BIOSTRATIGRAPHY OF THE SEKWI AND ROCKSLIDE FORMATIONS (LOWER TO MIDDLE CAMBRIAN; WRIGLEY LAKE AND SEKWI MOUNTAIN AREAS; NTS 95M AND 105P, NORTHWEST TERRITORIES, CANADA): IMPLICATIONS FOR BASIN DEVELOPMENT AND REGIONAL CORRELATION

By

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ABSTRACT

The lower and middle Cambrian, carbonate-dominated Sekwi and Rockslide formations were deposited in the Selwyn basin, a Neoproterzoic-Paleozoic depositional entity that occupied most of the ancestral western margin of Laurentia and spans parts of modern-day Yukon and Northwest Territories. Biostratigraphic data and limited chemostratigraphic data ($\delta^{13}C_{vpdb}$) from two Sekwi Formation sections in the Sekwi Mountain map-area (NTS 105P) are used to refine the current understanding of the spatial and temporal distribution of trilobite faunas in the area and to correlate the Sekwi Formation with other units throughout the Canadian Cordillera. Two species-based trilobite biozones (in ascending order: the *Nevadia addyensis* and *Nevadella eucharis* zones) previously best known from Arizona, California, and Nevada are documented in the lower Sekwi Formation, and a new genus-based assemblage zone, the *Elliptocephala* Zone, is proposed for the lower Dyeran of the Selwyn basin and surrounding areas. Trilobite data from three sections in the Wrigley Lake area (NTS 95M) are used to determine the chronology of basin events adjacent to the Redstone arch during the early and middle Cambrian, and lithostratigraphic data from other locations in the same map area is discussed to illuminate the nature of the basin events. There is evidence for two tectonic events during the late (traditional) early Cambrian and earliest middle Cambrian: (1) Event I, a regional uplift that eroded strata proximal to the Redstone Arch, and (2) Event II, a regional deepening event that heralded the onset of Rockslide Formation deposition. Trilobite biostratigraphy remains a mainstay of correlation in the Cambrian and is a powerful tool. However, further refinement is needed for the current biostratigraphic synthesis of the Cambrian of Laurentia, and biostratigraphy is enhanced when combined with chemostratigraphic curves.

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Chapter 1 – Introduction to the thesis

1.1 Geological setting

During the late Neoproterozoic and Paleozoic, Laurentia (the paleocontinent and cratonic core of modern North America) was isolated near the equator and rotated ~90° relative to its present orientation (McCausland et al. 2007, Davidson 2008). The Selwyn basin, a large, long-lived (Alaska to British Columbia; Neoproterozoic to mid-Paleozoic) deep-water depositional entity situated on the present-day northwestern margin of North America (Gordey and Anderson 1993) was an active depocentre during this time. In the Wrigley Lake and Sekwi Mountain areas (NTS 95M and 105P, respectively), the upper Neoproterozoic to lower Paleozoic stratigraphy of the Selwyn basin includes, in ascending order, the Backbone Ranges , Vampire, Sekwi, and Rockslide formations (Fortunian-middle Cambrian; Gordey and Anderson 1993, Turner et al. 2011). The Sekwi and Rockslide formations are known for their diverse and abundant trilobite faunas (Fritz 1972, 1976, 1978, 1979; Gabrielse et al. 1973), and the trilobite faunas of the Sekwi Formation type section were used by Fritz (1972) to establish part of the biostratigraphic scheme for the lower Cambrian of Laurentia. Shore-proximal areas of the Selwyn basin contain several arches, which are long-lived, elongate, episodically active paleotopographic highs (Cecile et al. 1997) that intermittently influenced Selwyn basin deposition. The (present-day) northwest-trending Redstone arch was adjacent to the Selwyn basin in present-day NTS 95M and NTS 105P and remained an important paleotopographic and depositional feature throughout the early Paleozoic (Gabrielse 1963, Cecile et al. 1997).

1.2 Previous Work

1.2.1 Sekwi Mountain Area (NTS 105P)

1.2.1.1 Backbone Ranges and “Backbone Ranges” formations; Vampire Formation

The Backbone Ranges Formation (Gabrielse et al. 1973) is a siliciclastic-dominated unit that is typically divided into three informal members: a lower sandstone-dominated member, a middle carbonate-dominated member, and an upper sandstone-dominated member (Gabrielse et al. 1973, MacNaughton 2011). The depositional age of the Backbone Ranges Formation is Ediacaran to lower Cambrian (MacNaughton 2011). These subdivisions of the Backbone Ranges Formation are evident in shore-proximal sections, including the type section in NTS 95L and exposures in NTS 95M (Gabrielse et al. 1973; MacNaughton 2011; MacNaughton and Fallas 2019, 2021). Corelations between the three members and more distally deposited units in NTS 105P have been controversial (MacNaughton 2011; MacNaughton and Fallas 2019).

During Operation Stewart, the Geological Survey of Canada (Blusson 1971, 1972) mapped the Sekwi Mountain area (NTS 105P), and his quartz arenite-dominated map unit 12 has generally been treated as correlative with some part of the “Backbone Ranges Formation.” (e.g., Aitken 1989). More recent studies indicate that map unit 12 is no older than Fortunian (MacNaughton and Narbonne 1999) and probably correlates only with the uppermost part of the succession assigned to the Backbone Ranges Formation in more proximal localities (MacNaughton and Fallas 2019). Herein, following MacNaughton (2011), map unit 12 is informally referred to the “Backbone Ranges Formation”. The position of this quartz-arenite-dominated succession below the Sekwi Formation was extensively documented in measured sections by Fritz (1976, 1978, 1979) from the Sekwi Mountain and adjacent map areas. In relatively distal sections, Blusson’s (1971) shale-dominated, recessive-weathering map unit 13 overlies the “Backbone Ranges Formation” and is overlain in turn by the Sekwi Formation (Fritz 1976, 1978, 1979).

MacNaughton et al. (1997) documented 18 parasequences in the Ingta, "Backbone Ranges," and Vampire formations. Fritz (1980) published three sections based on field measurements made during the International Precambrian-Cambrian Boundary Working Group's 1979 Field Study, each containing the "Backbone Ranges Formation." Fