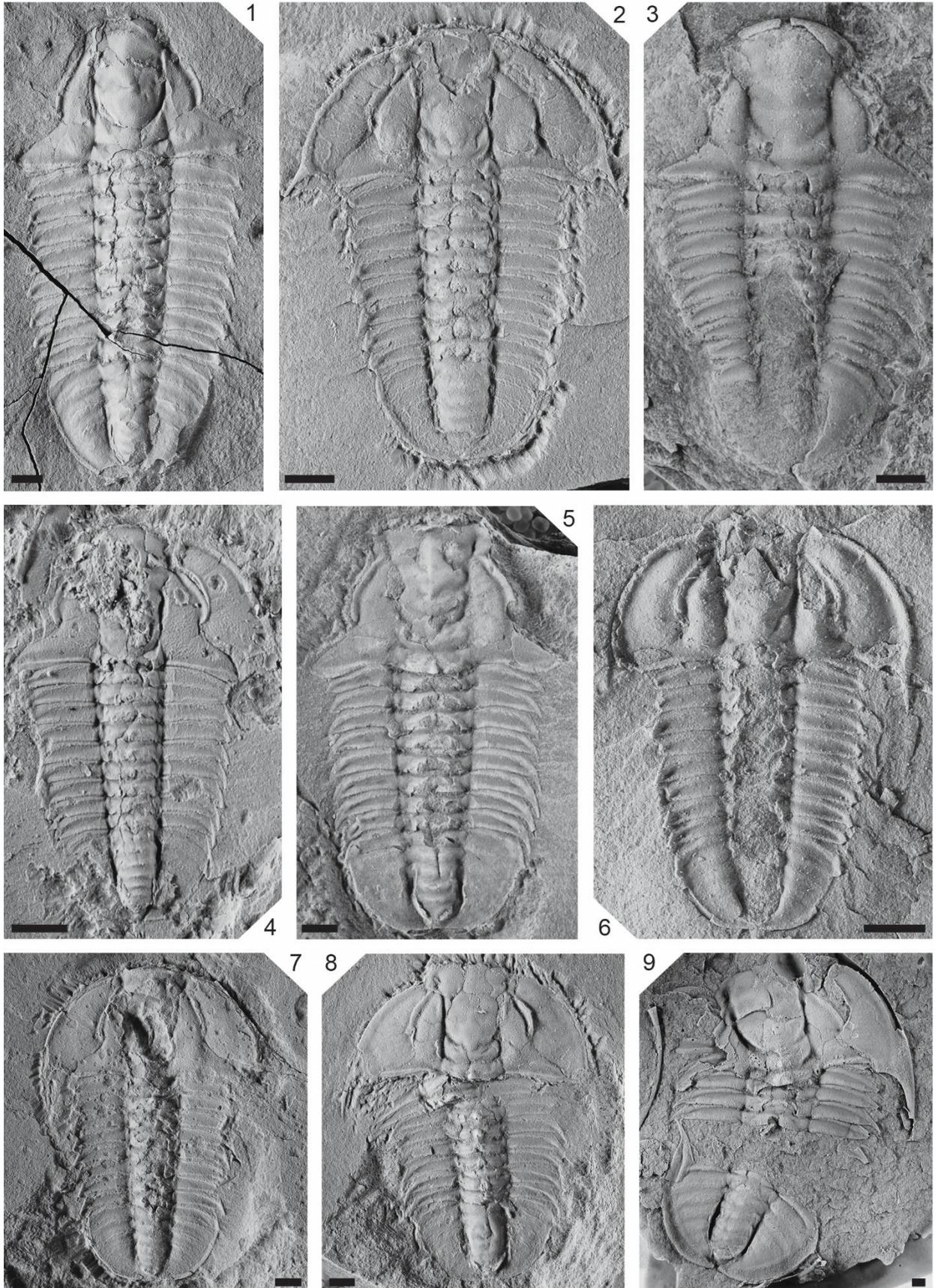


Figure 2.10. Dolichometopid n. gen. 1, n. sp. 1 from the upper Mount Cap Formation, Northwest Territories: (1) holotype exoskeleton lacking free cheeks (dorsal) GSC 142301, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (2) paratype complete exoskeleton (dorsal) GSC 142302, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (3) paratype exoskeleton lacking free cheeks (dorsal) GSC 142303, wackestone, Carcajou Falls, *Glossopleura walcotti* Zone; (4) paratype exoskeleton lacking a free cheek (dorsal) GSC 142304, mudstone, Little Bear River, *Albertelloides mischi* Zone; (5) paratype exoskeleton lacking free cheeks (dorsal) GSC 142305, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (6) paratype exoskeleton (dorsal) GSC 142306, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (7) paratype exoskeleton (dorsal) GSC 142307, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (8) paratype exoskeleton (dorsal) GSC 142308, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (9) disarticulated exoskeleton (dorsal, latex mold) GSC 142309, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone. All scale bars=2 mm.

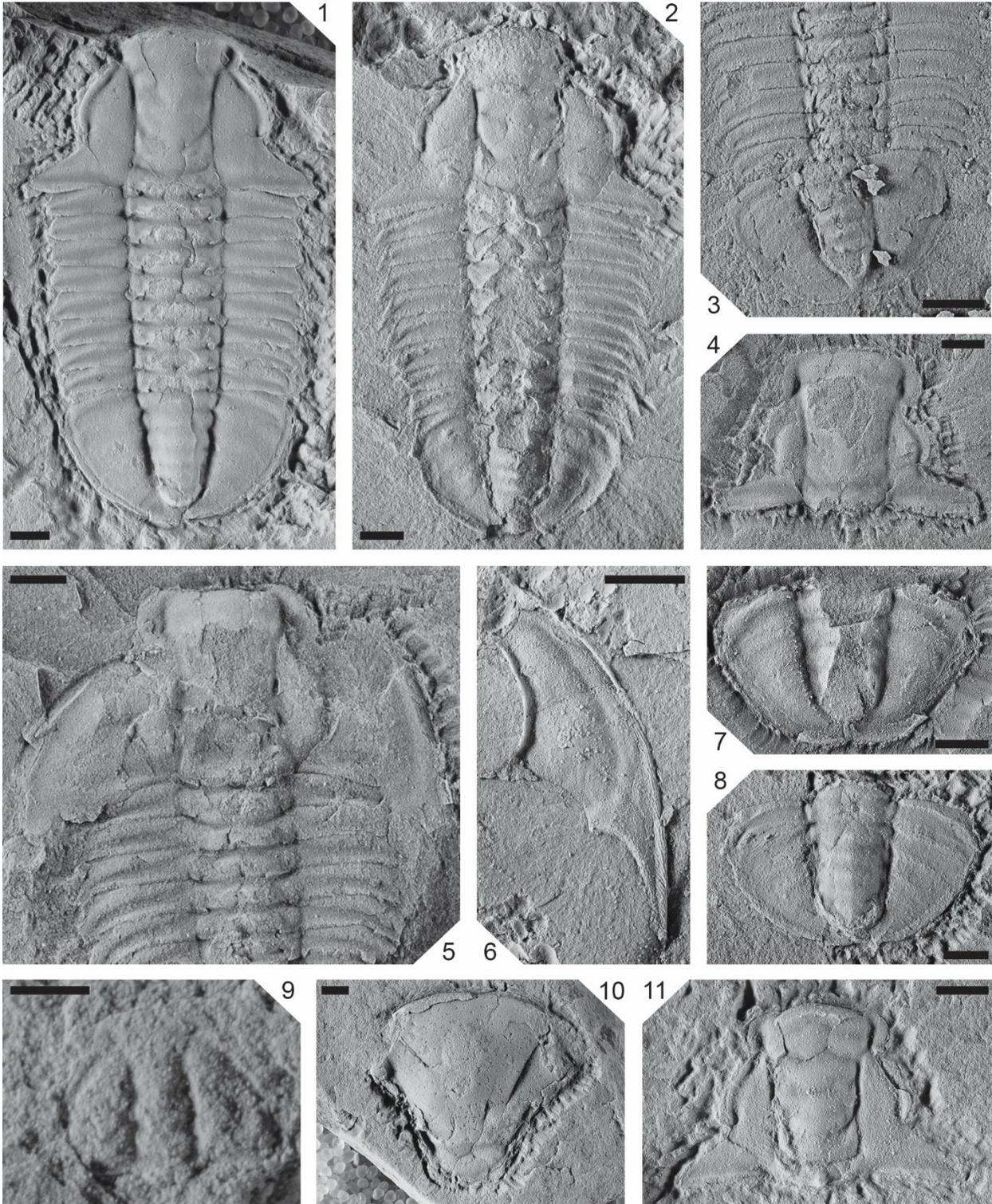


Figure 2.11. Dolichometopid n. gen. 1, n. sp. 1 from the upper Mount Cap Formation, Northwest Territories: (1) paratype exoskeleton lacking free cheeks (dorsal) GSC 142310, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (2) paratype exoskeleton lacking free cheeks (dorsal) GSC 142311, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (3) paratype disarticulated thorax and pygidium (dorsal) GSC 142312, siltstone, Carcajou Falls, *Glossopleura walcotti* Zone; (4) paratype cranidium (dorsal) GSC 142313, siltstone, Carcajou Falls, *Glossopleura walcotti* Zone; (5) paratype nearly complete exoskeleton (dorsal) GSC 142314, siltstone, Carcajou Falls, *Glossopleura walcotti* Zone; (6) paratype free cheek (dorsal) GSC 142315, mudstone, Little Bear River, *Albertelloides mischi* Zone; (7) paratype pygidium (dorsal) GSC 142316, siltstone, Carcajou Falls, *Glossopleura walcotti* Zone; (8) paratype pygidium (dorsal) GSC 142306, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; (9) paratype meraspid cranidium (dorsal) GSC 142317, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone, scale bar=500 μ m; (10) paratype hypostome (dorsal) GSC 142318, lime mudstone, Carcajou Falls, *Glossopleura walcotti* Zone, (11) paratype cranidium (dorsal) GSC 142319, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone. All scale bars=2 mm unless stated otherwise.

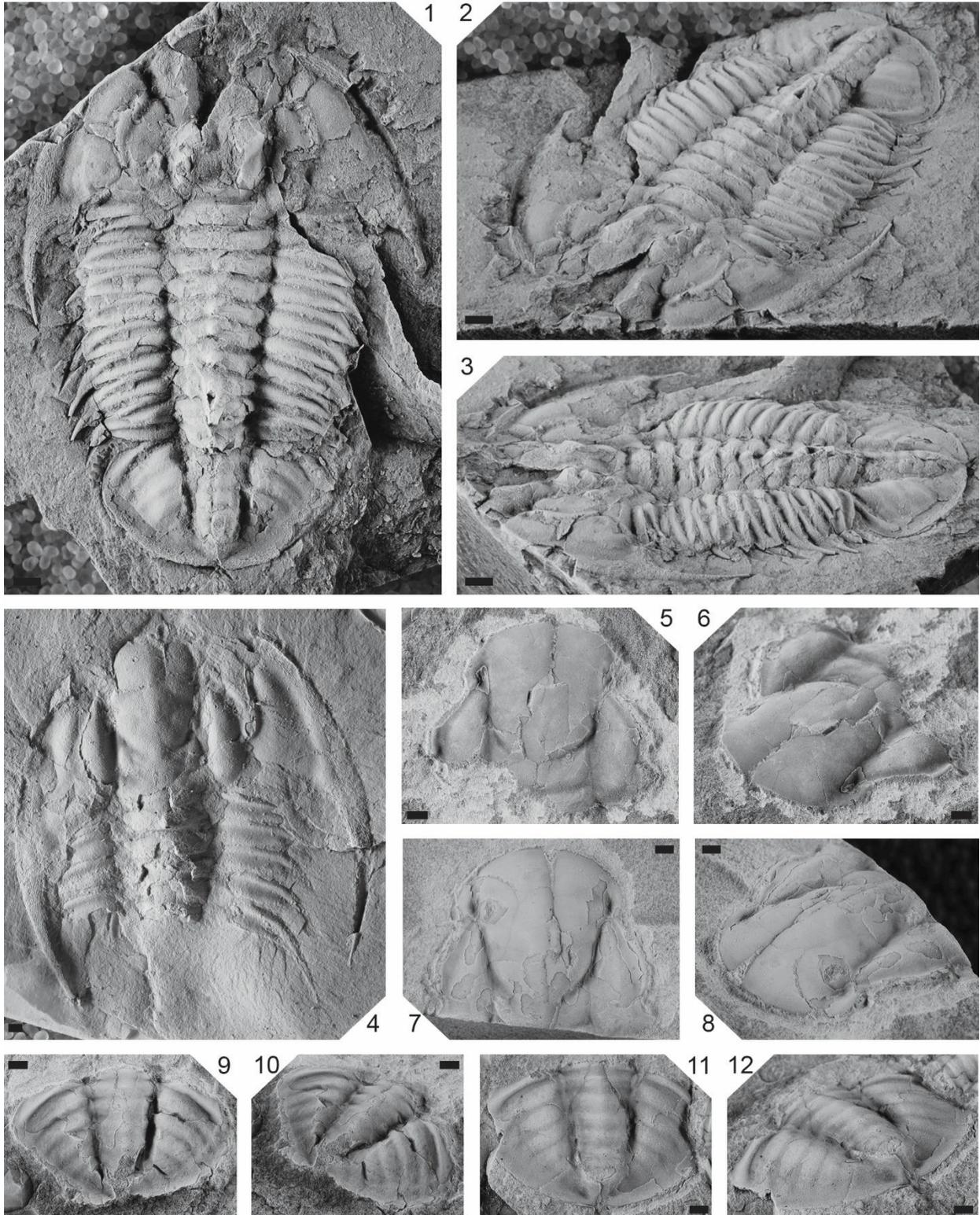


Figure 2.12. Dolichometopid n. gen. 1, n. sp. 2 from the *Glossopleura walcotti* Zone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: (1–3) holotype complete exoskeleton (dorsal, oblique, lateral) GSC 142320, lime mudstone; (4) paratype nearly complete exoskeleton (dorsal, latex mold) GSC 142321, lime mudstone; (5, 6) paratype cranidium (dorsal, oblique) GSC 142322, lime mudstone; (7, 8) paratype cranidium (dorsal, oblique) GSC 142323, wackestone; (9, 10) paratype pygidium (dorsal, oblique) GSC 142324, lime mudstone; (11, 12) paratype pygidium (dorsal, oblique) GSC 142323; wackestone. All scale bars=2mm

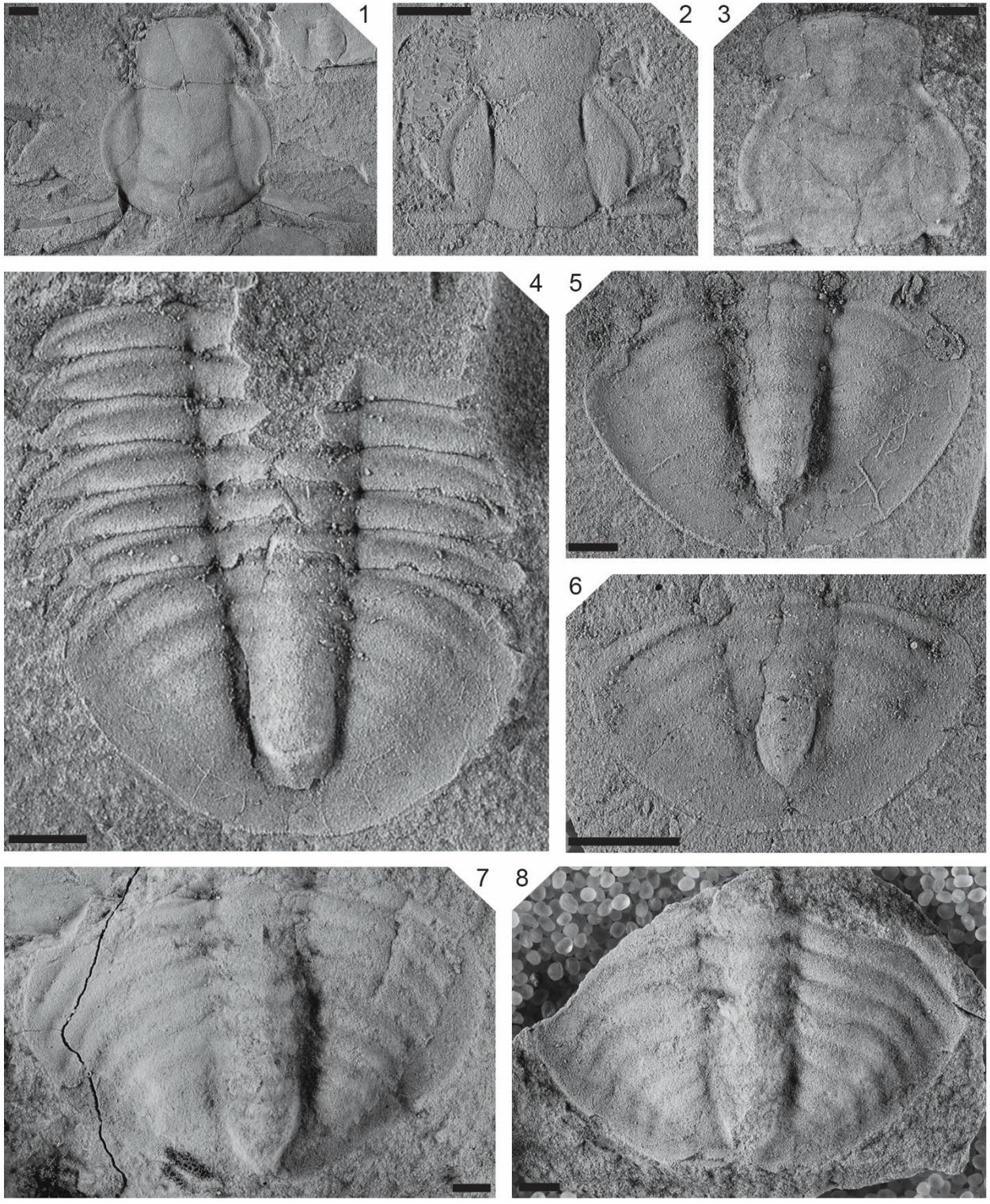


Figure 2.13. Dolichometopids from the *Glossopleura walcotti* Zone, upper Mount Cap Formation, Northwest Territories: **(1–6)** *Glossopleura boccar* (Walcott, 1916b), Dodo Canyon; **(1)** cranidium (dorsal) GSC 142324, mudstone; **(2)** cranidium (dorsal) GSC 142325, mudstone; **(3)** cranidium (dorsal) GSC 142326, lime mudstone; **(4)** partially complete exoskeleton lacking the cephalon (dorsal) GSC 143327, mudstone; **(5)** pygidium (dorsal) GSC 142328, mudstone; **(6)** pygidium (dorsal) GSC 142329, mudstone; **(7, 8)** *Polypleuraspis solitaria* Poulsen, 1927, lime mudstone, 12-MWB-04; **(7)** pygidium (dorsal) GSC 142330; **(8)** pygidium (dorsal) GSC 142331. All scale bars=2 mm.

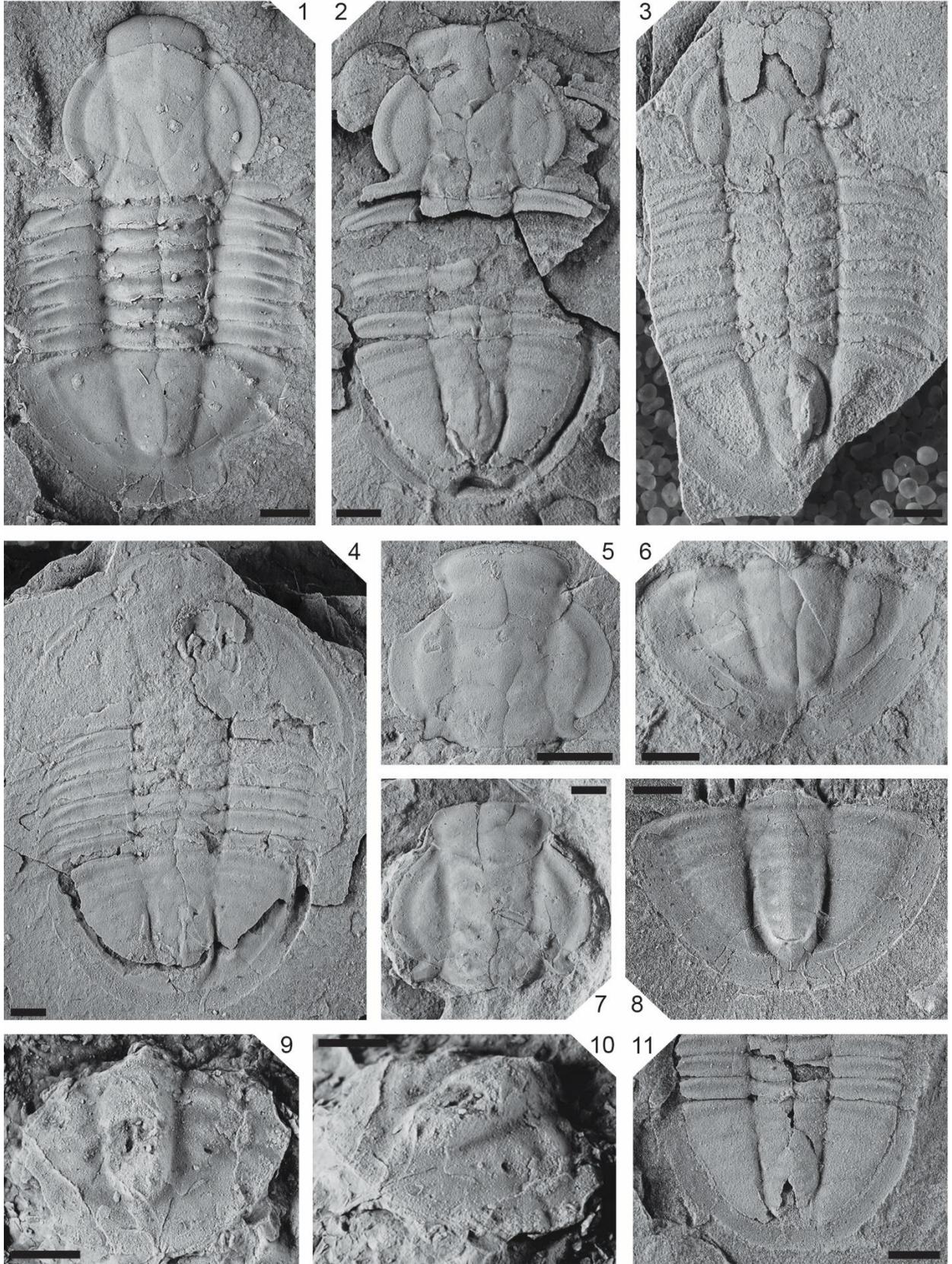


Figure 2.14. *Glossopleura* n. sp. from the *Glossopleura walcotti* Zone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: (1) holotype exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142332, mudstone; (2) paratype nearly complete exoskeleton (dorsal) GSC 142333, mudstone; (3) paratype partially complete exoskeleton (dorsal) GSC 142334, mudstone; (4) paratype complete exoskeleton (dorsal) GSC 142335, mudstone; (5) paratype cranidium (dorsal) GSC 142336, mudstone; (6) paratype pygidium (dorsal) GSC 142337, mudstone; (7) paratype cranidium (dorsal) GSC 142338, mudstone; (8) paratype pygidium (dorsal) GSC 142339, mudstone; (9, 10) paratype pygidium (dorsal) GSC 142340, grainstone; (11) paratype articulated pygidium and thorax (dorsal) GSC 142341, mudstone. All scale bars=2 mm.

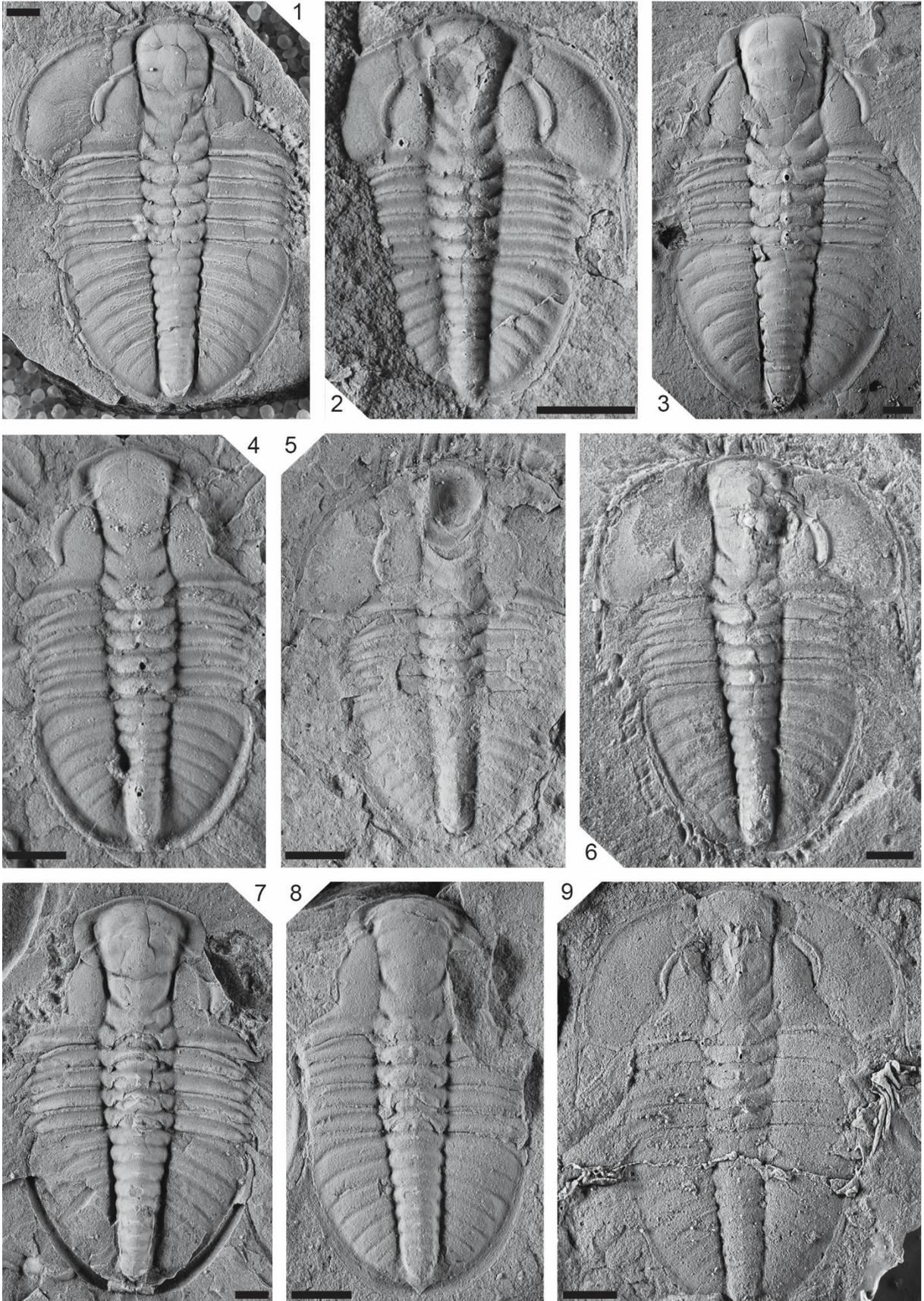


Figure 2.15. Dolichometopid n. gen. 2, n. sp. 1 from the *Glossopleura walcotti* Zone, mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: (1) holotype exoskeleton lacking a free cheek (dorsal) GSC 142342; (2) paratype complete exoskeleton (dorsal, latex mold) GSC 142343; (3) paratype exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142344; (4) paratype exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142345; (5) paratype nearly complete exoskeleton (dorsal) GSC 142346; (6) paratype complete exoskeleton (dorsal) GSC 142347; (7) paratype exoskeleton lacking free cheeks (dorsal) GSC 142348; (8) paratype exoskeleton lacking free cheeks (dorsal) GSC 142349; (9) paratype complete exoskeleton (dorsal, latex mold) GSC 142350. All scale bars=2 mm.

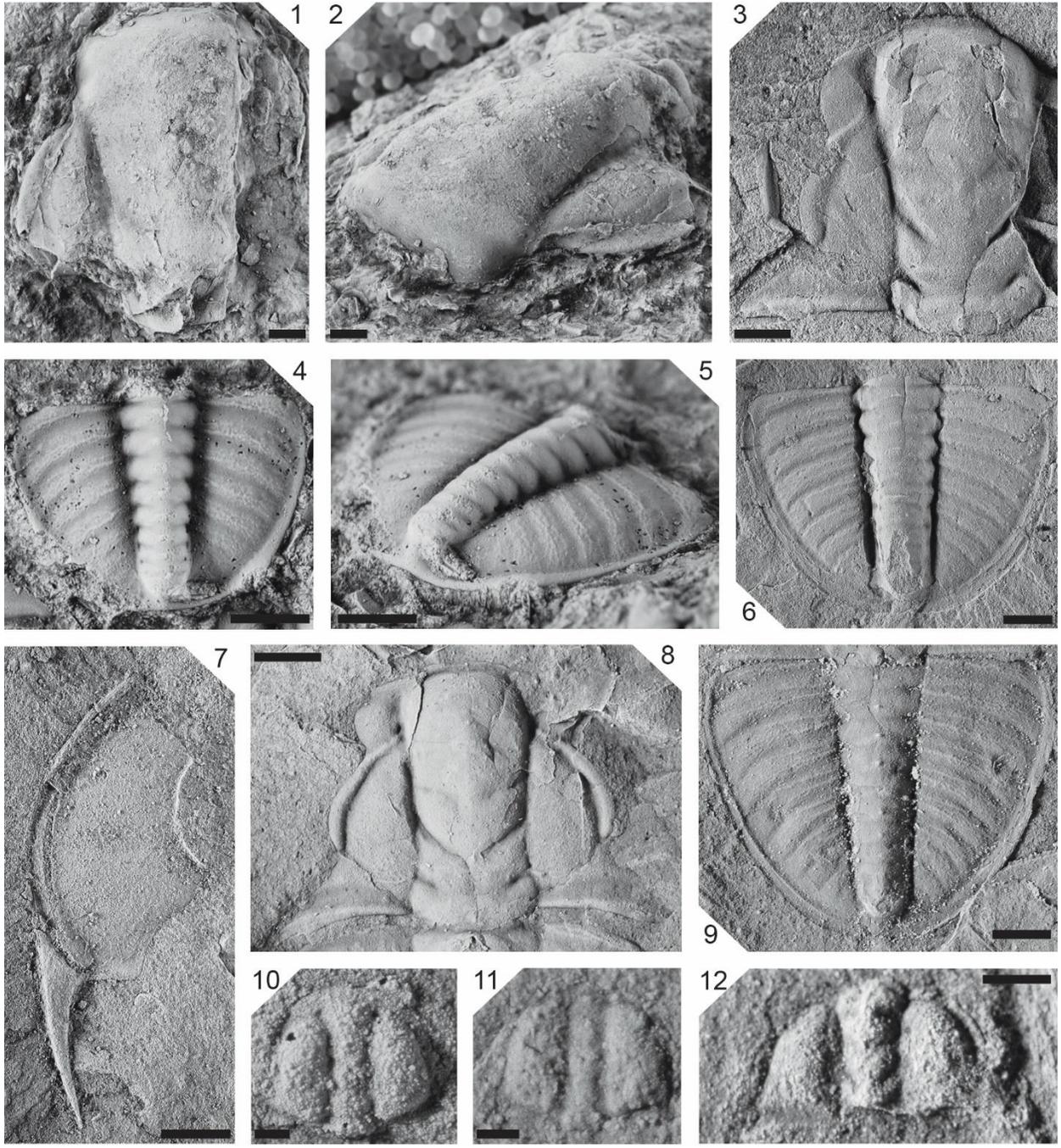


Figure 2.16. Dolichometopid n. gen. 2, n. sp. 1 from the *Glossopleura walcotti* Zone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: **(1, 2)** paratype cranidium (dorsal, oblique) GSC 142351, grainstone; **(3)** paratype cranidium (dorsal) GSC 142352, mudstone; **(4, 5)** paratype pygidium (dorsal, oblique) GSC 142353, grainstone; **(6)** paratype pygidium (dorsal) GSC 142354; mudstone; **(7)** paratype free cheek (dorsal) GSC 142355, mudstone; **(8)** paratype cranidium (dorsal) GSC 142356, mudstone; **(9)** paratype pygidium (dorsal) GSC 142357, mudstone; **(10)** paratype early meraspid cranidium (dorsal) GSC 142358, mudstone, scale bar=125 μm ; **(11)** paratype protaspid (dorsal) GSC 142359, mudstone, scale bar=125 μm ; **(12)** paratype late meraspid cranidium (dorsal) GSC 142360, mudstone, scale bar=500 μm . All scale bars=2 mm unless stated otherwise.

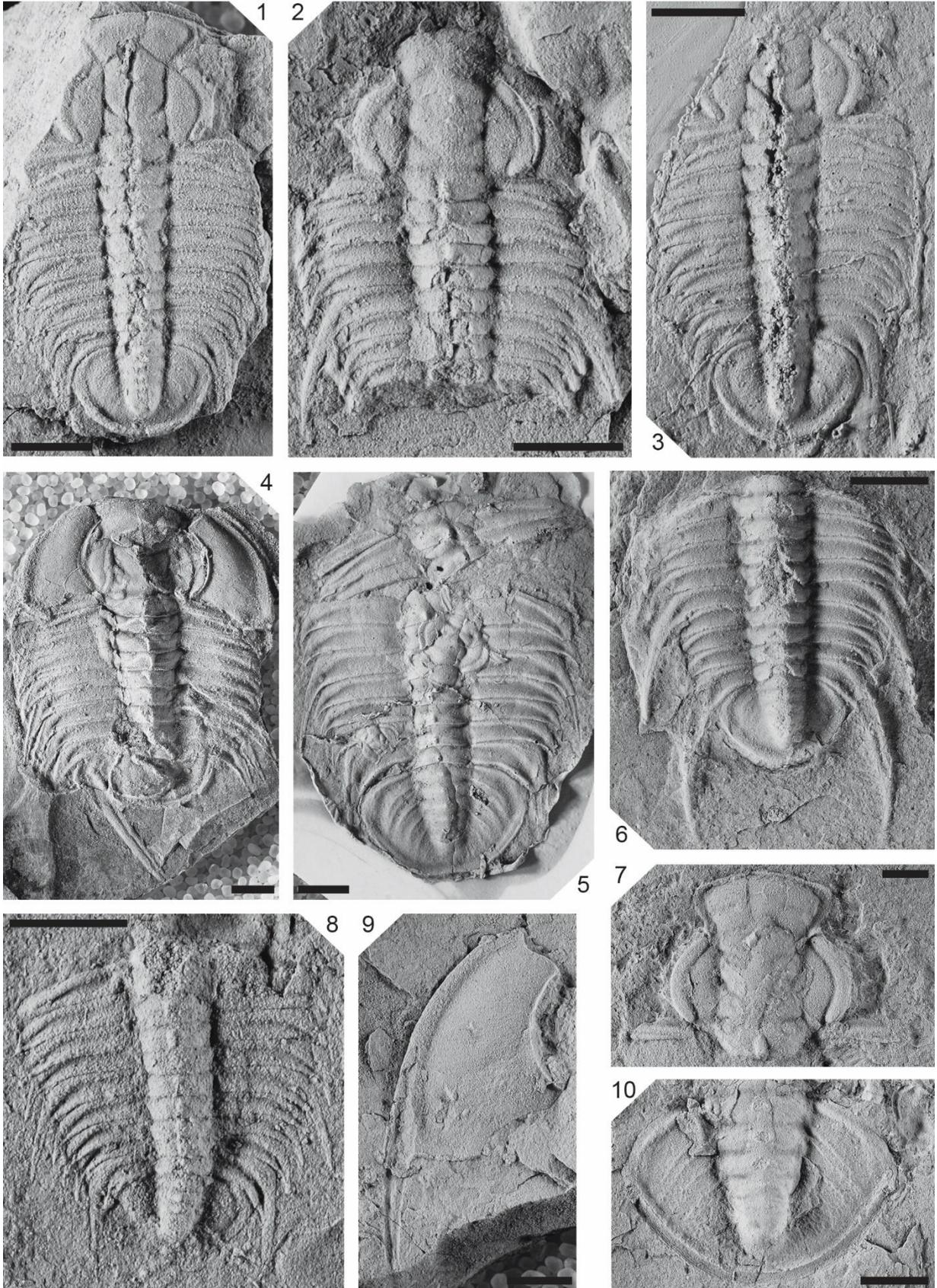


Figure 2.17. Zacanthoidid n. gen. 1, n. sp. 1 from the Zacanthoidid n. gen. 1, n. sp. 1 Zone, mudstone, upper Mount Cap Formation, Little Bear River, Northwest Territories: (1) holotype exoskeleton lacking free cheeks (dorsal) GSC 142361; (2) paratype exoskeleton lacking free cheeks and the pygidium (dorsal) GSC 142362; (3) paratype exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142363; (4) paratype nearly complete exoskeleton (dorsal) GSC 142364; (5) paratype exoskeleton lacking the cephalon (dorsal, latex mold) GSC 142365; (6) paratype exoskeleton lacking the cephalon (dorsal) GSC 142366; (7) paratype cranidium (dorsal) GSC 142367; (8) paratype exoskeleton lacking the cephalon (dorsal) GSC 142368; (9) paratype free cheek (dorsal) GSC 142369; (10) paratype pygidium (dorsal) GSC 142370. All scale bars=2 mm

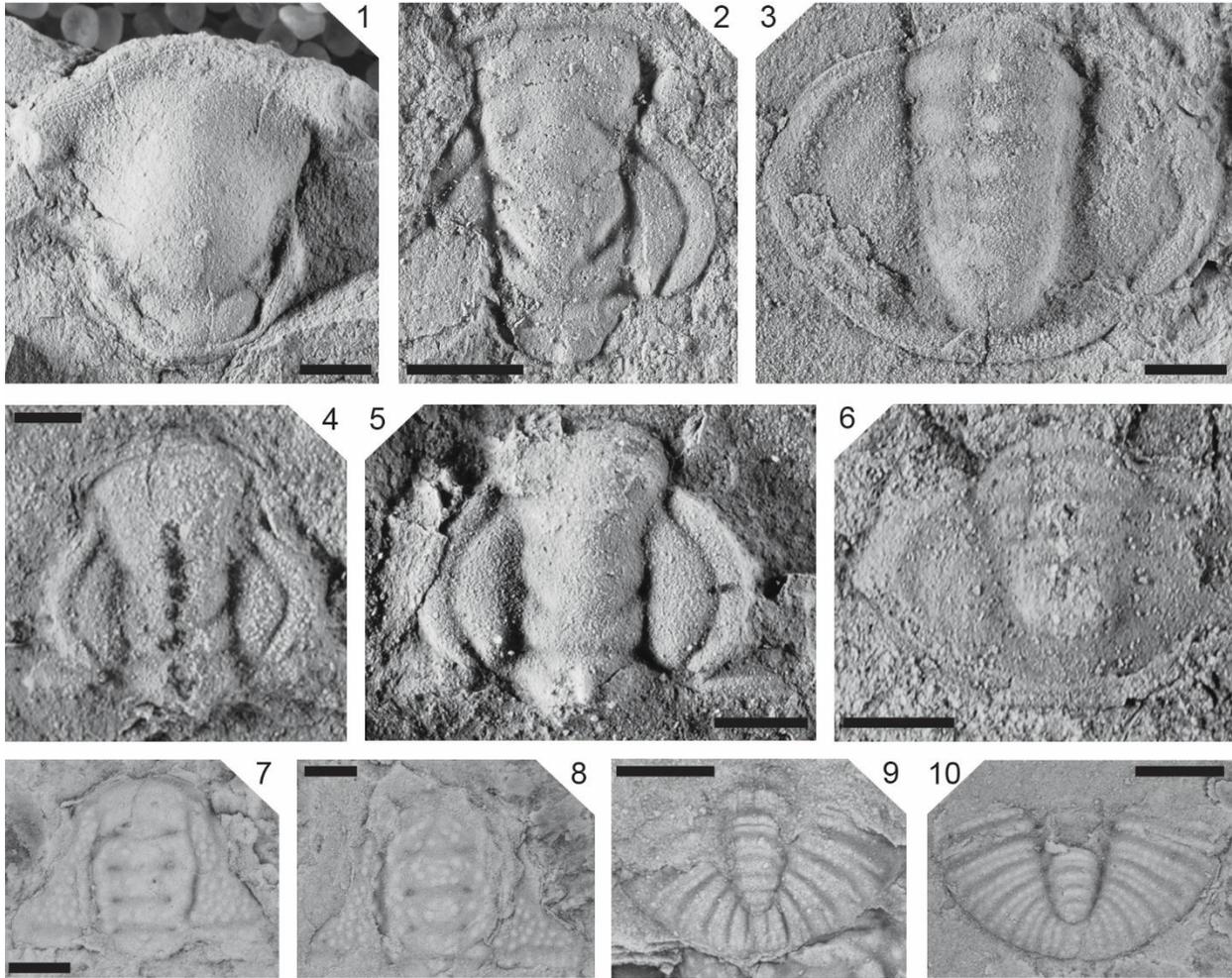


Figure 2.18. Corynexochids from the Mount Cap Formation, Northwest Territories: **(1–6)** Zacanthoidid n. gen. 1, n. sp. 1 from the Zacanthoidid n. gen. 1, n. sp. 1 Zone; **(1)** paratype hypostome (dorsal) GSC 142371, mudstone, upper Mount Cap Formation, Little Bear River; **(2)** paratype cranidium (dorsal, latex mold) GSC 142372, silty mudstone, lower Mount Cap Formation, Dodo Canyon; **(3)** paratype pygidium (dorsal) GSC 142373, siltstone, lower Mount Cap Formation, Dodo Canyon; **(4)** paratype cranidium (dorsal) GSC 142374, mudstone, upper Mount Cap Formation, Little Bear River, scale bar=500 μm ; **(5)** paratype cranidium (dorsal) GSC 142375, silty mudstone, upper Mount Cap Formation, Little Bear River, scale bar=1 mm; **(6)** paratype pygidium (dorsal) GSC 142376, siltstone, lower Mount Cap Formation, Dodo Canyon; **(7–10)** *Euarthrocephalus nevadensis* Sundberg and McCollum, 1997, mudstone, upper Mount Cap Formation, Little Bear River, *Albertelloides mischi* Zone; **(7)** cranidium (dorsal) GSC 142377, scale bar=350 μm ; **(8)** cranidium (dorsal) GSC 142378, scale bar=400 μm ; **(9)** pygidium (dorsal) GSC 142379, scale bar=500 μm ; **(10)** pygidium (dorsal) GSC 142377, scale bar=750 μm . All scale bars=2 mm unless stated otherwise.



Figure 2.19. Zacanthoidids from the upper Mount Cap Formation, Carcajou Falls, Northwest Territories: **(1–6)** *Albertella levis* Walcott, 1917a, *Glossopleura walcottii* Zone; **(1)** cranidium (dorsal) GSC 142380, silty mudstone; **(2, 3)** pygidium (dorsal, oblique) GSC 142381, grainstone; **(4)** cranidium (dorsal) GSC 142382, silty mudstone; **(5)** pygidium (dorsal) GSC 142383, silty mudstone; **(6)** pygidium (dorsal, latex mold) GSC 142384, silty mudstone; **(7–11)** *Albertelloides mischi* Fritz, 1968, silty mudstone, *Albertelloides mischi* Zone; **(7)** cranidium (dorsal) GSC 142385; **(8)** cranidium (dorsal) GSC 142386; **(9)** pygidium (dorsal) GSC 142387; **(10)** cranidium (dorsal) GSC 142388; **(11)** pygidium (dorsal) GSC 142389; **(12)** *Albertelloides pandispinata* Fritz, 1968, pygidium (dorsal) GSC 142390, silty mudstone, *Albertelloides mischi* Zone. All scale bars=2 mm.

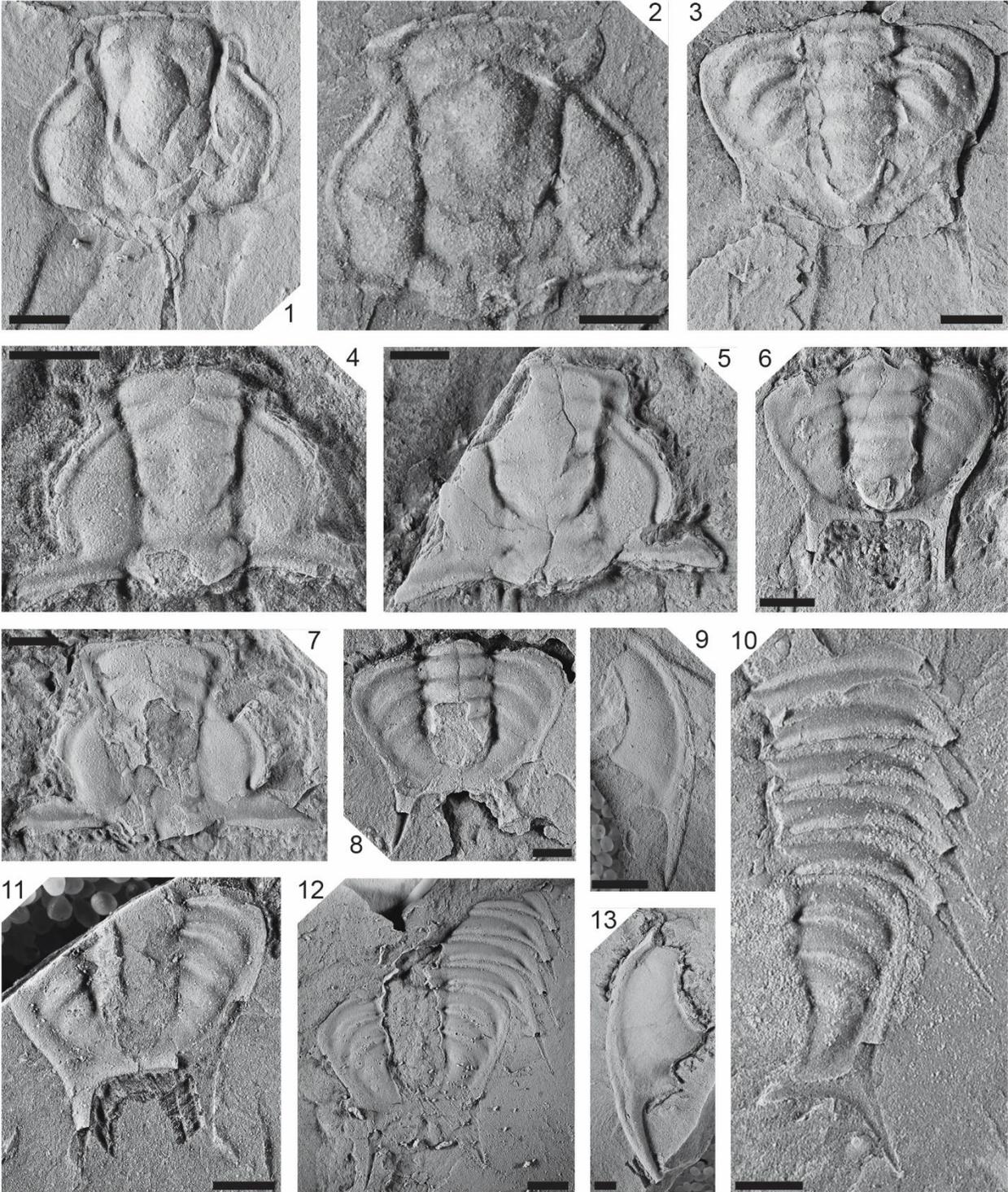


Figure 2.20. Species of *Albertelloides* Fritz, 1968 from the *Albertelloides mischi* Zone, silty mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: **(1–3)** *Albertelloides mischi* Fritz, 1968; **(1)** cranidium (dorsal, latex mold) GSC 142391; **(2)** cranidium (dorsal) GSC 142392; **(3)** pygidium (dorsal) GSC 142393; **(4–13)** *Albertelloides* n. sp.; **(4)** paratype cranidium (dorsal) GSC 142394; **(5)** paratype cranidium (dorsal) GSC 142395; **(6)** holotype pygidium (dorsal) GSC 142396; **(7)** paratype cranidium (dorsal) GSC 142397; **(8)** paratype pygidium (dorsal) GSC 142398; **(9)** paratype free cheek (dorsal) GSC 142399; **(10)** paratype partially articulated exoskeleton (dorsal) GSC 142400; **(11)** paratype pygidium (dorsal) GSC 142401; **(12)** paratype partially articulated exoskeleton (dorsal, latex mold) GSC 142402; **(13)** paratype free cheek (dorsal) GSC 142403. All scale bars=2 mm.

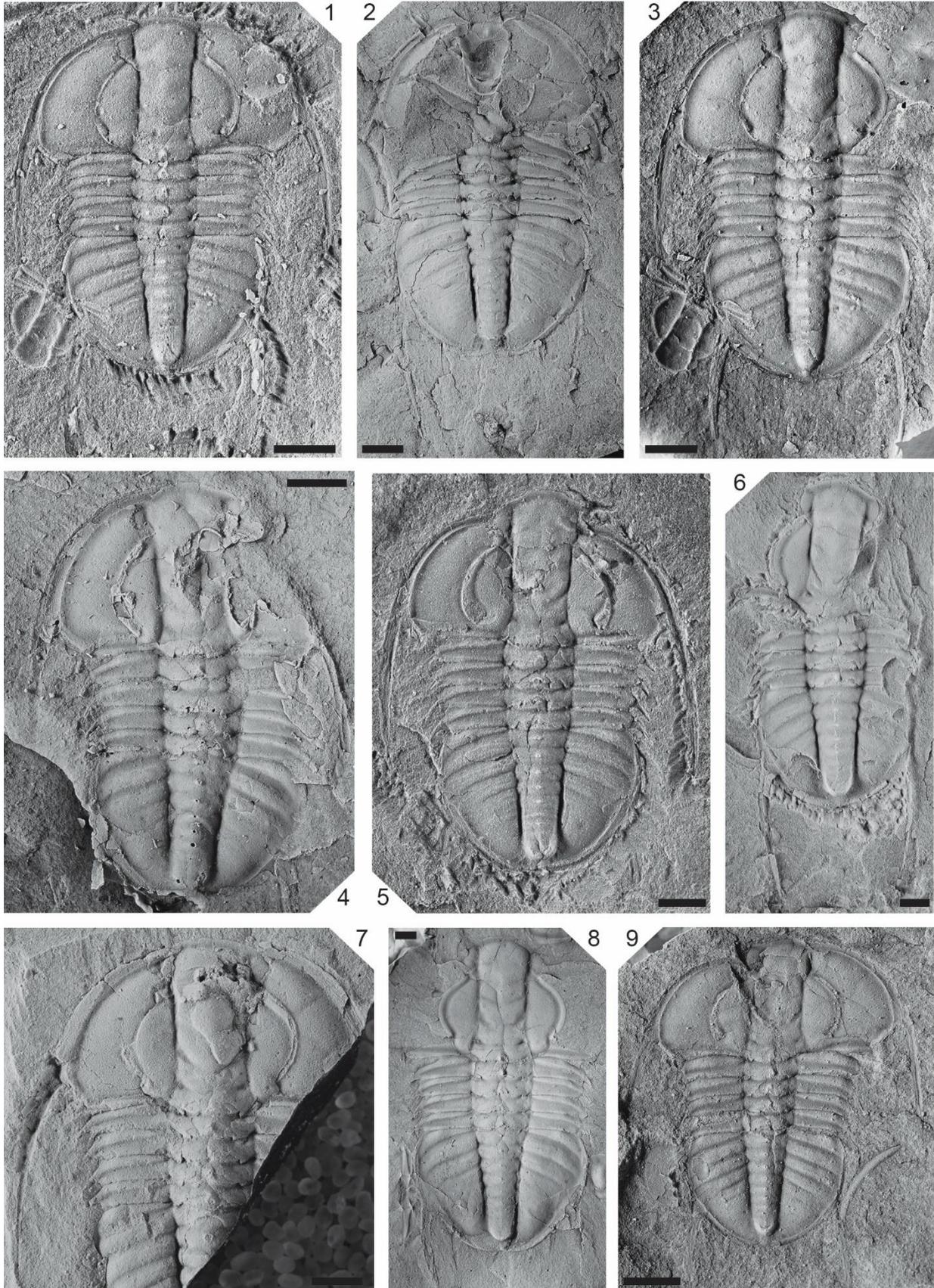


Figure 2.21. Zacanthoidid n. gen. 3, n. sp. 1 from the *Glossopleura walcotti* Zone, mudstone, upper Mount Cap Formation, Carcajou Falls, Northwest Territories: (1) holotype complete exoskeleton (dorsal) GSC 142404; (2) paratype fractured exoskeleton (dorsal) GSC 142405; (3) paratype complete exoskeleton (dorsal, latex mold) GSC 142406; (4) paratype complete exoskeleton (dorsal, latex mold) GSC 142407; (5) paratype complete exoskeleton (dorsal) GSC 142408; (6) paratype exoskeleton lacking free cheeks (dorsal) GSC 142409; (7) paratype fractured exoskeleton (dorsal) GSC 142410; (8) paratype exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142411; (9) paratype complete exoskeleton (dorsal) GSC 142412. All scale bars=2 mm.

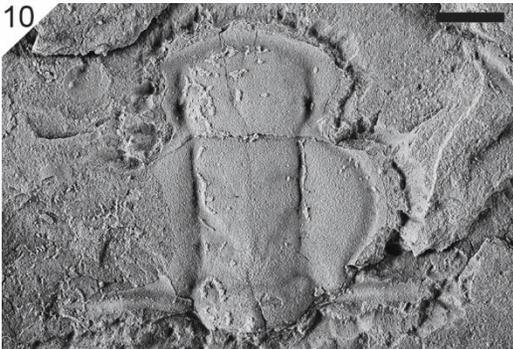
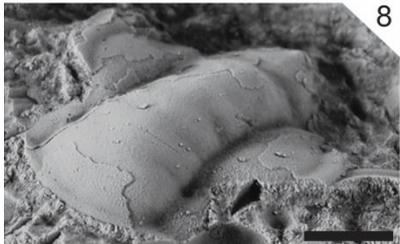
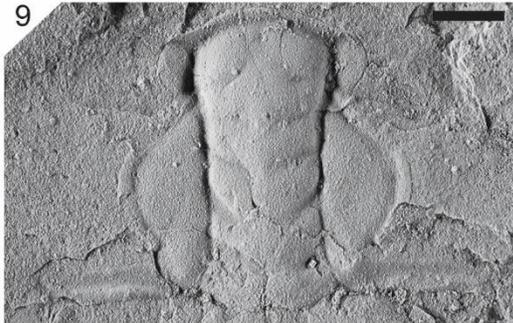
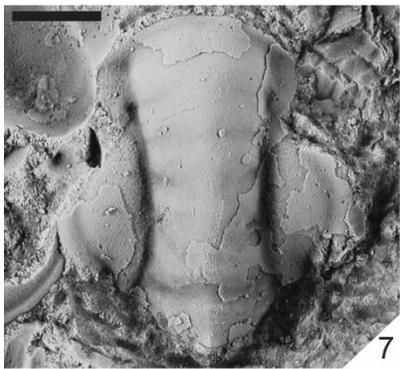
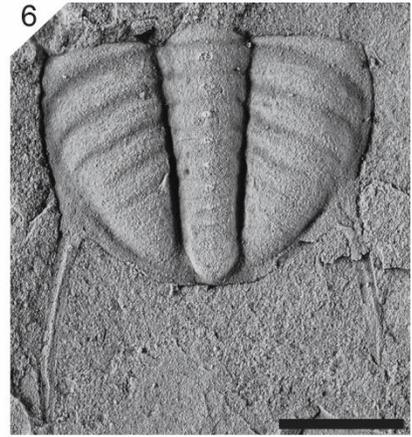
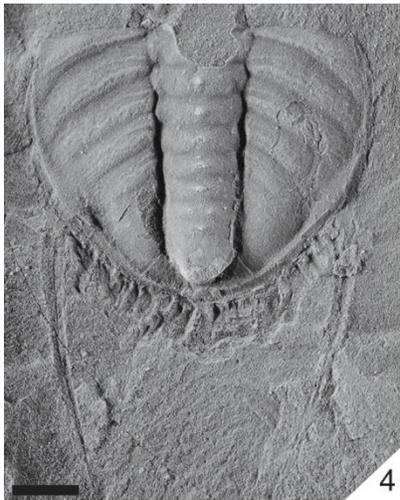


Figure 2.22. Zacanthoidids from the upper Mount Cap Formation, Northwest Territories: **(1)** Zacanthoidid n. gen. 3, n. sp. 2, holotype disarticulated exoskeleton (dorsal, latex mold) GSC 142413, mudstone, Carcajou Falls, *Glossopleura walcotti* Zone; **(2, 5)** Zacanthoidid n. gen. 2, n. sp. 1, mudstone, Dodo Canyon, *Albertelloides mischi* Zone; **(2)** holotype exoskeleton lacking a free cheek (dorsal, latex mold) GSC 142414; **(5)** possible paratype pygidium (dorsal) GSC 142417; **(3, 4, 6–11)** Zacanthoidid n. gen. 3, n. sp. 1, Carcajou Falls, *Glossopleura walcotti* Zone; **(3)** paratype exoskeleton lacking free cheeks (dorsal) GSC 142415, mudstone; **(4)** paratype pygidium (dorsal) GSC 142416, mudstone; **(6)** paratype pygidium (dorsal) GSC 142418, mudstone; **(7, 8)** paratype cranidium (dorsal, oblique) GSC 142353, grainstone; **(9)** paratype cranidium (dorsal) GSC 142419, mudstone; **(10)** paratype cranidium (dorsal) GSC 142420, mudstone; **(11)** paratype free cheek (dorsal) GSC 142349, mudstone. All scale bars=2 mm.

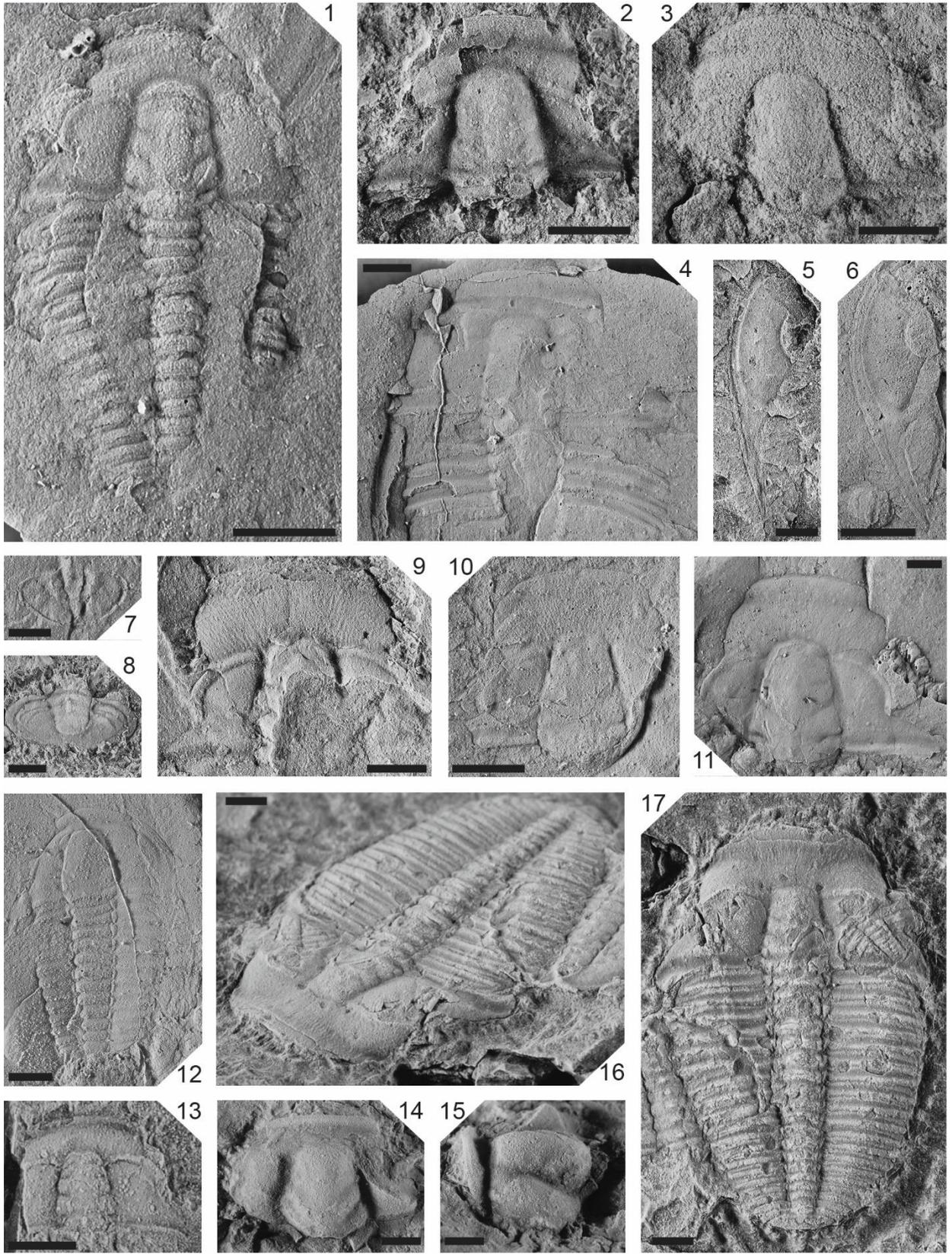


Figure 2.23. Ptychoparioids from the Mount Cap Formation, Northwest Territories: **(1–7)** *Amecephalus arrojensis* (Lochman, 1952); **(1)** exoskeleton lacking free cheeks (dorsal, latex mold) GSC 142421, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(2)** cranidium (dorsal) GSC 142422, silty mudstone, lower Mount Cap Formation, Dodo Canyon, Zacanthoidid n. gen. 1, n. sp. 1 Zone; **(3)** cranidium (dorsal) GSC 142423, siltstone, lower Mount Cap Formation, Dodo Canyon, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(4)** partially complete specimen (dorsal, latex mold) GSC 142424, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(5)** free cheek (dorsal) GSC 142425, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(6)** free cheek (dorsal, latex mold) GSC 142426, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(7)** pygidium, (dorsal, latex mold) GSC 142427, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(8, 12 and 13)** *Eokochaspis nodosa* Sundberg and McCollum, 2000, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(8)** pygidium (dorsal) GSC 142428; **(12)** complete exoskeleton (dorsal, latex mold) GSC 142432; **(13)** cranidium (dorsal) GSC 142433; **(9–11)** *A. agnesensis* (Walcott, 1912), silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone; **(9)** cranidium (dorsal) GSC 142429; **(10)** cranidium (dorsal, latex mold) GSC 142430; **(11)** cranidium (dorsal) GSC 142431; **(14, 15)** *Caborcella collaris* (Rasetti, 1951), cranidium (dorsal, lateral) GSC 142434, silty mudstone, lower Mount Cap Formation, Dodo Canyon, Zacanthoidid n. gen. 1, n. sp. 1 Zone; **(16, 17)** *Altiocculus americanus* (Walcott, 1916a), exoskeleton lacking free cheeks (lateral, dorsal) GSC 142435, mudstone, upper Mount Cap Formation, Carcajou Falls, *Glossopleura walcotti* Zone. All scale bars=2 mm.

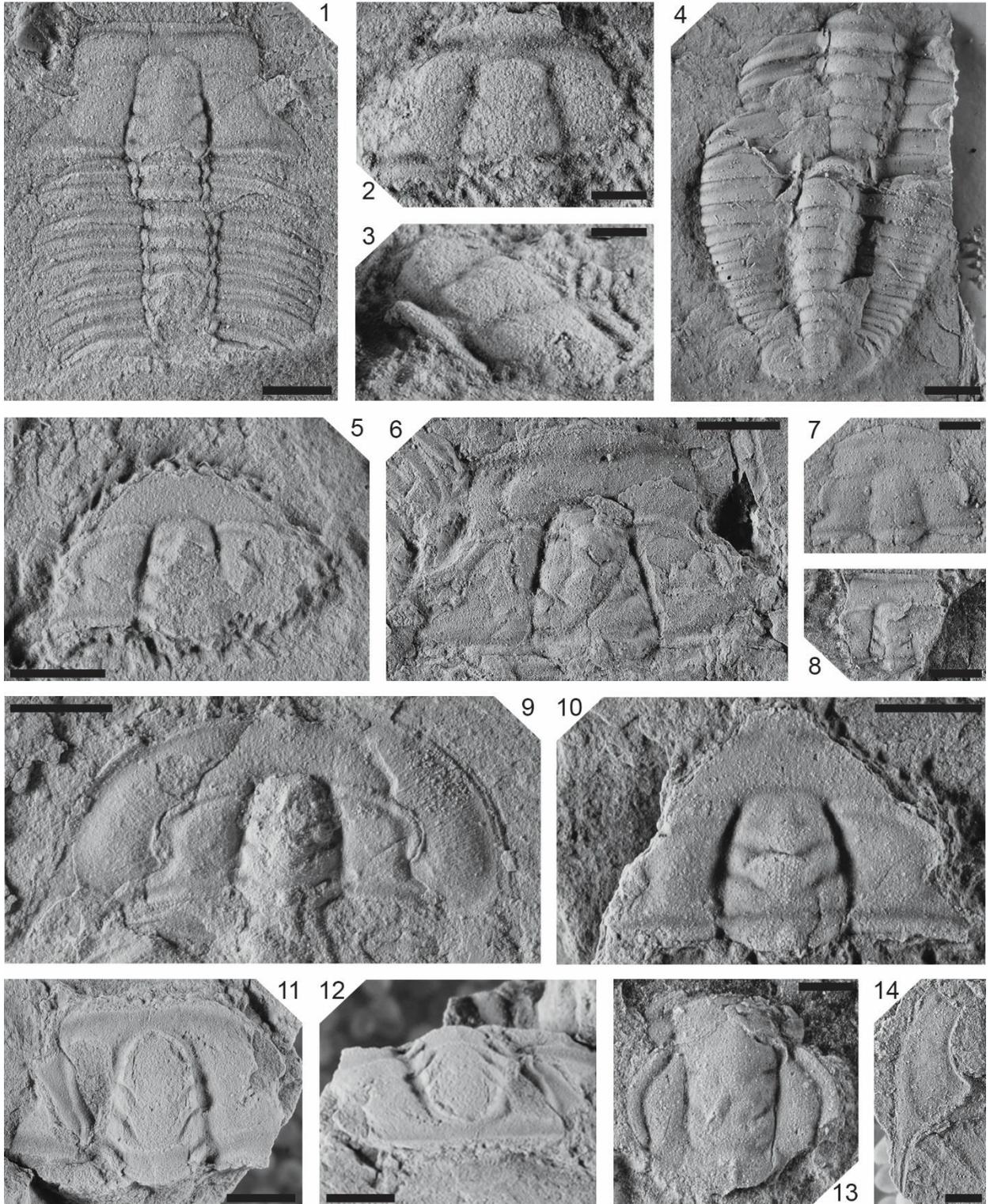


Figure 2.24. Ptychoparioids and corynexochid of the Mount Cap Formation, Northwest Territories. (1) *Chancia maladensis* (Resser, 1939b), exoskeleton lacking free cheeks (dorsal) GSC 142436, mudstone, upper Mount Cap Formation, Dodo Canyon, *Glossopleura walcotti* Zone; (2, 3) *Caborcella collaris* (Rasetti, 1951), cranidium (dorsal, oblique) GSC 142437, siltstone, lower Mount Cap Formation, Dodo Canyon, *Amecephalus arrojosisensis–Eokochaspis nodosa* Zone; (4, 7) *Eokochaspis* sp. indet., mudstone, upper Mount Cap Formation, Little Bear River, Zacanthoidid n. gen. 1, n. sp. 1 Zone; (4) exoskeleton lacking the cephalon (dorsal, latex mold) GSC 142438; (7) cranidium (dorsal, latex mold) GSC 142441; (5, 9 and 10) ptychoparioid gen. and sp. indet. 2, silty mudstone, upper Mount Cap Formation, Carcajou Falls, *Albertelloides mischi* Zone; (5) cranidium (dorsal) GSC 142439; (9) cephalon (dorsal) GSC 142443; (10) cranidium (dorsal) GSC 142444; (6, 8) *Tonopahella goldfieldensis* Sundberg and McCollum, 2003b, silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojosisensis–Eokochaspis nodosa* Zone; (6) cranidium (dorsal) GSC 142440; (8) cranidium (dorsal) GSC 142442; (11, 12) ptychoparioid gen. and sp. indet. 1, cranidium (dorsal, frontal) GSC 142445; silty mudstone, lower Mount Cap Formation, Dodo Canyon, Zacanthoidid n. gen. 1, n. sp. 1 Zone; (13, 14) corynexochid gen. and sp. indet., silty mudstone, upper Mount Cap Formation, Little Bear River, *Amecephalus arrojosisensis–Eokochaspis nodosa* Zone; (13) cranidium (dorsal) GSC 142446; (14) free cheek (dorsal) GSC 142447. All scale bars=2 mm.

CHAPTER 3

DISCUSSION AND CONCLUSION

Results from this project have provided novel insight into the regional sedimentology of the Mount Clark and Mount Cap formations, constrain biostratigraphic correlation with other localities and elucidate the paleoecological controls on trilobite biofacies. The sedimentological analysis of the Mount Clark and Mount Cap formations supports the previously proposed models (Aitken et al., 1973; Aitken and Cook, 1974; MacNaughton et al., 2013; Herbers et al., 2016; Sommers et al., 2020), although there are subtle distinctions between the outcrops of the eastern Mackenzie Mountains and the same strata in the subsurface. The sandstone units of the Mount Clark Formation record a storm-dominated shoreline with weak tidal influence, similar to those in the Colville Hills (Herbers et al., 2016; Sommers et al., 2020). There, coarser sandstone units were regarded as barred shorefaces due to the trace fossil assemblages, but no bedforms indicating a barrier shoreface bar were observed in the eastern Mackenzie Mountains. Also, the ichnoassemblages from the Colville Hills are dominated by vertical, filter-feeding burrows, which contrasts with the dominantly horizontal, deposit-feeding ichnoassemblages in the eastern Mackenzie Mountains (Herbers et al., 2016). These differences in the facies and ichnofauna suggest that the shoreline along the Mackenzie Arch was likely lower in energy compared to that present at the Colville Hills.

The sedimentology of the lower and upper Mount Cap formations of the eastern Mackenzie Mountains correlates with the established models as well (Aitken et al., 1973; Aitken and Cook, 1974; MacNaughton et al., 2013; Herbers et al., 2016; Sommers et al., 2020). The heterolithic strata of the lower Mount Cap Formation indicate an offshore setting laterally equivalent to the shoreface by biostratigraphic constraining, whereas the overlying mudstone and carbonate units of the upper Mount Cap Formation record a deeper water setting below the influence of waves and storms. Sea level transgression is inferred between the basal units and the upper Mount Cap Formation. The strata of the eastern Mackenzie Mountains have thicker and more numerous occurrences of carbonate, especially in the upper Mount Cap Formation. This suggests the

shoreline along the Mackenzie Arch was more conducive to a carbonate factory, though the source of the carbonate sediments is unknown. The sequence stratigraphic model developed by Sommers et al. (2020) for the Colville Basin used cycles of thick mudstone packages and thin dolostone packages to delineate four transgressive-regressive cycles. These cycles are not recognizable in the eastern Mackenzie Mountains, nor can carbonate units be locally correlated across field sites. Highly localized carbonate deposition could suggest that the factory was sourced from somewhere else and sediments were allochthonous. It seems conceivable that there was a large carbonate shelf that formed on the Mackenzie Arch, which then was planned off by later erosion. This correlates well with the model of three facies belts along the shoreline (Robison, 1960; Aitken, 1966). There is a conspicuous erosional gap between the inner-detrital belt facies of the Mount Cap Formation and the outer-detrital belt facies of the temporally equivalent Rockslide Formation. This supports the interpretation of post-Mount Cap Formation erosion of the carbonate belt, likely due to later uplift of the Mackenzie Arch (Aitken and Cook, 1974).

The species-based trilobite biostratigraphy of the Mount Clark and Mount Cap formations indicate the local presence of the *Olenellus* through *Glossopleura walcotti* zones, and that flooding of the shoreline was diachronous. Between these zones, the traditional *Amecephalus arrojensis*–*Eokochaspis nodosa* Zone and the new, regional Zacanthoidid n. gen. 1, n. sp. 1 and *Albertelloides mischi* zones are recognized. The continuous biostratigraphic succession does not support the presence of an unconformity in the Mount Cap Formation (contra Fritz, 1969). In the Colville Basin, flooding of the shoreline occurred during the *Olenellus* Zone (Morgan, 2019), which is temporally equivalent to the same surface at some of the sections in the eastern Mackenzie Mountains. However, at Carcajou Falls and Grafe River, flooding of the shoreline occurred later in *Albertelloides mischi* Zone, and these localities may have formed some type of monadnock in the region. Interestingly, Carcajou Falls is where the fossiliferous “shell beds” yielded the vast majority of the paedomorphic taxa from the upper Mount Cap Formation. Whether the paleotopographic high influenced the occurrence of paedomorphic trilobites in these strata is unknown. Lastly, the biostratigraphy of the Mount Clark and Mount Cap formations suggests that they are temporally equivalent to many formations in the southern Canadian Rock Mountains (Rasetti, 1951, Fletcher and Collins, 1998), Great Basin (Eddy and McCollum, 1998; Sundberg and McCollum, 2000; 2003a; b; Sundberg, 2005, 2018), northern Mexico (Cooper et

al., 1952; Noriega-Ruiz et al., 2020), Greenland (Peel, 2020) and the Precordillera of Argentina (Foglia and Vaccari, 2010; Pratt and Bordonaro, 2014). Globally, these formations span early Cambrian Series 2, Stage 4 to the later Miaolingian, Wuliuan (Geyer, 2019).

The middle Cambrian trilobite faunas of the Mount Cap Formation are dominated by the families Zacanthoididae and Dolichometopidae, with rare ptychoparioids and oryctocephalids. The absence of other major clades of trilobites that are common at other sections, such as the agnostoids, dorypygids and ogygopsidids, suggests a unique paleoecology in the basin. Zacanthoidids and dolichometopids are also dominant in other inner-detrital belt settings of the middle Cambrian of Laurentia, such as in the Pioche Formation (Fritz, 1968; Eddy and McCollum, 1998), Chisholm Formation (Sundberg, 2005), inner-detrital Carrara Formation (Palmer and Halley, 1979) and probably the Ross Lake Shale of the Cathedral Formation (Rasetti, 1951). However, these two families are significantly more numerous in the eastern Mackenzie Mountains. Trilobite faunas in facies of the outer-detrital belt are inverse to those in facies of the inner-detrital belt. In the *Albertella* Zone of the Carrara Formation of Nevada, outer-detrital belt facies contain a fauna composed mostly of ptychoparioids, agnostoids, ogygopsidids and dorypygids (Palmer and Halley, 1979). Similarly, the *Oryctocephalus indicus* Zone of the Emigrant Formation of Nevada is dominated by oryctocephalids and ptychoparioids (Sundberg and McCollum, 1997; 2003b), while the *Glossopleura walcotti/Ptychagnostus praecurrens* Zone of the same formations is dominated by mostly ptychoparioids and agnostoids with minor dolichometopids and zacanthoidids (Sundberg, 2018). The slightly younger Burgess Shale Formation of the Chancellor Group in British Columbia contains a fauna of dorypygids, ogygopsidids, ptychoparioids and agnostoids with rare zacanthoidids and dolichometopids (Rasetti, 1951; Fletcher and Collins, 1998). Lastly, the correlative Rockslide Formation, while slightly younger, has a trilobite fauna composed of agnostoids and ptychoparioids (Kimmig and Pratt, 2018).

The even greater abundance of zacanthoidids and dolichometopids in the Mount Cap Formation compared to other localities favors the interpretation that these groups were able to tolerate environmental conditions which others could not. In the Carrara Formation, the diversity and abundance of zacanthoidids was hypothesized to be produced by the radiation of a deeper water ancestor, likely *Zacanthoides*, into shallow water and undergoing progenesis (an increased

rate of sexual maturity) into progressively more paedomorphic taxa such as *Albertelloides*, *Paralbertella* and *Albertella* respectively (McNamara, 1986b). The triggering mechanism of progenesis in zacanthoidids was speculated to be warmer water temperatures possibly present in the inner-detrital belt settings (McNamara, 1986b), and a similar interpretation was generated for the origin of paedomorphic species of *Olenellus* from Scotland (McNamara, 1978). It is agreed here that warm water may have influenced the radiation of the faunas, but it must be noted that variations in salinity and bottom-water oxygen concentration can not be ruled out as causes either. Furthermore, McNamara's (1986b) hypothesis, that warmer water (and other fluctuating stressors) in a restricted basin caused the radiation of zacanthoids through paedomorphosis, is also supported by the presence of paedomorphic taxa in the Mount Cap Formation.

These paedomorphic taxa, Dolichometopid n. gen. 2, n. sp. 1; Zacanthoidid, n. gen. 2, n. sp. 1; Zacanthoidid n. gen. 3, n. sp. 1; and Zacanthoidid n. gen. 3, n. sp. 2, are endemic to the eastern Mackenzie Mountains. Paedomorphism in these taxa, indicating heterochrony (a change in the onset of sexual maturity), is defined by novel morphological features: a reduced number of thoracic segments, increased number of pygidial segments and shorter thoracic spines, all relative to apaedomorphic representatives. The morphological differences between paedomorphic and apaedomorphic taxa is due to a retardation of segment release from the pygidium to the thorax, regarded as post-displacement. Post-displacement is a change in the timing of development of a certain morphological feature(s) (Alberch et al., 1979; McNamara, 1986a). As paedomorphism occurs in three separate genera, the cause is interpreted as an environmental signal, which agrees with McNamara's (1986b) hypothesis. The sedimentology of the Mount Cap Formation is broadly similar to other sections representing the inner-detrital belt (Fritz, 1968; Eddy and McCollum, 1998; Sundberg and McCollum, 2003a; Sundberg, 2005), so the environmental stress is interpreted to be cryptic, paleoecological conditions as opposed to substrate or energy variables. The inner-detrital belt likely experienced greater fluctuations in salinity, temperature and oxygen-concentration than in the outer-detrital belt, and fluctuations in the waters of the Colville Basin were probably of even greater magnitude due to the nature of the basin tectonics.

Paedomorphosis has been documented in several trilobite lineages, such as olenellids, zacanthoidids, oryctocephalids, xystridurines and phacopids (McNamara, 1978; 1981; 1982;

1986b; Feist, 1995). Compared with the progenetic paedomorphocline (increasing progenesis in progressively younger taxa) developed by McNamara (1986b), the paedomorphic zacanthoidids of the upper Mount Cap Formation are descended from the *Albertelloides* and *Albertella/Mexicaspidella* branch that underwent post-displacement. No paedomorphocline of dolichometopids has ever been documented. This process occurring in descendants of two separate parts of the paedomorphocline, as well as a species not descended from it, indicates that the switch was not a natural transition to post-displacement once a species had reached an optimal level of progenesis, but as being forced upon three separate ancestors which had not undergone the same level of progenetic development. Forced post-displacement suggests that heterochrony in trilobites is plastic in nature, though so far, the process or stimulus that causes the change in the type of paedomorphosis is yet unknown.

Within extant arthropods, paedomorphosis is documented through the maturation of the developing animals, and therefore temporally-extended paedomorphoclines like those in the fossil record can not be interpreted (Fisher, 1999; Fockedey et al., 2005). When this does occur in extant arthropods, the cause is usually due to a change in water temperature, salinity or oxygen concentration. Blue Crabs undergo an earlier onset of sexual maturity in both higher salinity and in warmer water conditions (Fisher, 1999). Similarly, Opossum Shrimps will mature earlier in warmer waters, whereas developmental changes from salinity is temperature dependent (Fockedey et al., 2005). In the brine shrimp *Artemia franciscana*, warmer waters generally produce increased somatic growth in the juvenile stage, when segments are released into the thorax, while the opposite occurs in the later adult stage when segments are released into the abdomen (Foster and Hirst, 2012). Post-displacement is documented in limb-size reduction in groundwater copepods, though the cause or function of this is unknown (Galassi et al., 2009).

The evolutionary advantage to the retention of segments in the pygidium, if any, is not well understood, and it seems plausible that paedomorphosis is only a consequence of an environmental change(s) as opposed to an adaptation to it. If this is an adaptation, the advantage of requiring less thoracic segments is likely related to the anatomy of thoracic and pygidial appendages, or the articulation of the thorax. Speculation will be based on the morphology of other specimens with preserved, soft-bodied appendages, as the limbs of paedomorphic species from the Mount Cap Formation are unknown. Thoracic segments in polymerid trilobites are

known to have had biramous appendages which supported an exopodite for respiration and an endopodite for locomotion (Stürmer and Bergström, 1973; Whittington, 1980; Whittington and Almond, 1987). In most trilobites where these are preserved, such as *Phacops ferdinandi* (Stürmer and Bergström, 1973) and *Triarthrus eatoni* (Stürmer and Bergström, 1973; Whittington and Almond, 1987), the appendages of the pygidium are smaller in size compared to those of the thorax (see also Hughes, 2003). If the same is true for the paedomorphic taxa of the Mount Cap Formation, it is conceivable that the smaller size of many biramous appendages is related to either a reduced requirement for reparation or locomotion, possibly evolving under well-oxygenated conditions and/or a firm substrate. However, the closest-related species where the appendages are known is the dorypygid *Olenoides serratus*, which had similar sized exopodites and endopodites along the thorax and pygidium (Whittington, 1980). The exception to this is the posterior-most pair, which were long, posteriorly directed cerci. If this appendage pattern is what specimens of the Mount Cap Formation had, it suggests that the retardation of segment release was not governed by appendage requirements but possibly by thoracic articulation. One possible reason for the evolution of a less-articulated exoskeleton is for defense from durophagous predators.

Recommended future work on the sedimentology of the basin should investigate the Mount Cap Formation in the Franklin Mountains, and stratal correlation between the Colville Hills and the eastern Mackenzie Mountains. Of particular interest is the lateral extent of the dolostone intervals that Sommers et al., (2020) used as sequence boundaries. Future work that deals with either trilobite biostratigraphy or the paleoecology should focus on the temporally equivalent faunas present in the Rockslide Formation. The presence of taxa endemic to the eastern Mackenzie Mountains in the Rockslide Formation could suggest the partial submergence of the Mackenzie Arch during the Cambrian, allowing migrations between the faunas. Lastly, future study into the paleoecological controls on heterochrony of trilobites should focus on trying to tease out which paleoecological proxy had the greatest influence. Paleoecological forcing of paedomorphic development was more profound in the Mount Cap Formation than in other areas, which may have formed an abnormal sedimentological or geochemical signal in this unit. First, scanning electron microscopy (SEM) should analyze the mudstone from the *Albertelloides mischi* and *Glossopleura walcotti* zones of the upper Mount Cap Formation to identify any indication of major diagenesis of the clays. Bulk element analysis should be conducted to

identify paleosalinity proxies, such as boron, gallium, strontium, sulphur and total organic carbon (Wei and Algeo, 2020). Trace and body fossil evidence in the upper Mount Cap Formation has conflicting evidence for paleosalinity: Well-bioturbated sandstones and silty mudstones suggests that normal-marine salinity was persistent, while the absence of echinoderm fragments in carbonates, common components in temporally and lithologically equivalent units (Palmer and Halley, 1979), suggests non-marine salinity. Trace element analysis has already been conducted on these mudstones to interpret bottom-water oxygen conditions, though without SEM data, the only interpretation that can be made is that the clays are not detrital in origin (Tribovillard et al., 2006). Measuring paleotemperature using stable carbon and oxygen isotopes in carbonate units is likely not reliable, due to the variable dolomitization of these strata and the possible allochthonous origin of the carbonate sediments in the basin. Once all geochemical data is collected, it should be synthesized with sedimentological, ichnological and paleontological data to elucidate further the environmental stressors which forced faunal patterns and pedomorphism in the eastern Mackenzie Mountains.

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APPENDIX A: MEASURED SECTION DATA, DODO CANYON

Section 1: Dodo Canyon: (NTS 96D, 64.937525° N, 127.265209° W)

This appendix, and the following four, appeared as part of the following published report in Handkamer (2020). This section (Figs. A.1, A.2 and A.3) is exposed along the north side of Dodo Creek in Dodo Canyon, a few kilometres north of the junction with Echo Creek. Dodo Canyon is a reference section for the Cambrian stratigraphy of the MacDougal Anticline and has been previously measured several times before (Aitken et al., 1973; Serié et al., 2013; Bouchard and Turner, 2017) (see also MacNaughton et al., 2013). The lowest Cambrian strata, which are upriver from the measured section, could not be visited, though they were previously reported to overly the Stone Knife Formation of the Little Dal Group (Serié et al., 2013). Thus, the log of the heterolithic Mount Cap Formation is incomplete. The Saline River Formation overlies the Mount Cap Formation downriver in a poorly exposed section, but this could not be correlated to section 1 (roughly 4–6 m above the top of the section). Normal faulting is present in the middle of the outcrop, where a talus cone has formed along the fault plane. This was adjusted for in the measured section.

Unit	Description	Unit thickness (m)	Cumulative thickness (m)
mudstone-dominated Mount Cap Formation			
21	Light grey, tan-weathering, variably dolomitic lime mudstone interbedded with black, dark grey-weathering mudstone. Beds are laterally continuous, 50% lime mudstone and 50% mudstone grading upwards into 40% lime mudstone and 60% mudstone. Minor beds of wackestone and packstone are present at the base of the unit. Lime mudstone beds and laminae are 5–12 mm thick, planar bedded, thinly laminated and composed of microspar. Wackestone and packstone beds are wavy bedded, wave-rippled and consist of peloids in a micrite and microspar	6.8	73.9

matrix. Some peloids have dark, micritic rims. Mudstone beds and laminae are 5–20 mm thick, featureless, composed of clay-sized particles and variably calcareous. Trace fossils are absent. Corynexochids and ptychoparioids are present in mudstone beds, particularly at the base of this unit and rare in lime mudstone beds. Collection 1.7. Internal contacts are sharp. Basal contact is sharp.

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| 20 | <p>Tan, brown-weathering carbonate breccia and wackestone interbedded with black, dark grey-weathering mudstone. Carbonate breccia and wackestone beds are 15–30 mm thick, wavy bedded and deformed with syn-sedimentary folds and faults. Carbonate clasts are 5–15 cm in diameter. Wackestone beds are composed of peloids in a micrite matrix. Mudstone beds are 25–50 cm thick, featureless, composed of clay-sized particles and organic-rich with minor deformed carbonate laminae and carbonate clasts. <i>Palaeophycus</i> is present on hypichnial surfaces of wackestone beds. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p> | 1.5 | 67.1 |
| 19 | <p>Black, dark grey-, red- and green-weathering mudstone with minor pale blue, tan-weathering limestone beds. This unit is fissile and composed of clay-sized particles with horizons that are sulfur- and organic-rich. Limestone beds are 5–10 cm thick, planar bedded and composed of microspar. Trace fossils are absent. Corynexochids are present in mudstone beds. Collection 1.6. Internal contacts are sharp. Basal contact is sharp.</p> | 3.9 | 65.6 |

18	<p>Black, dark grey-weathering mudstone with minor pale blue, tan-weathering lime mudstone. Mudstone beds are 5–18 cm thick, fissile and composed of clay-sized particles with minor sulfur- and organic-rich horizons. Lime mudstone beds are 3–8 cm thick, planar bedded and consist of micrite. Trace fossils are absent. Corynexochids, hyoliths and linguliformean brachiopods are present in mudstone beds. Collection 1.5B. Internal contacts are sharp. Basal contact is gradational</p>	1.9	61.7
17	<p>Black, dark grey-, red- and green-weathering mudstone with minor pale blue, tan-weathering lime mudstone beds. Mudstone beds are fissile and consist of clay-sized particles with sulfur- and organic-rich horizons. Limestone beds are 5–10 cm thick and composed of microspar. <i>Planolites</i> is rare on endichnial and hypichnial surfaces of mudstone beds. BI=0–1. Corynexochids and linguliformean brachiopods are present. Collection 1.5A. Internal contacts are sharp. Basal contact is sharp.</p>	18.1	59.8
16	<p>Dark brown, grey- and reddish brown-weathering, bedded and laminated crystalline limestone. Beds and laminae are 1–5 cm thick, wavy and rippled and composed of sparite with minor siliciclastic grains. Trace and body fossils are absent. Internal contacts are erosional. Basal contact is sharp</p>	1.4	41.7
15	<p>Pale brown, orange- and brown-weathering, laminated lime mudstone with minor beds of black, dark grey-weathering mudstone. Lime mudstone beds are planar bedded and laminated and composed of micrite and microspar. Mudstone beds are 10–20 cm thick, fissile, consist of clay-sized</p>	0.4	40.3

particles and are organic-rich. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.

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| 14 | Pale brown, orange-weathering limestone. Beds are 10–50 cm thick, planar and wavy bedded and composed of micrite. <i>Palaeophycus</i> and <i>Phycodes</i> are rare on hypichnial surfaces. BI=1–2. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp. | 3.7 | 39.9 |
| 13 | Green, greyish green-weathering siltstone interbedded with pale blue, buff-weathering carbonate concretions. This unit is 75% siltstone and 25% carbonate. Siltstone beds and laminae are 5–16 mm thick, fissile and composed of silt-sized particles with minor clay. Concretions are 1–30 mm thick, occur in beds and consist of microspar. Trace fossils are absent. Corynexochids, ptychoparioids, hyoliths and linguliformean brachiopods are present in siltstone beds. Collection 1.4. Internal contacts are sharp. Basal contact is gradational. | 2.1 | 36.2 |

heterolithic Mount Cap Formation

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| 12 | Green, greenish brown-weathering sandstone interbedded with green, greenish brown-weathering siltstone. This unit is planar bedded, 60% siltstone and 40% sandstone. Siltstone beds are 3–14 cm thick, fissile and composed of silt-sized particles with minor clay. Sandstone beds are 5–10 cm thick, internally featureless, argillaceous sandstones in composition with minor glauconite and consist of fine sand-sized grains. <i>Teichichnus</i> is present on hypichnial surfaces of sandstone beds. BI=1–2. Linguliformean brachiopods are present in | 2.0 | 34.1 |
|----|--|-----|------|

siltstone beds. Internal contacts are sharp. Basal contact is gradational.

11	Green, greenish grey-weathering mudstone. This unit is massive, fissile and composed of clay-sized particles. Trace fossils are absent. Ptychoparioids, corynexochids, linguliformean brachiopods and hyoliths are present. Collection 1.3B. Basal contact is sharp.	2.5	32.1
10	Green, greyish green-weathering siltstone interbedded with pale blue, buff-weathering lime mudstone. This unit is 75% siltstone and 25% lime mudstone. Siltstone beds are 8–20 mm thick, fissile and composed of silt-sized particles. Lime mudstone beds and laminae are 1–37 mm thick, commonly nodular or consist of beds of concretions and composed of microspar. Trace fossils are absent. Ptychoparioids are present in siltstone lithology. Collection 1.3A. Internal contacts are sharp. Basal contact is sharp	1.8	29.6
9	Green, greenish grey-weathering mudstone interbedded with pale blue, tan-weathering lime mudstone. Beds are laterally continuous, with lime mudstone beds and laminae present in the middle of the unit. Mudstone beds are 3–20 cm thick, fissile and composed of clay-sized particles. Lime mudstone beds are 1–8 cm thick, planar bedded and composed of microspar. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	0.5	27.8
8	Green, greyish green-weathering siltstone and pale blue, tan-weathering lime mudstone. This unit is 75% siltstone and 25% lime mudstone. Siltstone beds and laminae are 5–20	3.5	27.3

mm thick, featureless, fissile and consist of silt-sized particles. Lime mudstone beds and laminae are 1–45 mm thick, nodular, or consist of beds of concretions and composed of microspar. Trace fossils are absent.

Linguliformean brachiopods and hyoliths are present in siltstones. Internal contacts are sharp. Basal contact is gradational.

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| 7 | <p>Light grey, orange-weathering sandstone interbedded and interlaminated with green, greyish green-weathering siltstone. This unit is 50% sandstone and 50% siltstone. Sandstone beds and laminae are 2–35 mm thick, planar and wavy bedded and internally featureless with minor current-ripple cross-laminated beds. Sandstones are argillaceous sandstones in composition and consist of very- fine to fine sand-sized grains. Siltstone laminae are 1–3 mm thick, fissile, composed of silt-sized particles and variably calcareous. Trace fossils are absent. Ptychoparioids, linguliformean brachiopods and hyoliths are present in siltstone beds. Collection 1.2 Internal contacts are sharp. Basal contact is sharp.</p> | 2.0 | 23.8 |
| 6 | <p>Light grey, orange- and dark grey-weathering sandstone. Beds are 2–10 cm thick, wavy bedded, amalgamated, internally featureless or mottled with minor wave-rippling. Sandstones are arenitic in composition and consist of fine sand-sized grains. The top-most 15 cm is composed of laminated siltstone. <i>Planolites</i>, <i>Palaeophycus</i>, <i>Teichichnus</i> and rare <i>Rusophycus</i> are present on hypichnial and endichnial surfaces of mottled beds. BI=3–4 for mottled</p> | 3.6 | 21.8 |

beds. No body fossils are present. Internal contacts are sharp. Basal contact is sharp.

5	Brown, orange-weathering sandstone. This unit is wavy bedded, wave-ripple cross-laminated, arenitic in composition and consists of coarse to very- coarse sand-sized grains. <i>Teichichnus</i> and <i>Palaeophycus</i> are present on endichnial surfaces. BI=0–1. Linguliformean brachiopods are rare. Basal contact is erosional.	0.2	18.2
4	Light grey, orange brown-weathering arenaceous wackestone interbedded and interlaminated with pale green, pale grey-weathering argillaceous lime mudstone. Beds and laminae are planar and wavy, 50% arenaceous and 50% argillaceous. Arenaceous wackestone beds and laminae are 1–150 mm thick and are wave-rippled and wave-ripple cross-laminated with minor gutter casts and current-ripples. Wackestones consist of very- fine siliciclastic grains and trilobite bioclasts in a micrite matrix with blocky sparite. Argillaceous lime mudstone beds and laminae are <1–30 mm thick, laminated and composed of micrite with minor argillaceous particles. <i>Planolites</i> and <i>Palaeophycus</i> are present on endichnial and hypichnial surfaces of arenaceous wackestone beds and laminae. BI=0–1. Olenellid trilobites are present in arenaceous wackestone beds and laminae. Collection 1.1. Internal contacts are sharp. Basal contact is sharp.	1.8	18.0
3	Brown grey, orange-weathering sandstone interbedded with pale grey, dark grey-weathering argillaceous lime mudstone. This unit is planar and wavy bedded, 70% sandstone and	4.6	16.2

30% lime mudstone. Sandstone beds are 25–105 cm thick, internally featureless or mottled with minor wave-rippling. Sandstones are arenitic in composition and consist of very-fine to medium sand-sized grains. Argillaceous lime mudstone beds are 5–10 cm thick, laminated and composed of micrite with minor argillaceous material. *Palaeophycus*, *Planolites*, *Skolithos* and *Diplocraterion* are present on endichnial and hypichnial surfaces of sandstone beds. BI=1–3. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.

2	<p>Grey, orange-weathering sandstone interbedded with pale green, green-weathering mudstone. This unit is planar bedded, 50% sandstone and 50% mudstone. Sandstone beds are 3–50 cm thick, internally featureless, argillaceous sandstones in composition and consisting of fine sand-sized grains. Mudstone beds are 3–10 cm thick, fissile and composed of clay-sized particles with minor silt. <i>Diplocraterion</i> is rare on endichnial and epichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p>	1.6	11.6
1	<p>Greenish-grey, orange-, red- and green-weathering sandstone with minor pale green, dark green-weathering mudstone beds. Sandstone beds are 5–10 cm thick, wavy bedded, amalgamated and wave-rippled with minor wave-ripple and tabular cross-lamination. Sandstones are argillaceous sandstones in composition with minor arenites and glauconite and consist of fine sand-sized grains. Mudstone beds are 5–20 cm thick, featureless, fissile and composed of clay-sized particles with minor silt. <i>Palaeophycus</i>, <i>Planolites</i></p>	10.0	10.0

and *Monocraterion* are present on hypichnial surfaces of sandstones. BI=1–2. Body fossils are absent. Internal contacts are sharp or erosive. The basal contact is covered.

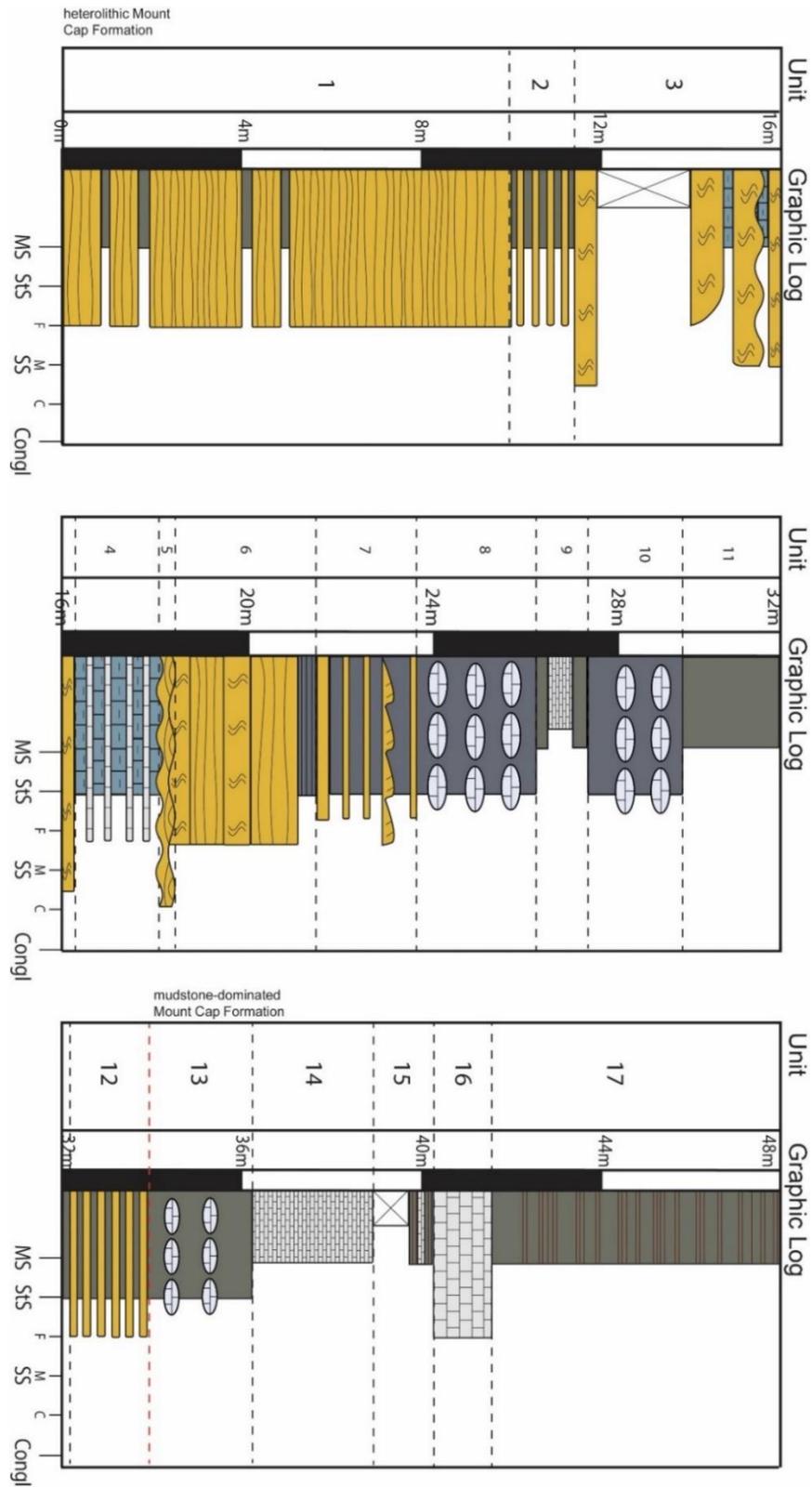


Figure A.1. Graphic log of the section at Dodo Canyon, showing unit divisions; 0–48.0 m. Red dashed line indicates the lithostratigraphic boundary.

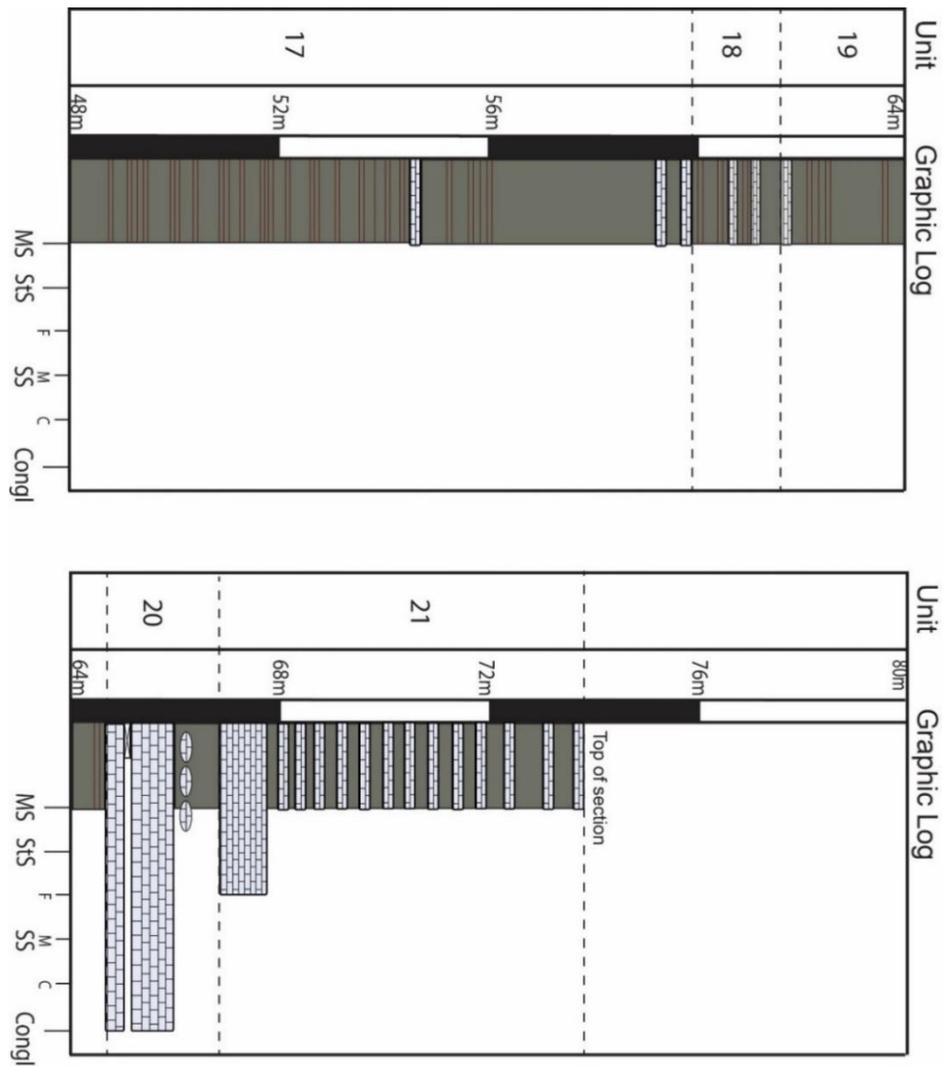


Figure A.2. Graphic log of the section at Dodo Canyon, showing unit divisions; 48.0–73.9 m.

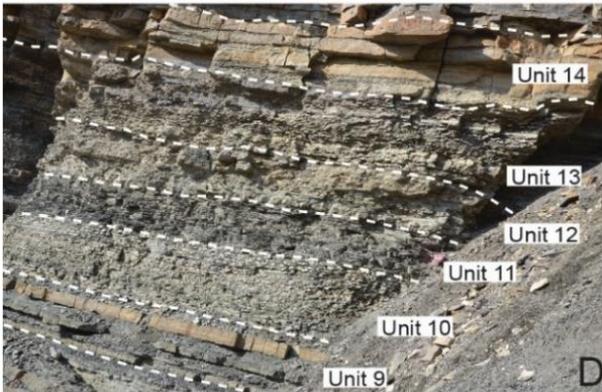
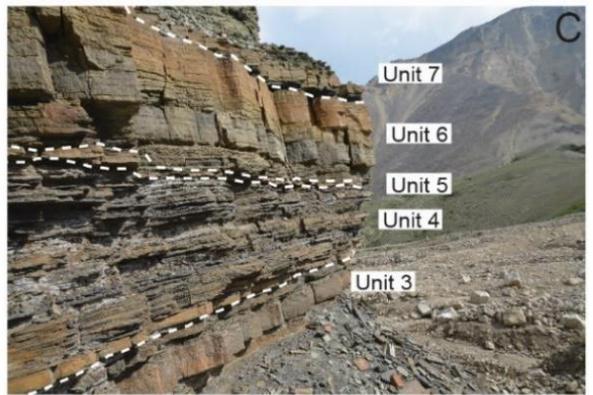
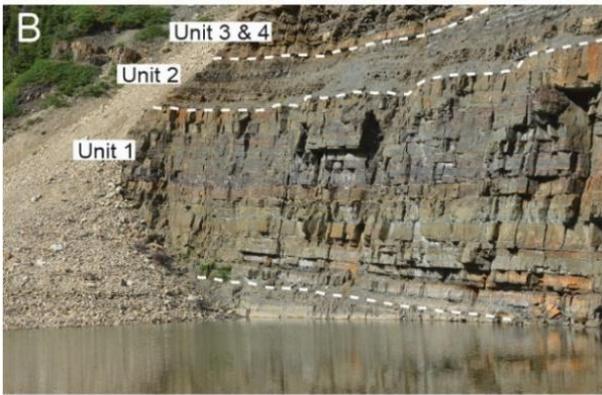
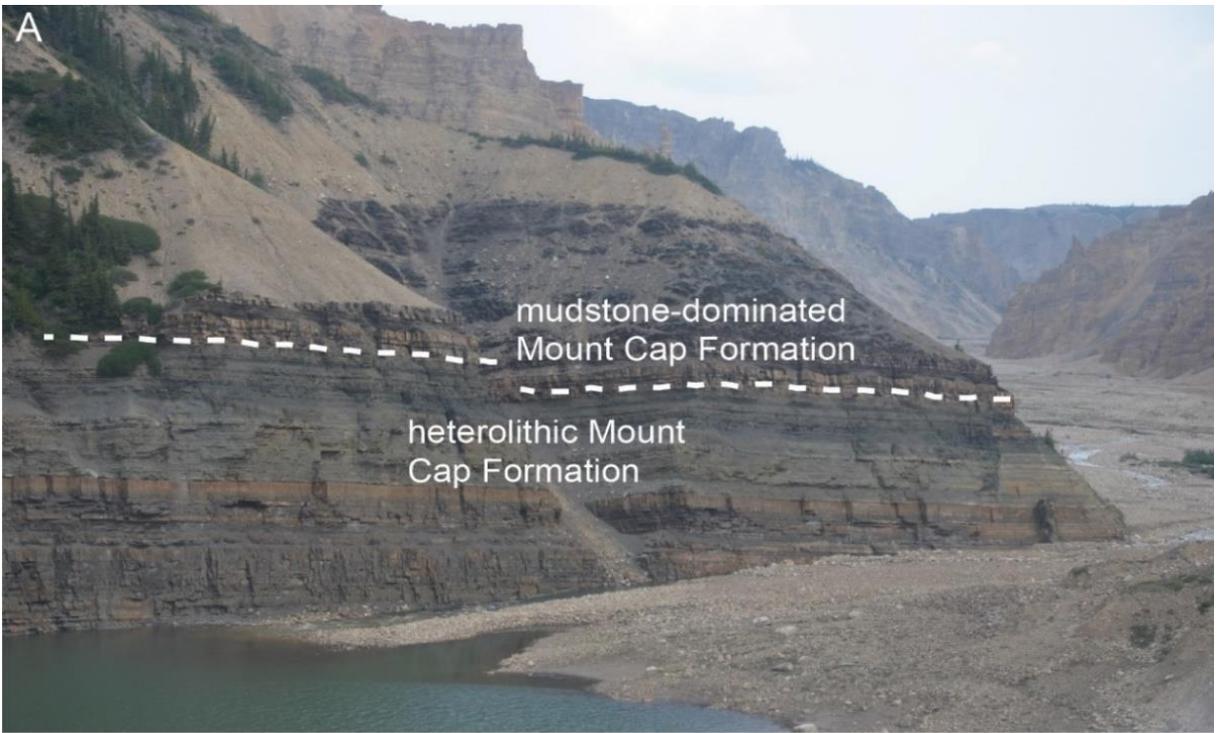


Figure A.3. Outcrop view at Dodo Canyon. All photographs by N.M. Handkamer. **A)** Lithostratigraphic divisions at Dodo Canyon. Upper, pale beige talus slope likely indicates the approximate position of the Mount Cap Formation-Saline River Formation contact. Outcrop thickness = 73.9 m. Photo 2020-245. **B)** Basal heterolithic Mount Cap Formation. Stratal thickness = ~18 m. Photo 2020-246. **C)** Middle heterolithic Mount Cap Formation. Stratal thickness = 7.2 m. Photo 2020-247. **D)** Upper heterolithic Mount Cap Formation and lower mudstone-dominated Mount Cap Formation. Stratal thickness = 13.5 m. Photo 2020-248. **E)** Middle mudstone-dominated Mount Cap Formation. Stratal thickness = ~4.5 m. Photo 2020-249.

APPENDIX B: MEASURED SECTION DATA, LITTLE BEAR RIVER

Section 2: Little Bear River: (NTS 96D, 64.479199° N, 126.794262° W)

This section (Figs. B.1, B.2 and B.3) exposes the Mount Clark and Mount Cap formations on the south side of the Little Bear River. This section has been previously measured by Aitken et al. (1973) and C. Nicholas (Harvey and Butterfield, 2011) and studied by Serié et al. (2013). The underlying unit, and Unit 1 in this section, are part of the Stone Knife Formation (Little Dal Group) (Serié et al., 2013), which has been thrust upwards to form a deep canyon upriver (to the west) from where the section was measured. The Stone Knife Formation-Mount Clark Formation contact is covered in this locality, as is the upper contact of the Mount Cap Formation. Significant thrust faulting is observed throughout this section and was accounted for during measuring.

Unit	Description	Unit thickness (m)	Cumulative thickness (m)
mudstone-dominated Mount Cap Formation			
14	Dark grey, pale grey-weathering mudstone interbedded and interlaminated with buff, beige-weathering, dolomitic lime mudstone. This unit is planar bedded, 50% lime mudstone and 50% mudstone which grades upwards into 10% lime mudstone and 90% mudstone. Lime mudstone beds and laminae are 4–80 mm thick, thin upwards and nodular. Lime mudstones are composed of minor trilobite and linguliformean brachiopod bioclasts in a microspar matrix that is partially dolomitized. Mudstone beds and laminae are <1–60 mm thick, fissile and fossiliferous. Mudstones consist of clay-sized particles with minor silt. Thin sections show that burrows are present in lime mudstones. Dolomitization	7.4	61.0

is greater within burrows. Corynexochids, ptychoparioids and hyoliths are present in mudstones. Collection 2.9.

Internal contacts are sharp. Basal contact is sharp.

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| 13 | Dark grey, pale grey-weathering mudstone interbedded with buff, beige-weathering dolomitic lime mudstone. This unit is planar bedded, 60% lime mudstone and 40% mudstone, grading upwards into 10% lime mudstone and 90% mudstone. Lime mudstone beds are 4–80 mm thick, thinning upwards and nodular. Lime mudstones are composed of minor trilobite and linguliformean brachiopod bioclasts in a matrix of microspar that is partially dolomitized. Mudstone beds are <1–60 mm thick, fissile and fossiliferous. Mudstones consist of clay-sized particles with minor silt. Thin sections show that burrows are present in lime mudstones. Dolomitization is greater within burrows. Linguliformean brachiopods, corynexochids and hyoliths are present in mudstones. Collection 2.8. Internal contacts are sharp. Basal contact is sharp. | 4.7 | 53.6 |
| 12 | Dark grey, pale grey- and yellowish orange-weathering mudstone. This unit is massive, fissile, poorly exposed and has discontinuous horizons rich in both sulfur and large concretions. This unit is composed of clay-sized particles with minor silt and rare pyrite crystals. Trace fossils are absent. Ptychoparioids are rare. Collection 2.7. The base is poorly exposed due to faulting. | 5.3 | 48.9 |
| 11 | Black, dark grey-weathering mudstone. This unit is poorly exposed, fissile and composed of clay-sized particles with minor pyrite crystals. Trace fossils are absent. This unit is | 4.1 | 43.6 |

mostly unfossiliferous except for rare fossiliferous horizons. Corynexochids and hyoliths are present. Collection 2.6. Base is not exposed.

10	Dark grey, pale grey- and yellowish orange-weathering mudstone. This unit is massive, fissile, poorly exposed and has discontinuous sulfur-rich horizons. This unit is composed of clay-sized particles with minor silt and rare pyrite crystals. Trace fossils are absent. Corynexochids and ptychoparioids are present. Collections 2.4 and 2.5. Base is gradational	4.7	39.5
9	Pale blue, pale yellow-weathering dolomitic lime mudstone interbedded with black, dark grey-weathering mudstone. The unit is planar bedded, 80% mudstone and 20% lime mudstone. Mudstone beds are 10–150 cm thick, fissile and composed of clay-sized particles with minor silt and pyrite crystals. Lime mudstone beds are 5–12 cm thick, nodular and composed of micrite, microspar and sparite that is partially dolomitized with variable, but minor if present, argillaceous material. Thin sections show that burrows are present in lime mudstone beds. Dolomitization is greater within burrows. The basal part of this unit contains olenellids within both mudstones (Collection 2.1) and lime mudstones (Collection 2.2). Above this, ptychoparioids are present, though only in mudstone beds. Collection 2.3. Linguliformean brachiopods and hyoliths are present in mudstone beds throughout. Internal contacts are sharp. Base is sharp.	3.2	34.8
	Covered	3.0	31.6

8	Brownish grey, tan-weathering arenaceous dolostones. This unit is wavy bedded, amalgamated and beds are 5–10 cm thick. Beds are composed of non-planar dolomite (dolomite with non-planar crystal boundaries) and siliciclastic grains. Thin mudstone laminae and partings are present between dolostone beds and are <1mm thick. <i>Teichichnus</i> , <i>Palaeophycus</i> , <i>Planolites</i> , <i>Skolithos</i> and <i>Cruziana</i> are present on endichnial and hypichnial surfaces. BI=2–3. Linguliformean brachiopods are rare. Internal contacts are sharp. Basal contact is gradational.	1.3	28.6
7	Brownish grey, tan-weathering dolostone interbedded with dark grey, light grey-weathering mudstone. This unit is planar and wavy bedded. Dolostones are 2.5–15 cm thick, wave-rippled and composed of non-planar dolomite with minor siliciclastic grains. Mudstone laminae are <1–5 mm thick, featureless and composed of clay-sized particles with minor silt. <i>Planolites</i> , <i>Palaeophycus</i> and <i>Teichichnus</i> are present on endichnial and hypichnial surfaces of dolostones. BI=0–2 (lowest in the middle of the unit). Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	4.3	27.3

Mount Clark Formation

6	Brownish grey, pale brown-weathering sandstone. Beds are 10–35 cm thick, planar and wavy, amalgamated and internally featureless. Sandstones are arenitic in composition and consist of medium to fine sand-sized grains. Thin	2.2	23.0
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	<p>mudstone laminae and partings are present in between sandstone beds. <i>Teichichnus</i> and <i>Planolites</i> are present on endichnial and hypichnial surfaces. BI=1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p>		
5	<p>Brownish grey, pale brown-weathering sandstone. This unit is mottled, argillaceous sandstone in composition and consists of fine to very- fine sand-sized grains. The top 10 cm's of this unit is featureless mudstone composed of clay-sized particles with minor silt. <i>Teichichnus</i>, <i>Palaeophycus</i>, <i>Planolites</i>, <i>Skolithos</i> and rare <i>Cruziana</i> are present on endichnial and hypichnial surfaces of sandstones. BI=3–4. Body fossils are absent. Internal contacts are gradational or sharp. Basal contact is gradational.</p>	1.3	20.8
4	<p>Brownish grey, pale brown-weathering sandstones. This unit is planar and wavy bedded. Beds are 10–35 cm thick, amalgamated and internally featureless. Sandstones are arenitic in composition and consist of fine sand-sized grains. Thin mudstone laminae and partings are present in between sandstone beds. <i>Skolithos</i> and <i>Palaeophycus</i> are present on hypichnial, epichnial and endichnial surfaces. BI=1. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.</p>	0.5	19.5
3	<p>Brownish grey, pale brown-weathering sandstone. This unit is mottled, argillaceous sandstone in composition and consists of fine to very- fine sand-sized grains. The top 5 cm's of this unit is featureless mudstone composed of clay-sized particles with minor silt. <i>Teichichnus</i> and <i>Planolites</i> are present on endichnial and hypichnial surfaces. BI= 3–4.</p>	1.6	19.0

Body fossils are absent. Internal contacts are gradational or sharp. Basal contact is sharp.

2	<p>Pale grey, reddish brown-weathering sandstone. This unit is tabular and trough cross-bedded and cross-laminated with minor wave-ripple cross-laminations. Sandstones are arenitic in composition and consist of medium sand-sized grains. Thin mudstone laminae are present in between sand beds. <i>Skolithos</i>, <i>Arenicolites</i> and <i>Diplocraterion</i> are present on endichnial surfaces and <i>Palaeophycus</i> is present on hypichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is covered.</p>	2.1	17.4
	Covered	5.0	15.3

Stone Knife Formation

1	<p>Brown, orange-weathering dolostone. This unit is featureless or planar bedded with minor brecciated horizons and stromatolites. This unit is composed of crystalline dolomite. Trace and body fossils are absent. Basal contact is covered.</p>	10.3	10.3
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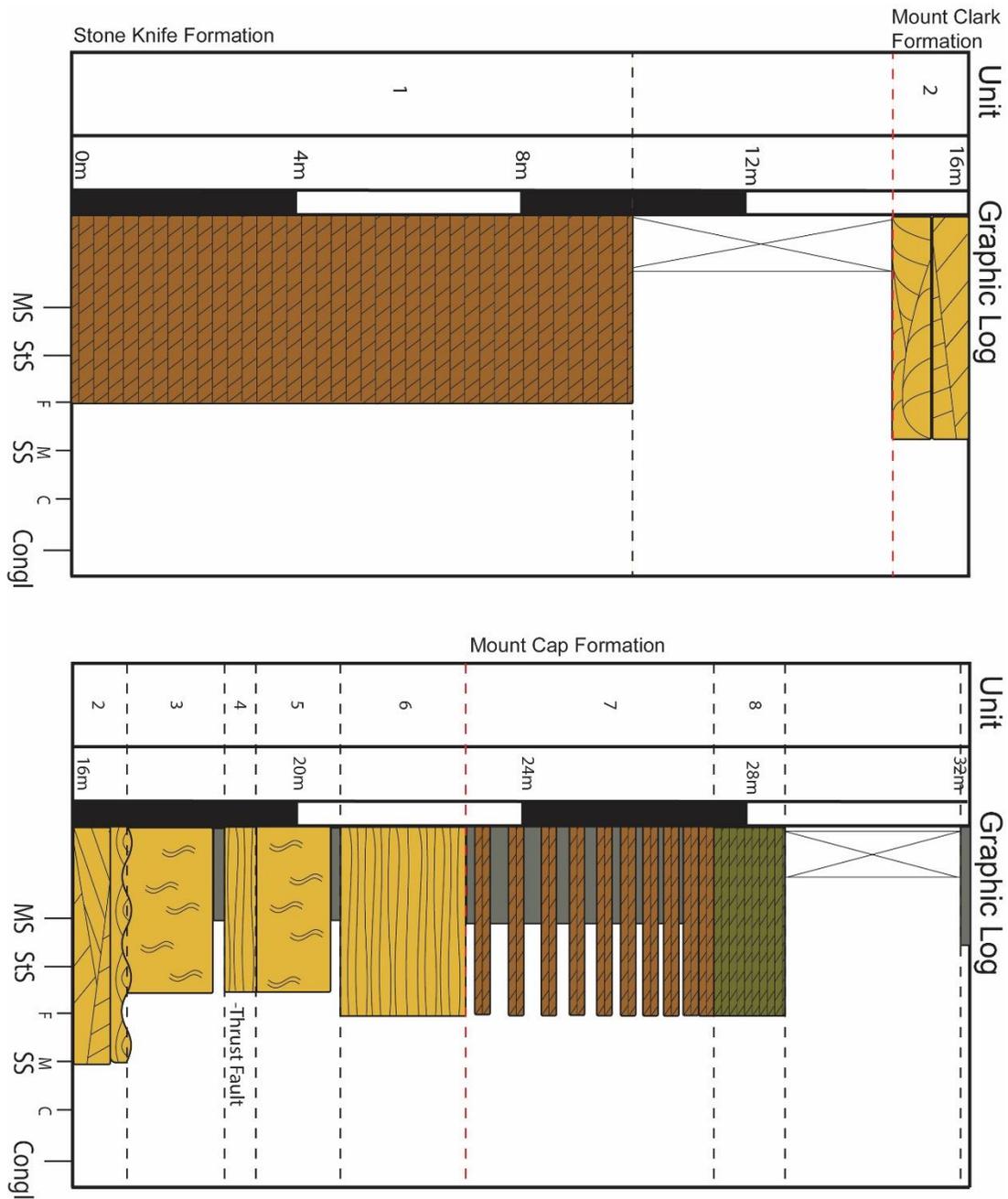


Figure B.1. Graphic log of the section at Little Bear River, showing unit divisions; 0–32.0 m. Red dashed lines indicate lithostratigraphic boundaries.

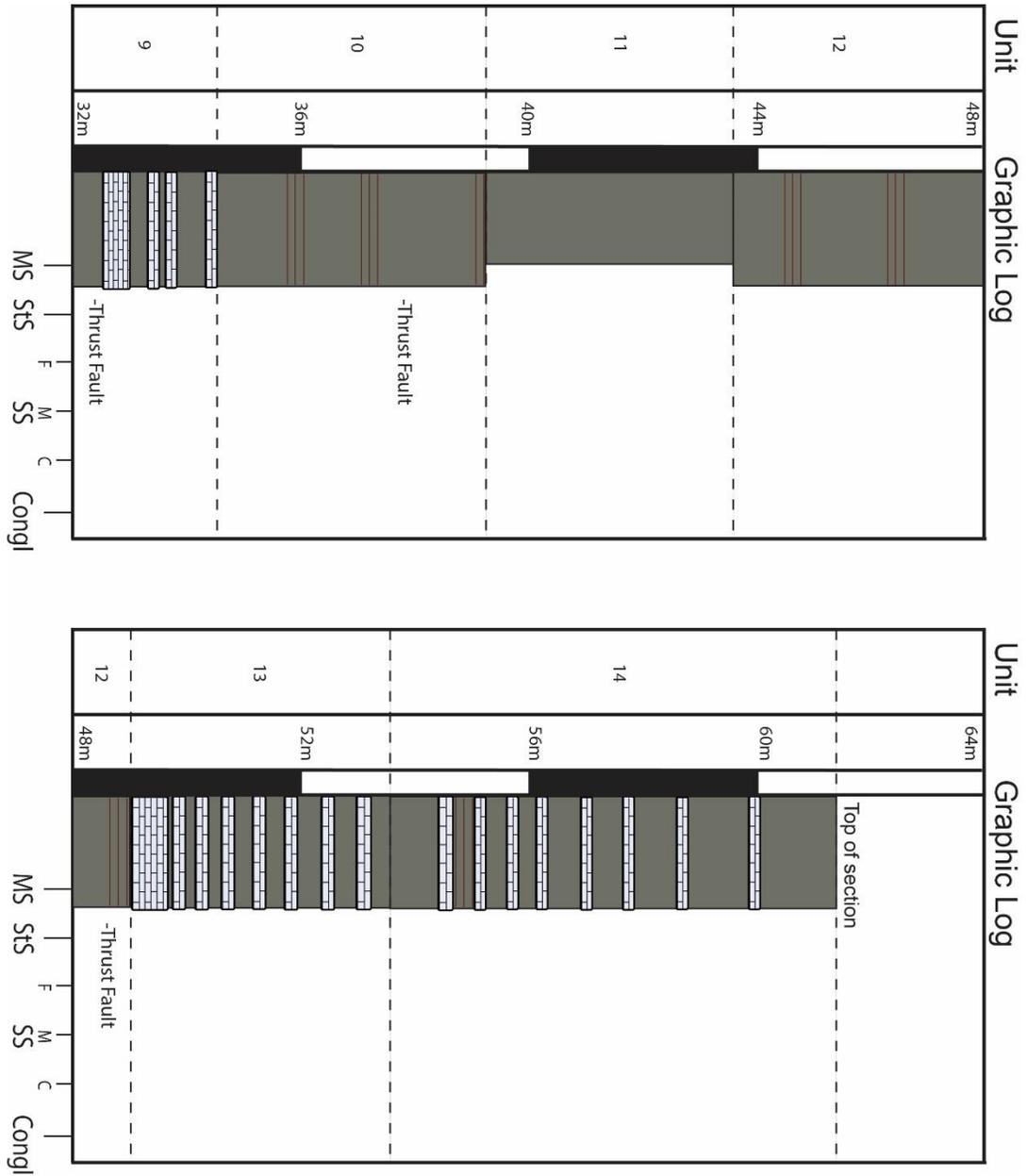


Figure B.2. Graphic log of the section at Little Bear River, showing unit divisions; 32.0–61.0 m.

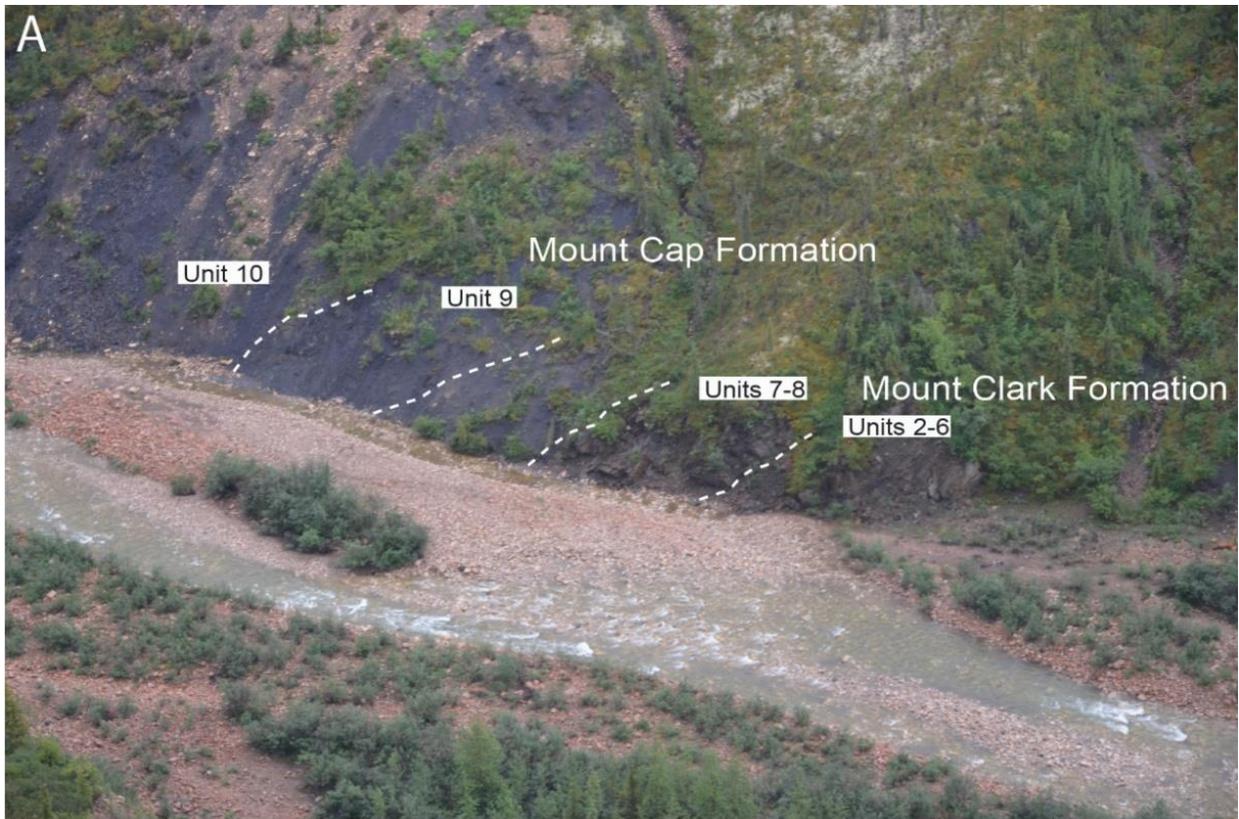


Figure B.3. Outcrop view at Little Bear River. All photographs by N.M. Handkamer. **A)** Unit divisions of the Mount Clark and upper Mount Cap formations. Outcrop thickness = ~40 m. Photo 2020-250. **B)** Unit 8 interbedded arenaceous dolostone with thin mudstone laminae and partings. Hammer length = 27.5 cm. Photo 2020-251. **C)** Unit 3 mottled sandstone. Hammer length = 27.5 cm. Photo 2020-252. **D)** Contact between units 13 and 14 showing decreasing carbonate upwards in each unit. Stratal thickness = ~5.2 m. Photo 2020-253. **E)** Thrust fault cross-cutting unit 12. Stratal thickness of hanging wall block = ~2 m. Photo 2020-254.

APPENDIX C: MEASURED SECTION DATA, INLIN BROOK

Section 3: Inlin Brook: (NTS 96D, 64.282846° N, 126.543348° W)

This section (Figs. C.1 and C.2) is exposed on the west side of Inlin Brook, about 8 km upriver from the junction with Keele River. This section was previously measured by Serié et al. (2013). Limited time was available for measuring the upper part of this section, and these observations should be considered to be at reconnaissance level. The section is within an overturned anticline that has been thrust onto the Saline River and Franklin Mountains formations. The Mount Clark Formation reportedly overlies the Stone Knife Formation of the Little Dal Group (Serié et al., 2013). Only the basal part of the mudstone-dominated Mount Cap Formation is accessible in this section. Some faulting was observed at the base of the Mount Clark Formation, but the sense of movement is unknown.

Unit	Description	Unit thickness (m)	Cumulative thickness (m)
mudstone-dominated Mount Cap Formation			
7	Dark grey, grey-, red- and yellow-weathering mudstone. This unit is massive, fissile and composed of clay-sized particles with sulfur-rich horizons. Trace fossils are absent. Olenellids and hyoliths are present at the top, but overall, the unit is unfossiliferous. Collection 3.1. Basal contact is sharp.	4.8	18.9
6	Black, dark grey-weathering arenaceous dolostone. Beds are 1–15 cm thick, wave-rippled and composed of non-planar dolomite with minor siliciclastic grains. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is poorly exposed but appears to be sharp.	1.3	14.1

Mount Clark Formation

5	<p>Beige, tan- and brown-weathering sandstone. Beds are 3–14 cm thick, wavy bedded, amalgamated and internally featureless with minor wave-rippling and siltstone laminae in between sandstone beds. Sandstones are argillaceous sandstones in composition and consist of coarse to medium sand-sized grains. Bioturbated horizons are present, but overall bioturbation is low. <i>Teichichnus</i>, <i>Palaeophycus</i> and <i>Planolites</i> are present on endichnial and hypichnial surfaces. BI=0–4. Body fossils are absent. Internal contacts are sharp. Basal contact is poorly exposed</p>	2.9	12.8
4	<p>Beige, tan- and brown-weathering sandstone. This unit is wavy bedded and mottled with minor trough cross-lamination and mudstone laminae. Sandstones are argillaceous sandstones in composition and consist of fine to medium sand-sized grains. <i>Palaeophycus</i>, <i>Teichichnus</i>, <i>Planolites</i> and rare <i>Cruziana</i>, <i>Skolithos</i>, <i>Arenicolites</i> and <i>Diplocraterion</i> are present on endichnial surfaces. BI=3–4. Body fossils are absent. Basal contact is sharp.</p>	0.8	9.9
3	<p>Grey and pale blue, beige-weathering sandstone. This unit is normally graded and trough and tabular cross-laminated. Sandstones are arenitic in composition and consist of coarse to fine sand-sized grains with minor granules at the base. Trace and body fossils are absent. Internal contacts are sharp or erosional. Basal contact is gradational.</p>	7.8	9.1
2	<p>Beige and pale blue, pale blue-weathering conglomerate. This unit is lenticular and wavy, clast supported at the base</p>	0.7	1.3

(70% clasts, 30% matrix) and gradually becomes matrix supported upwards (50% sand, 50% matrix). Clasts are 0.5–7 cm in size, subangular to subrounded, equant and composed of quartzite. Matrix is trough and tabular cross-laminated or featureless sandstone, composed of coarse sand-sized grains and is arenitic in composition. Trace and body fossils are absent. Basal contact is erosive.

Stone Knife Formation

- | | | | |
|---|--|-----|-----|
| 1 | Brown, orange-weathering dolostone. This unit is massive or thick bedded with minor mudstone beds. Dolostone is composed of crystalline dolomite. Trace and body fossils are absent. Basal contact was not observed. | 0.6 | 0.6 |
|---|--|-----|-----|

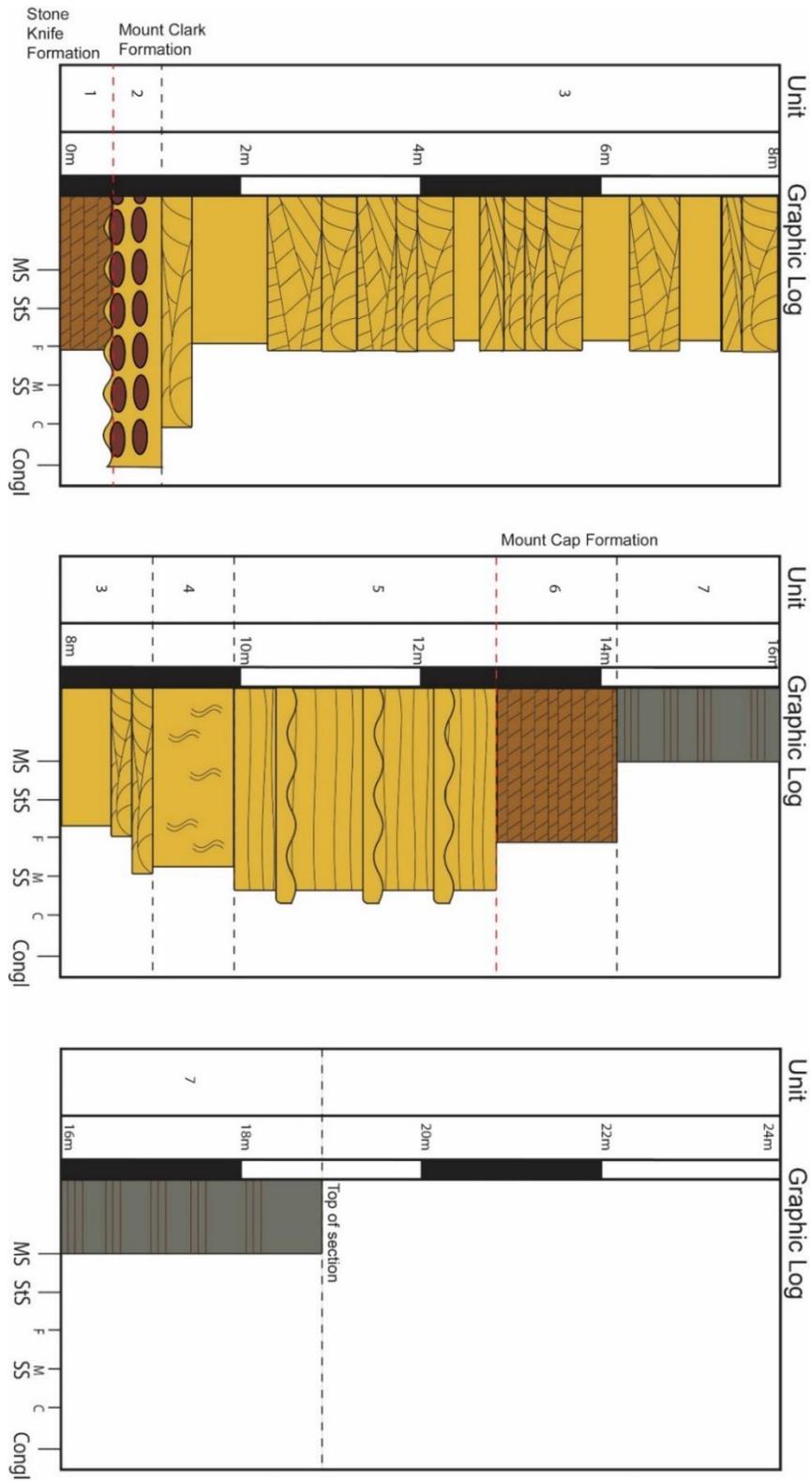


Figure C.1. Graphic log of the section at Inlin Brook, showing unit divisions; 0–18.9 m. Red dashed lines indicate lithostratigraphic boundaries.

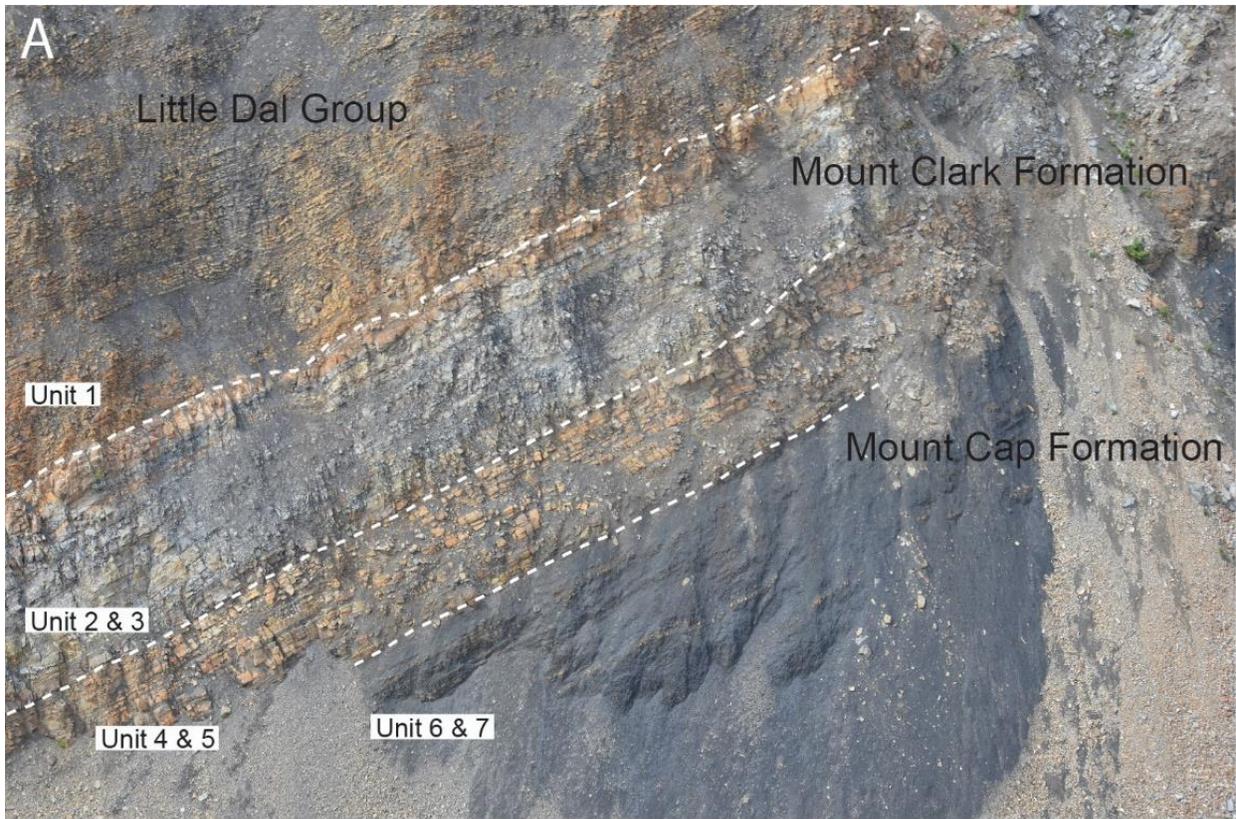


Figure C.2. Outcrop view at Inlin Brook. All photographs by N.M. Handkamer. **A)** Lithostratigraphic and unit divisions at Inlin Brook. Beds are overturned. Outcrop thickness = 18.9 m. Photo 2020-255. **B)** Unit 2 conglomerate. This bed is overturned, and the base is visible. Pen length = 12 cm. Photo 2020-256. **C)** Unit 3 trough cross-lamination. Cross-beds are overturned. Finger length = 7 cm. Photo 2020-257. **D)** Unit 6 dolostone. Beds are overturned. Stratal thickness = 1.3 m. Photo 2020-258. **E)** Cut and polished sample of an endichnial surface of the bioturbated sandstone of unit 4. Photo 2020-259.

APPENDIX D: MEASURED SECTION DATA, CARCAJOU FALLS

Section 4: Carcajou Falls: (NTS 96D, 64.670639° N, 127.1616.82° W)

This section (Figs. D.1, D.2 and D.3) was measured on the south side of Carcajou River, between the first and second set of falls. This section is a reference section for the Cambrian stratigraphy of the Foran Anticline. It has been previously studied by (Serié et al., 2013) (see also MacNaughton et al., 2013). The upper part of the section is well exposed in a canyon upstream from the second set of falls (Figure 12A), while the lower part was measured farther upstream from the second set of falls. The lower part of the section was compared to another exposure downriver by the second set of falls to the north in order to understand the lateral thickness of the basal units. The entire succession is exposed in a very open syncline. Basal Mount Clark Formation and Precambrian strata were not accessible, but the Mount Clark Formation has been reported to overlie the Stone Knife Formation of the Little Dal Group (Serié et al., 2013). The upper contact of the Mount Cap Formation with the Saline River Formation is not exposed at this section.

Unit	Description	Unit thickness (m)	Cumulative thickness (m)
mudstone-dominated Mount Cap Formation			
31	Black, dark grey-weathering mudstone with minor buff, beige-weathering bioclastic lime mudstone and rare minor bioclastic floatstones. Mudstone beds are fissile, fossiliferous and composed of clay-sized particles with minor calcareous material. Limestone beds and laminae are 2–50 mm thick, planar bedded, featureless and composed of trilobite bioclasts in a micrite and microspar matrix. Floatstones have higher concentrations of bioclasts. Trace fossils are absent.	1.1	38.3

Identifiable corynexochids are present in outcrop. Collection 4.6F. Internal contacts are sharp. Basal contact is sharp.

30	Dark grey, brownish green-weathering mudstone. This unit is planar-bedded, thinly laminated, fissile, fossiliferous and composed of clay-sized particles. Trace fossils are absent. Corynexochids are present. Collection 4.6E. Internal contacts are sharp. Basal contact is sharp.	0.9	37.2
29	Black, dark grey-weathering mudstone with minor buff, beige-weathering bioclastic lime mudstone with rare bioclastic floatstones. Mudstone beds are fissile, fossiliferous and composed of clay-sized particles with minor silt and calcareous material. Limestone beds are 2–50 mm thick, nodular and composed of trilobite bioclasts in a micrite and microspar matrix. Floatstones have higher concentrations of bioclasts. Trace fossils are absent. Identifiable corynexochids are present in outcrop. Collection 4.6D. Internal contacts are sharp. Basal contact is gradational.	3.4	36.3
28	Black, dark grey-weathering mudstone interbedded with pale blue, yellowish beige-weathering lime mudstone and minor wackestones. This unit is 60% mudstone, 40% lime mudstone and wackestone and planar bedded. Mudstone beds are 20–50 mm thick, fissile, fossiliferous and composed of clay-sized particles with minor calcareous material. Lime mudstone and wackestone beds are 10– 20 mm thick, nodular and composed of trace linguliformean brachiopod and trilobite bioclasts in a matrix of micrite with microspar. Thin sections reveal that burrows are present in lime mudstone. Identifiable corynexochids and linguliformean	0.7	32.9

brachiopods are present in outcrop. Collection 4.6C. Internal contacts are sharp. Basal contact is sharp.

27	Pale beige, orange- and beige-weathering bioclastic grainstone. This unit is lenticular, featureless and composed trilobite and minor linguliformean brachiopod bioclasts in sparite. Bioclasts have bladed calcite rinds, and pores are infilled by blocky sparite and minor micrite and microspar. Trace fossils are absent. Identifiable corynexochids are present in outcrop. Collection 4.7B. Basal contact is sharp.	0.1	32.2
26	Black, dark grey-weathering mudstone interbedded with pale blue- and yellow beige-weathering lime mudstone and minor wackestones. This unit is 60% mudstone, 40% lime mudstone and wackestone and planar bedded. Mudstone beds are 20–50 mm thick, fissile, fossiliferous and composed of clay-sized particles with minor calcareous material. Lime mudstone and wackestone beds are 10– 20 mm thick, nodular and composed of trace linguliformean brachiopod and trilobite bioclasts in a matrix of micrite and microspar. Thin sections reveal that burrows are present in lime mudstone beds. Identifiable corynexochids are present in outcrop. Collection 4.6B. Internal contacts are sharp. Basal contact is sharp.	1.8	32.1
25	Pale beige, orange- and beige-weathering bioclastic grainstone. This unit is lenticular, featureless and composed trilobite and minor linguliformean brachiopod bioclasts in sparite. Bioclasts have bladed calcite rinds, and pores are infilled by blocky sparite with minor micrite and microspar.	0.1	30.3

Trace fossils are absent. Identifiable corynexochids are present in outcrop. Collection 4.7A. Basal contact is sharp.

24	<p>Black, dark grey-weathering mudstone interbedded with pale blue, yellow beige-weathering lime mudstone and minor wackestone. This unit is 60% mudstone, 40% lime mudstone and wackestone and planar bedded. Mudstone beds are 20–50 mm thick, fissile, fossiliferous and composed of clay-sized particles with minor calcareous material. Lime mudstone and wackestone beds are 10– 20 mm thick, nodular and composed of trace linguliformean brachiopod and trilobite bioclasts in a matrix of micrite and microspar. Thin sections reveal that burrows are present in lime mudstone beds. Identifiable corynexochids are present in outcrop. Collection 4.6A. Internal contacts are sharp. Basal contact is sharp.</p>	0.6	30.2
23	<p>Pale blue, beige-weathering lime mudstone. This unit is planar and wavy bedded and laminated, beds and laminae 2–20 mm thick and composed of microspar that is partially dolomitized. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p>	0.4	29.6
22	<p>Black, dark grey-weathering mudstone. This unit is laterally continuous, thinly laminated, fissile and composed of clay-sized particles with minor silt, calcareous material and pyrite. Trace fossils are absent. Corynexochids are rare. Collection 4.5C. Internal contacts are sharp. Basal contact is sharp.</p>	1.1	29.2

21	Blue, beige-weathering lime mudstone. This unit is planar bedded and laminated, beds and laminae 2–20 mm thick and composed of microspar that is partially dolomitized. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	0.4	28.1
20	Grey, light grey- and rusty-weathering siltstone and mudstone. This unit is laterally continuous, fissile and composed of silt-sized particles at the base grading upward into clay-sized particles with minor calcareous material. Trace fossils are absent. Corynexochids are rare. Collection 4.5B. Internal contacts are gradational. Basal contact is sharp.	1.1	27.7
	Covered	2.2	26.6
19	Pale blue, greenish beige-weathering lime mudstone. Beds are 2–24 cm thick, nodular and composed of microspar with trace argillaceous particles. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	4.9	24.4
18	Grey, pale grey- and rusty-weathering mudstone. This unit is laterally continuous, fissile, composed of clay-sized particles and is sulfur-rich with minor calcareous material. The middle of this unit is lenticular, weakly fissile and composed of silt-sized particles. Trace fossils are absent. Corynexochids are rare. Collection 4.5A. Internal contacts are gradational. Basal contact is sharp.	1.0	19.5
17	Pale blue, greenish beige-weathering lime mudstone. This unit is planar bedded. Beds are 2–20 cm thick, nodular and	0.6	18.5

composed of microspar that is partially dolomitized. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.

16	<p>Grey, pale grey- and rusty-weathering mudstone. This unit is laterally continuous, fissile, composed of clay-sized particles and is sulfur-rich with minor calcareous material. The middle of the unit is lenticular, weakly-fissile and composed of silt-sized particles. Trace fossils are absent. Corynexochids and linguliformean brachiopods are rare. Collection 4.4. Internal contacts are gradational. Basal contact is sharp.</p>	1.6	17.9
15	<p>Pale blue, greenish beige-weathering lime mudstone. Beds are 2–20 cm thick, nodular and composed of microspar that is partially dolomitized. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p>	0.3	16.3
14	<p>Grey, pale grey- and rusty-weathering mudstone. This unit is laterally continuous, fissile, composed of clay-sized particles and is sulfur-rich. The middle of the unit is lenticular, weakly-fissile and composed of silt-sized particles. Trace fossils are absent. Corynexochids are rare. Collection 4.3. Internal contacts are gradational. Basal contact is covered.</p>	1.6	16.0
	<p>Covered</p>	1.2	14.4
13	<p>Pale blue, orange-weathering dolomitic lime mudstone with minor mudstone beds. Lime mudstone beds and laminae are 1–80 mm thick, planar and wavy bedded and composed of microspar that is partially dolomitized with minor</p>	2.9	13.2

argillaceous particles. Minor wave-ripples, hummocks and swales are present. Mudstone beds are 2–15 cm thick, fissile and composed of clay-sized particles with minor silt. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.

- | | | | |
|----|--|-----|------|
| 12 | Dark grey, pale grey-weathering siltstone with pale blue, beige-weathering limestone concretions. This unit is 65% siltstone, 35% limestone concretions and wavy bedded. Siltstone beds and laminae are 1–20 mm thick, featureless, fissile and composed of silt-sized particles with minor clay. Limestone concretion beds are 4–20 mm thick and composed of micrite and microspar with trace argillaceous material and linguliformean brachiopod bioclasts. <i>Planolites</i> , <i>Teichichnus</i> , <i>Cruziana</i> and other unidentified trace fossils are present on hypichnial and epichnial surfaces of limestone concretions. BI=0–2. Corynexochids and ptychoparioids are present in siltstone beds. Collection 4.2B. Internal contacts are sharp. Basal contact is gradational. | 0.7 | 10.3 |
| 11 | Dark grey, pale grey-weathering mudstone. This unit is laterally continuous, fissile and composed of clay-sized particles with minor silt. <i>Planolites</i> are rare on endichnial surfaces. BI=0–1. Corynexochids and ptychoparioids are present. Collection 4.2A. Basal contact is gradational. | 0.8 | 9.6 |
| 10 | Dark grey, light grey-weathering siltstone with pale blue, beige-weathering limestone concretions. This unit is 65% siltstone, 35% limestone concretions and wavy bedded. Siltstone beds are 1–20 mm thick, featureless, fissile and composed of silt-sized particles with minor clay. Limestone | 0.1 | 8.8 |

	concretion beds are 4–20 mm thick and composed of micrite and microspar. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is covered.		
	Covered	0.2	8.7
9	Black, dark grey-weathering mudstone. This unit is laterally consistent, fissile and composed of clay- and silt-sized particles. A thin, well-cemented and fossiliferous bed composed of silt-sized particles is present close to the top of this unit. Above and below the fossiliferous bed are horizons rich in large phosphatic concretions. Trace fossils are absent. Hyoliths and trace ptychoparioids are present in the fossiliferous bed. Hyoliths, ptychoparioids and corynexochids are present in mudstone beds. Collection 4.1. Internal contacts are sharp. Basal contact is covered.	0.6	8.5
	Covered	0.8	7.9
8	Pale blue, orange- and grey-weathering calcareous dolostone interbedded with pale blue, grey-weathering arenaceous dolostone. This unit is 70% calcareous dolostone, 30% arenaceous dolostone and is wavy bedded. Calcareous dolostone beds are 2–10 cm thick, wave-rippled and composed of planar and non-planar dolomite with minor microspar and argillaceous particles. Arenaceous dolostone beds and laminae are 0.5–2 cm thick and composed of planar and non-planar dolomite with minor siliciclastic grains. <i>Skolithos</i> is rare. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	2.0	7.1

Mount Clark Formation

7	<p>Pale green, greenish red-weathering sandstone. Beds are wavy with trough cross-laminations at the base and wave-ripple cross-laminations at the top. Sandstone is arenitic in composition with minor glauconite and consists of coarse sand-sized grains. Unidentified horizontal burrows are present at the base. BI=0–1. Body fossils are absent. Internal contacts are erosive. Basal contact is erosive.</p>	0.4	5.1
6	<p>Pale blue, pale grey-weathering sandstone. This unit thickens towards the north. Beds are wavy, amalgamated and internally featureless with minor tabular and trough cross-laminations. Sandstones are arenitic in composition and consist of coarse to medium sand-sized grains. The top 3 cm of this unit contains glauconite and minor phosphatic concretions. <i>Skolithos</i> and <i>Arenicolites</i> are present on endichnial surfaces. BI=1–2. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.</p>	0.6	4.7
5	<p>Pale blue, pinkish white-weathering sandstone. This unit is not present to the north. Beds are 5–15 cm thick, the basal bed is wave-rippled and overlain by trough and tabular cross-stratified beds. Sandstones are arenitic in composition and consist of coarse to medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is erosional.</p>	0.5	4.1
4	<p>Yellowish brown, maroon-weathering sandstone. This unit thins towards the north. Beds are 1–15 cm thick, wavy and lenticular, amalgamated and wave-rippled with minor</p>	0.5	3.6

swales. Sandstones are argillaceous sandstones in composition and consist of fine to very- fine sand-sized grains. *Teichichnus*, *Planolites*, *Cruziana*, *Rusophycus*, *Palaeophycus*, *Skolithos*, *Diplocraterion* and *Monocraterion* are present on endichnial and hypichnial surfaces. BI=3–4. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.

3	Pale blue, pinkish white-weathering sandstone. This unit thickens to the north. Beds are 5–13 cm thick, the basal bed is wave-rippled and overlain by trough cross-stratified beds. Sandstones are arenitic in composition and consist of coarse to medium sand-sized grains. <i>Skolithos</i> and <i>Bergaueria</i> are rare on endichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is erosive.	0.5	3.1
2	Yellowish brown, maroon-weathering sandstone. This unit thins towards the north. Beds are 1–15 cm thick, wavy and lenticular, amalgamated and wave-rippled with minor swales. Sandstones are argillaceous sandstones in composition and consist of fine to very- fine sand-sized grains. <i>Skolithos</i> , <i>Diplocraterion</i> , <i>Techichnus</i> , <i>Planolites</i> , <i>Palaeophycus</i> and minor escape traces are present on endichnial and hypichnial surfaces. BI=1–3. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	1.5	2.6
1	Pale-blue, pinkish white-weathering sandstone. Beds 2–18 cm thick, planar and wavy, amalgamated and internally featureless. Beds are arenitic in composition and consist of fine sand-sized grains. <i>Skolithos</i> , <i>Arenicolites</i> and rare	1.1	1.1

Planolites and *Palaeophycus* are present on endichnial surfaces. BI=1. Body fossils are absent. Internal contacts are sharp. Basal contact is covered.

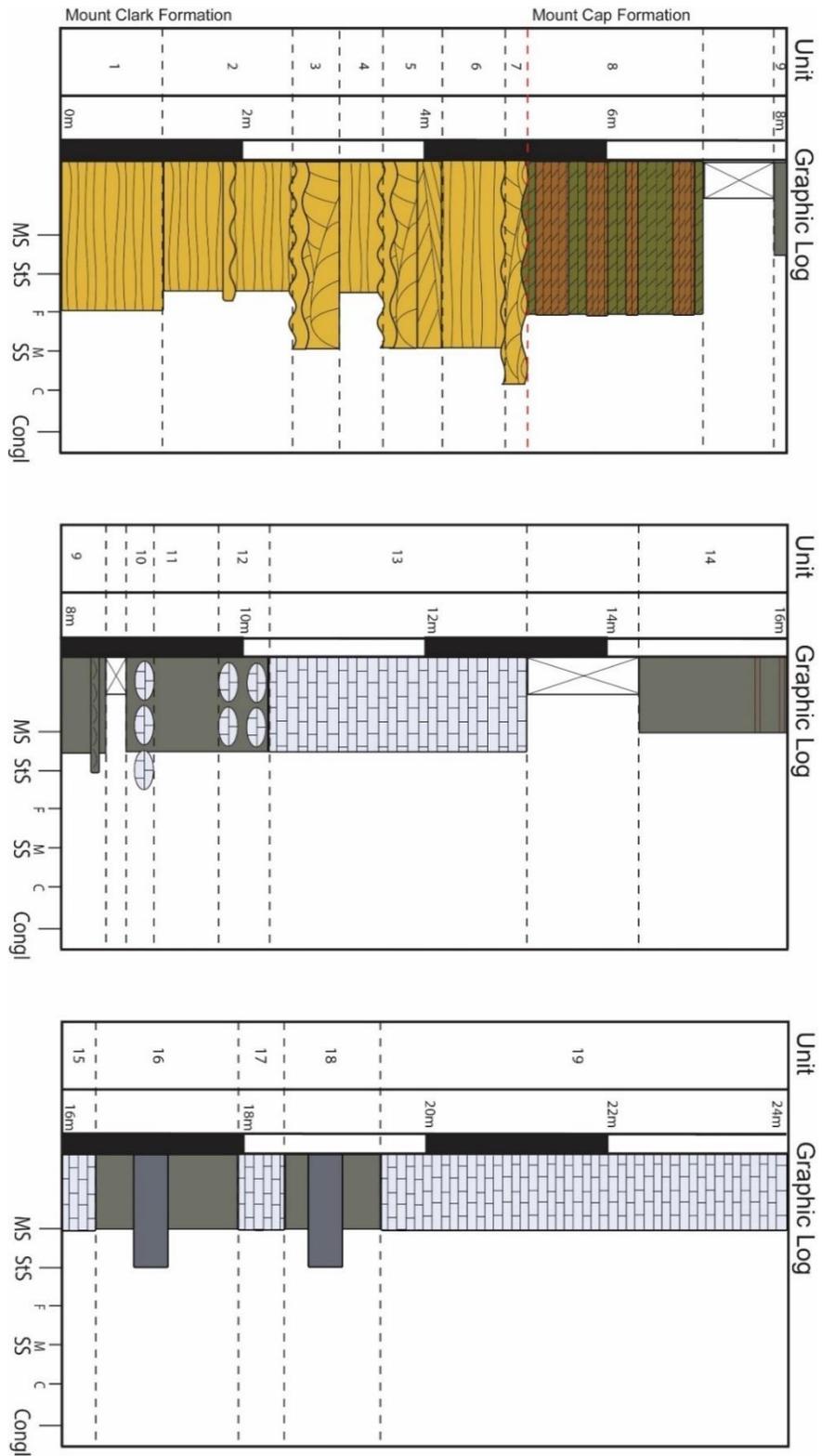


Figure D.1. Graphic log of the section at Carcajou Falls, showing unit divisions; 0–24.0 m. Red dashed line indicates the lithostratigraphic boundary.

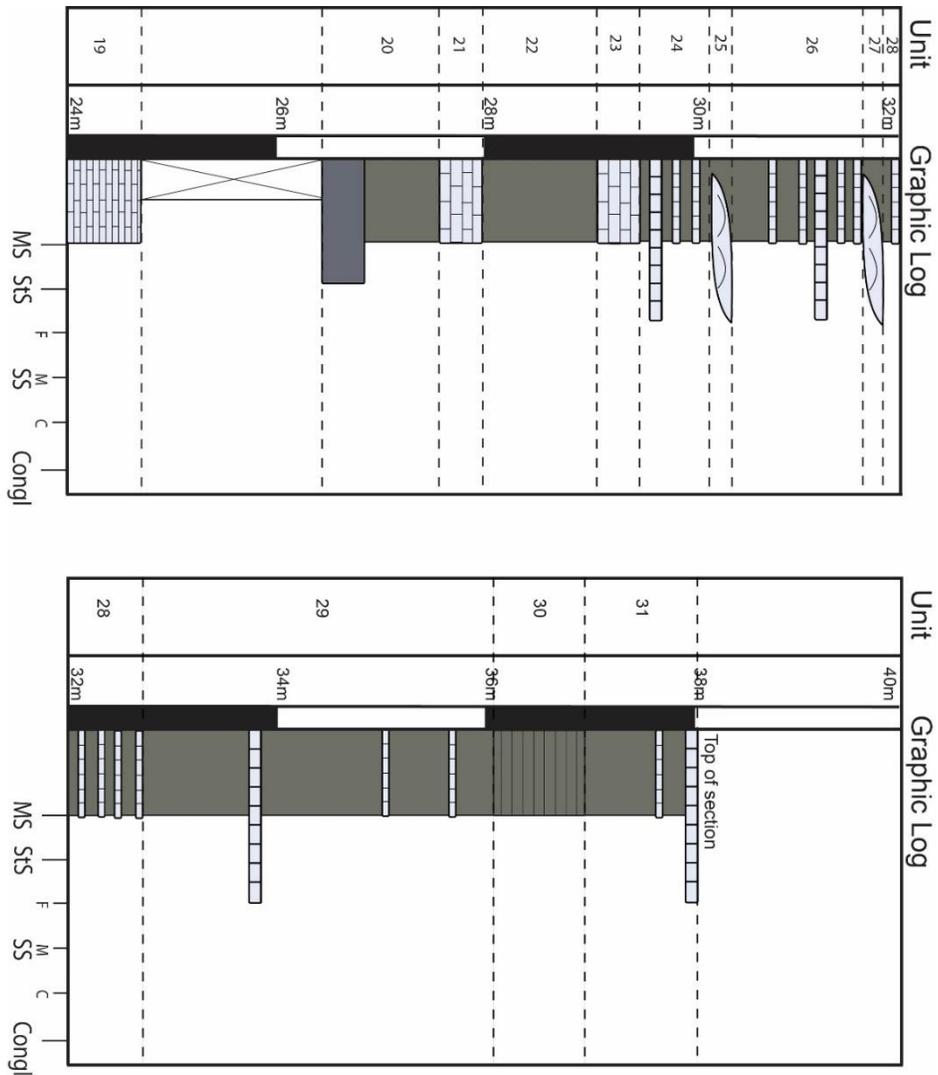


Figure D.2. Graphic log of the section at Carcajou Falls, showing unit divisions; 24.0–38.3 m.

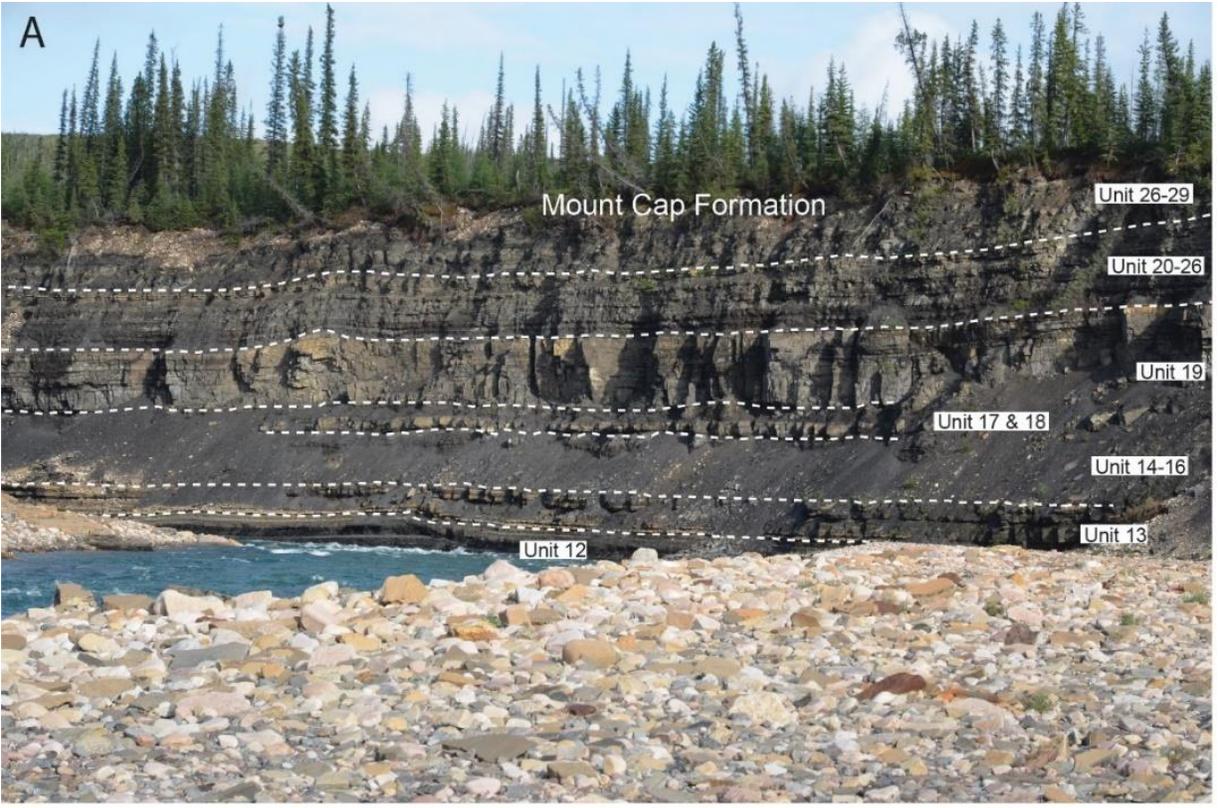


Figure D.3. Outcrop view at Carcajou Falls. All photographs by N.M. Handkamer. **A)** Unit divisions of the Mount Cap Formation. This was not the outcrop measured due to access, but exposure is good. Outcrop thickness = 28.2 m. Photo 2020-260. **B)** Basal units of the Mount Clark Formation. The bed with the hammer leaning against it represents a preserved 3D dune. Hammer length = 27.5 cm. Photo 2020-261. **C)** Basal to middle units of the Mount Clark Formation. Note, in unit 4, the thinning of a bed with the pencil leaning on it preserves a swale. Pencil length = 7 cm. Photo 2020-262. **D)** Hypichnial surface of unit 4. Fingernail length = 1 cm. This bed is located north of the measured outcrop upstream from the second set of falls, where hypichnial surfaces are better exposed. Photo 2020-263. **E)** Unit 24 interbedded lime mudstone and mudstone. Pencil length = 7cm. Photo 2020-264.

APPENDIX E: MEASURED SECTION DATA, GRAFE RIVER

Section 5: Grafe River: (NTS 96D, 64.988407° N, 127.649351° W)

This section (Figs. E.1, E.2, E.3 and E.4) was measured on both the west and east sides of Grafe River. This section was previously measured by Serié et al. (2013). Each side of the canyon walls is on separate fault blocks and the river cuts along the fault plane, forming the canyon. The basal Precambrian units have been reported as the Abraham Plains Formation of the Katherine Group and the Dodo Creek Formation of the Little Dal Group (Serié et al., 2013). The upper contact of the Mount Cap Formation was not accessible at this site.

Unit	Description	Unit thickness (m)	Cumulative thickness (m)
mudstone-dominated Mount Cap Formation			
39	Black, dark grey-weathering mudstone interbedded with pale beige, yellow-weathering dolomitic lime mudstone. This unit is 50% mudstone and 50% dolomitic lime mudstone at the base and increasing in mudstone upwards. Mudstone beds are 5–40 cm thick, laterally continuous, fissile and composed of clay-sized particles with minor silt and calcareous material. Dolomitic lime mudstone beds are 10–20 cm thick, nodular and composed of microspar that is partially dolomitized. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	4.0	116.2
38	Black, dark grey-weathering mudstone. This unit is laterally continuous and fissile with minor dolomitic limestone concretions. Mudstones are composed of clay-sized particles with minor silt and calcareous material. Dolomitic limestone	2.6	112.2

concretions form beds 2–8 cm thick and are composed of microspar. *Palaeophycus* and *Teichichnus* are present on hypichnial surfaces of limestone concretions and *Planolites* is rare on epichnial surfaces of mudstone beds. BI=0–1. Corynexochids and linguliformean brachiopods are rare. Collection 5.1. Internal contacts are sharp. Basal contact is gradational.

37	Black, dark grey-weathering mudstone interbedded with pale beige, yellow-weathering dolomitic lime mudstone. This unit is 50% mudstone and 50% dolomitic lime mudstone at the base and increasing in mudstone upwards. Mudstone beds are 5–40 cm thick, laterally continuous, fissile and composed of clay-sized particles with minor silt and calcareous material. Dolomitic lime mudstone beds are 10–20 cm thick, nodular and composed of microspar that is partially dolomitized. <i>Palaeophycus</i> and <i>Teichichnus</i> are present on hypichnial surfaces of dolomitic lime mudstone beds. BI=0–1. Linguliformean brachiopods and hyoliths are present in mudstone beds. Internal contacts are sharp. Basal contact is covered.	2.0	109.6
	This unit was inaccessible but appeared to be a brown sandstone or carbonate due to the weathering profile.	6.0	107.6
36	Grey, grey-weathering argillaceous and arenaceous dolostone. Beds are 10–50 cm thick, wavy and lenticular bedded and nodular with minor stylolites. This unit is composed of planar and non-planar dolomite with variable siliciclastic grains and argillaceous particles. Trace fossils are absent. Linguliformean brachiopods are rare, visible only	5.4	101.6

in thin section. Internal contacts are sharp. Basal contact is sharp.

Mount Clark Formation

35	White, yellow-weathering sandstone. This unit is wavy bedded, wave-ripple cross-laminated, arenitic in composition and consisting of medium sand-sized grains. Trace and body fossils are absent. Basal contact is erosional.	0.1	96.2
34	Maroon and white, greenish yellow- and brown-weathering sandstone. Beds are 10–16 cm thick, wavy, amalgamated and internally featureless. Sandstones are argillaceous sandstones in composition and consist of medium to fine sand-sized grains. <i>Planolites</i> , <i>Teichichnus</i> , <i>Palaeophycus</i> and minor <i>Skolithos</i> and <i>Arenicolites</i> are present on endichnial and hypichnial surfaces. BI= 2–3. The top-most bed (15 cm thick) displays <i>Skolithos</i> and <i>Arenicolites</i> on endichnial surfaces. BI=1–2. Body fossils are absent. Internal contacts are sharp. Basal contact is covered.	1.4	96.1
	Covered	3.0	94.7
33	Maroon, dark brown-weathering sandstone. This unit is trough cross-bedded and beds are internally featureless with minor wave-rippling and current-rippling. Sandstones are arenitic in compositions and consist of fine sand-sized grains. <i>Skolithos</i> , <i>Teichichnus</i> , <i>Palaeophycus</i> and <i>Planolites</i> are present on endichnial and hypichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	3.1	91.7

32	<p>Maroon, brown-weathering sandstone. Beds are wavy, amalgamated and internally featureless with minor wave-rippling. Sandstones are arenitic in composition and consist of fine to very- fine sand-sized grains. <i>Skolithos</i> is present on endichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.</p>	0.7	88.6
31	<p>Brown, dark brown-weathering sandstone. This unit is trough cross-bedded and wave-rippled. The basal 30 cm is planar-laminated. Sandstones are argillaceous sandstones in composition and consist of fine to very- fine sand-sized grains. <i>Palaeophycus</i> is rare on hypichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is erosional.</p>	4.0	87.9
30	<p>Brown, dark brown-weathering sandstone interbedded with green, pale green-weathering siltstone. This unit is 80% sandstone and 20% siltstone. Sandstone beds are 2–23 cm thick, planar and wavy bedded and featureless grading into wave-rippling and hummocky cross-stratification. The bases of sandstone beds have gutter casts. Sandstones are argillaceous sandstones in composition and consist of fine to very- fine sand-sized grains. Siltstone beds and laminae are <1–20 mm thick, laterally continuous, fissile and composed of silt-sized particles. <i>Palaeophycus</i> and <i>Phycodes</i> are rare on hypichnial surfaces of sandstones. BI=0–1. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is erosional.</p>	2.2	83.9

29	Brown, dark brown-weathering sandstone interbedded with green, pale green-weathering siltstone. This unit is composed of 75% sandstone and 25% siltstone. Sandstones form lenses (not observed on the other side of the creek) which are 3–25 cm thick and form large hummocks. Sandstones are argillaceous sandstones in compositions and consist of fine to very- fine sand-sized grains. Siltstone beds are 2–7 cm thick, laterally continuous, fissile and composed of silt-sized particles. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	0.5	81.7
28	Red, maroon-weathering sandstone. This unit is normally graded with tabular and trough cross-bedding. Sandstones are arenitic in composition and consist of medium to fine sand-sized grains. <i>Palaeophycus</i> and <i>Cruziana</i> are present on hypichnial surfaces. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is gradational.	4.9	81.2
27	Pale red, maroon-weathering conglomerate. This unit is planar, clast-supported at the base, gradually becoming matrix-supported upwards. Clasts are 2–50 mm in size, angular to rounded and composed of quartzite and arenite. The matrix is arenitic in composition and consists of coarse to medium sand-sized grains. <i>Skolithos</i> , <i>Diplocraterion</i> , <i>Arenicolites</i> and rare <i>Planolites</i> and <i>Teichichnus</i> are present on endichnial surfaces. BI=0–1. Body fossils are absent. Basal contact is erosive.	0.7	76.3
26	Maroon and white, pale orange-weathering finer sandstones interbedded with coarser sandstones. This unit is wavy and lenticular bedded. Finer sandstone beds are 10–35 cm thick,	9.8	75.6

amalgamated and internally featureless except for minor wave-rippling. Finer sandstones are arenitic in composition and consist of fine sand-sized grains. Coarser sandstone beds are 10–50 cm thick, internally featureless except for wave-rippling, wave-ripple cross-laminations and trough and tabular cross-laminations. Coarser sandstones are arenitic in composition with minor glauconite and consist of medium sand-sized grains. *Planolites*, *Teichichnus* and trace *Skolithos* and *Arenicolites* are present on endichnial surfaces of finer sandstone beds. BI=1–2. *Arenicolites* and *Skolithos* are present on endichnial and epichnial surfaces of coarser sandstone beds. BI=0–1. Body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.

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| 25 | White, pale orange-weathering sandstone. Beds are 7–17 cm thick, planar or wavy and mottled or tabular cross-bedded with minor wave-rippling. Mottled and cross-bedded sandstones are both arenitic in composition and consist of fine sand-sized grains. <i>Teichichnus</i> , <i>Planolites</i> , <i>Palaeophycus</i> , <i>Rusophycus</i> and rare <i>Arenicolites</i> and <i>Skolithos</i> are present on endichnial and epichnial surfaces of mottled sandstones. BI=3–4. <i>Arenicolites</i> and <i>Skolithos</i> are present on endichnial and epichnial surfaces of cross-bedded sandstones. BI=0–1. Body fossils are absent. Internal contacts are sharp. Basal contact is sharp. | 1.8 | 65.8 |
| 24 | Pale red, maroon-weathering sandstone. This unit is trough and tabular cross-bedded and wave-rippled. Sandstones are arenitic in composition and consist of medium to fine sand-sized grains. <i>Arenicolites</i> , <i>Skolithos</i> and rare <i>Planolites</i> and <i>Teichichnus</i> are present on endichnial surfaces. BI=0–1. | 2.6 | 64.0 |

Body fossils are absent. Internal contacts are sharp. Basal contact is gradational.

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| 23 | <p>Pale red, maroon-weathering conglomerate. This unit is planar, clast-supported, gradually becoming matrix-supported upwards. Clasts are 2–50 mm in size, angular to rounded and composed of quartzite and crystalline quartz. The matrix is arenitic in composition and consists of coarse to medium sand-sized grains. <i>Skolithos</i>, <i>Diplocraterion</i> and <i>Arenicolites</i> are present on endichnial surfaces. BI=0-1. Body fossils are absent. Basal contact is erosive.</p> | 0.7 | 61.4 |
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Dodo Creek Formation

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| 22 | <p>Pale beige, brown-weathering lime mudstone interbedded with green, dark green-weathering argillite. Limestone beds are 10–16 cm thick, planar bedded, microbially laminated with minor thin argillite laminae and composed of micrite that is partially dolomitized. Argillite beds are 4–20 cm thick, fissile and composed of micaceous minerals with minor silt and sulfur-rich horizons. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is covered.</p> | 7.1 | 60.7 |
| 21 | <p>Light brown, dark brown-weathering quartzite interbedded with red and green, pale green-weathering argillite. This unit is planar bedded, 50% argillite and 50% quartzite at the base fining upward into 80% argillite and 20% quartzite. Argillite beds and laminae are 2–50 mm thick with minor shrinkage cracks and salt pseudomorphs and composed of micaceous minerals with minor silt. Quartzite beds are 10–40 mm thick,</p> | 4.2 | 53.6 |

wave-ripple cross-laminated, internally featureless or wave-rippled. Quartzites consist of fine to very- fine sand-sized grains with minor granules. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.

20	Brown, dark brown-weathering quartzite. This unit is trough cross-bedded and wave-rippled. Minor palimpsest ripples and linear shrinkage cracks are present at the top of the unit. Quartzites consist of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp. Basal contact is sharp.	2.0	49.4
19	Brown, pale tan-weathering quartzite interbedded with green, pale green-weathering argillite. This unit is planar and wavy bedded, 60% argillite and 40% quartzite. Quartzite laminae and beds are 3–110 mm thick and internally featureless or wave-ripple cross-laminated. Quartzites are composed of fine sand-sized grains. Argillite beds are 10–180 mm thick, fissile and composed of micaceous minerals with minor silt. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	0.2	47.4
18	White, reddish white-weathering quartzite. Beds are 2–12 cm thick, planar and wavy, amalgamated and internally featureless. Quartzites consist of medium sand sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	0.7	47.2
17	Brown, tan-weathering quartzite interbedded with green, pale green-weathering argillite. Syn-sedimentary folds and	1.5	46.5

faults are present. This unit is composed of 70% argillite and 30% quartzite. Quartzite laminae and beds are 3–115 mm thick, internally featureless or wave-ripple cross-laminated and consist of fine sand-sized grains. Argillite beds are 10–180 mm thick, fissile and composed of micaceous minerals with minor silt. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.

Covered	6.0	45.0
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Abraham Plains Formation

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| 16 | White, reddish white-weathering quartzite. Beds are 2–8 cm thick, planar and wavy, amalgamated and internally featureless. Quartzite is composed of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp. | 6.0 | 39.0 |
| 15 | Brown, tan-weathering quartzite interbedded with green, pale green-weathering argillite. This unit is planar bedded, 60% argillite and 40% quartzite. Quartzite laminae and beds are 2–40 mm thick, featureless or wave-rippled and consist of fine sand-sized grains. Argillite beds and laminae are 4–60 mm thick, fissile and composed of micaceous minerals with minor silt. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp. | 1.0 | 33.0 |
| 14 | White, reddish white-weathering quartzite. Beds are 2–10 cm thick, planar and wavy, amalgamated and internally featureless. Quartzites consist of medium sand-sized grains. | 1.8 | 32.0 |

	Trace and body fossils are absent. Internal contacts are sharp or erosional. Basal contact is sharp.		
13	White, reddish white-weathering quartzite. This unit is trough cross-bedded. Quartzites consist of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	0.5	30.2
12	White, reddish white-weathering quartzite. Beds are 2–10 cm thick, planar and wavy, amalgamated and internally featureless. Quartzites consist of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	1.3	29.7
11	White, reddish white-weathering quartzite. This unit is trough cross-bedded and composed of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	0.6	28.4
10	White, reddish white-weathering conglomerate. This unit is wavy, clast-supported, gradually becoming matrix-supported upwards. Clasts are 2–80 mm in size, subangular to subrounded and are composed of quartzites, argillites and cherts. The matrix is quartzite in composition and consists of coarse sand-sized grains. Trace and body fossils are absent. Basal contact is erosive.	0.3	27.8
9	Green, pale green-weathering argillite. This unit is laterally continuous, fissile and composed of micaceous minerals. Trace and body fossils are absent. Basal contact is sharp.	0.2	27.5

8	White, reddish white-weathering quartzite. Beds are 2–10 cm thick, planar and wavy, amalgamated and internally featureless. Quartzites are composed of medium sand-sized grains. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is sharp.	1.5	27.3
7	Maroon, pale red-weathering quartzite. This unit is trough and tabular cross-bedded and cross-laminated with minor wave-rippled beds. Quartzites consist of coarse to medium sand-sized grains. Minor lenses of very- coarse sand-sized grains to granular-sized grains of quartz are present. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is gradational.	6.2	25.8
6	Maroon, pale red-weathering conglomerate. This unit is wavy, clast-supported, gradually becoming matrix-supported upwards. Clasts are 2–80 mm in size, subangular to subrounded and composed of quartzites, argillites and cherts. The matrix is quartzite in composition and consist of coarse sand-sized grains. Trace and body fossils are absent. Basal contact is erosive.	0.3	19.6
5	Maroon, pale red-weathering quartzite. This unit is trough and tabular cross-bedded and cross-laminated with minor wave-rippled beds. Quartzites are composed of coarse to medium sand-sized grains. Minor lenses of very- coarse sand-sized grains to granular-sized grains of quartz are present. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is gradational.	13.3	19.3

4	Maroon, pale red-weathering conglomerate. This unit is wavy, clast-supported, gradually becoming matrix-supported upwards. Clasts are 2–60 mm in size, subangular to subrounded and are composed of quartzites and cherts. The matrix is quartzite in composition and consists of coarse sand-sized grains. Trace and body fossils are absent. Basal contact is erosive.	0.2	6.0
3	Maroon, pale red-weathering quartzite. This unit is trough and tabular cross-bedded and cross-laminated with minor wave rippled beds. Quartzites are composed of coarse to medium sand-sized grains. Minor lenses of very- coarse sand-sized grains to granular-sized grains of quartz are present. Trace and body fossils are absent. Internal contacts are sharp or erosive. Basal contact is gradational.	4.5	5.8
2	Maroon, pale red-weathering conglomerate. This unit is wavy, clast-supported, gradually becoming matrix-supported upwards. Clasts are 2–80 mm in size, subangular to subrounded and composed of quartzites, argillites and cherts. The matrix is quartzite in composition and consist of coarse sand-sized grains. Trace and body fossils are absent. Basal contact is erosional.	0.5	1.3

McClure Formation (?)

1	Tan, brownish orange-weathering dolostone with minor laminae of green argillite. This unit is planar bedded, stromatolitic and composed of dolomite. Argillites are featureless, fissile and composed of micaceous minerals.	0.8	0.8
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Trace and body fossils are absent. Basal contact was not measured.

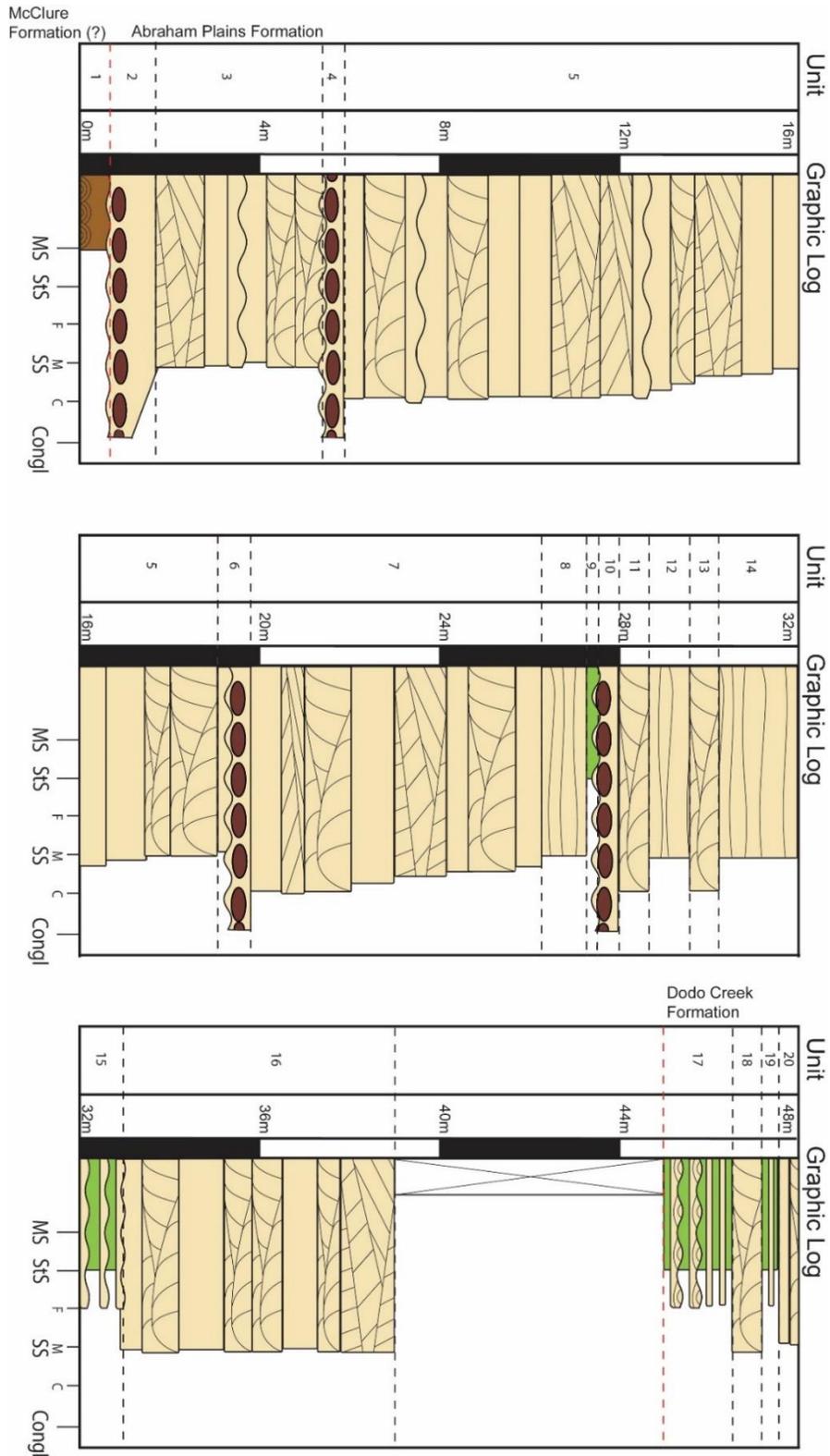


Figure E.1. Graphic log of the section at Grafe River, showing unit divisions; 0–48.0 m. Red dashed lines indicate lithostratigraphic boundaries.

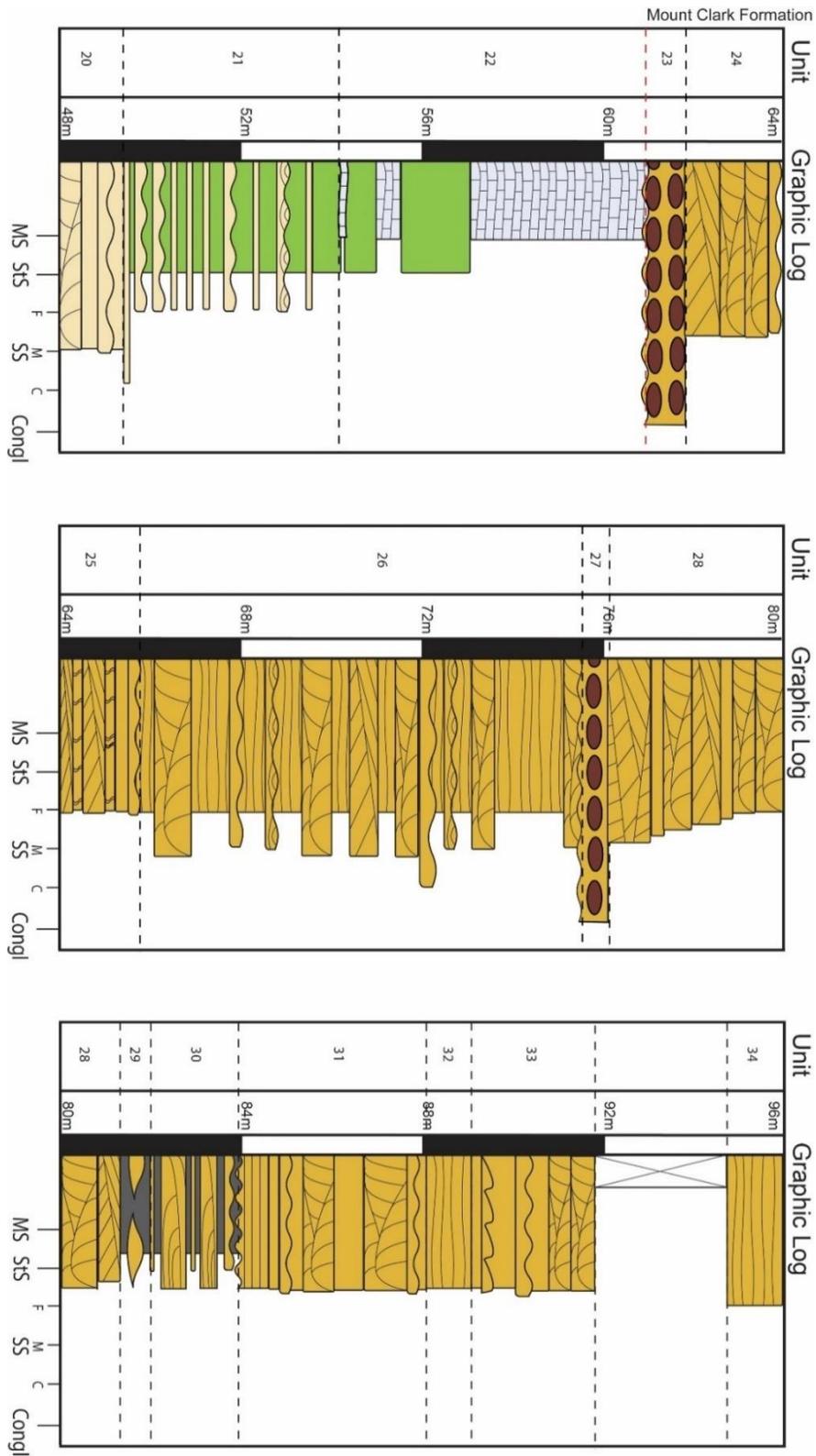


Figure E.2. Graphic log of the section at Grafe River, showing unit divisions; 48.0–96.0 m. Red dashed line indicates lithostratigraphic boundary.

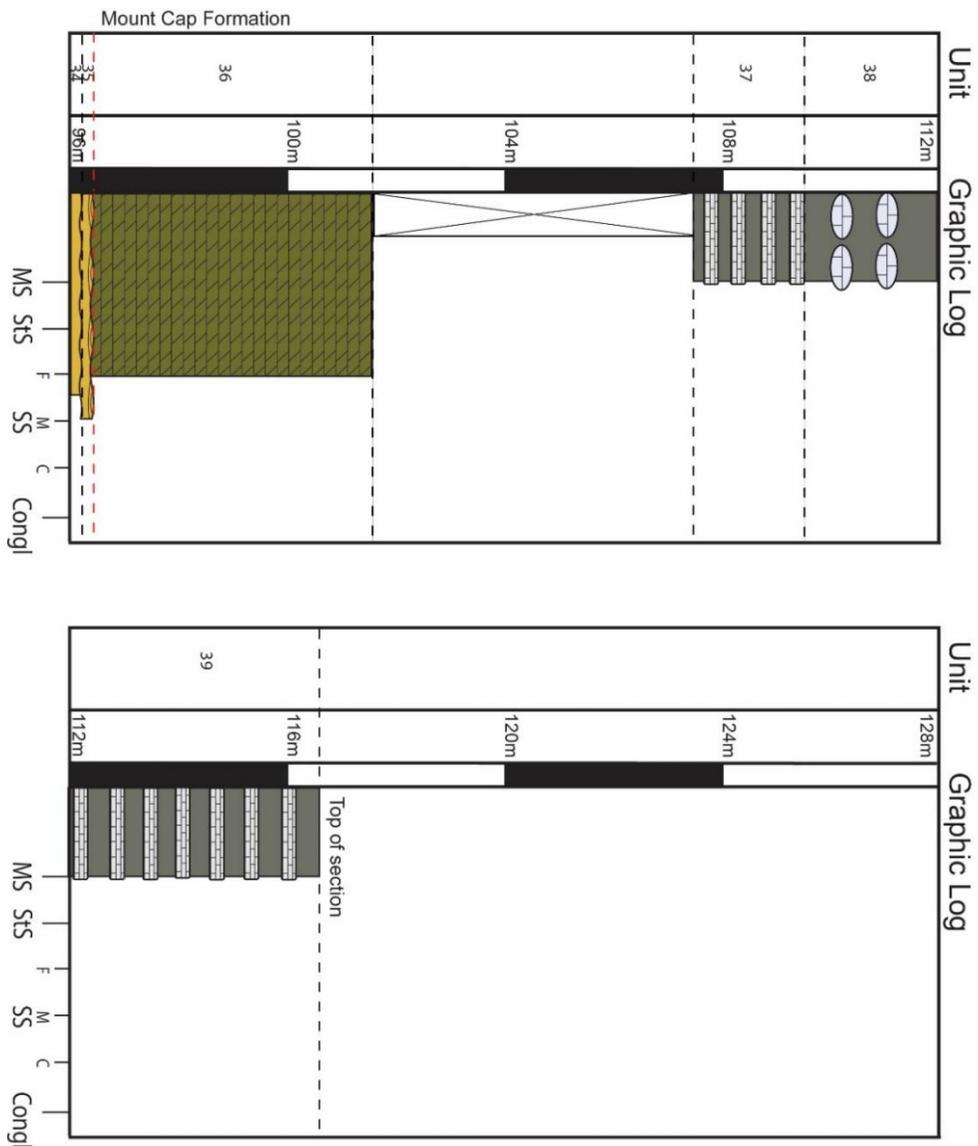


Figure E.3. Graphic log of the section at Grafe River, showing unit divisions; 96.0–116.2 m. Red dashed line indicates lithostratigraphic boundary.

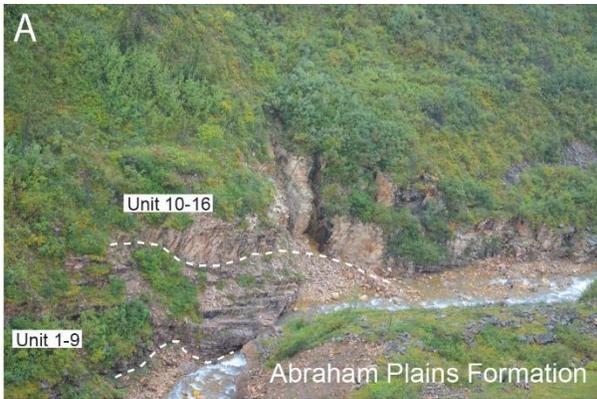


Figure E.4. Outcrop view at Grafe River. All photographs by N.M. Handkamer. **A)** Unit divisions of the basal to middle Abraham Plains Formation. Outcrop thickness = 39 m. Photo 2020-265. **B)** Unit divisions of the Dodo Creek Formation and basal to middle Mount Clark Formation. Outcrop thickness = ~ 50 m. Photo 2020-266. **C)** Unit divisions of the Mount Cap Formation. Outcrop thickness = 8.6 m. Photo 2020-267. **D)** Contact of upper Mount Clark Formation and basal Mount Cap Formation between units 35 and 36. Hammer length = 27.5 cm. Photo 2020-268. **E)** Middle Mount Clark Formation. Note the hammer is lying against a rippled sand lens of unit 29. Hammer length = 27.5 cm. Photo 2020-269. **F)** Unit 30 hummocky cross-stratified sandstone. Hammer length = 27.5 cm. Photo 2020-270.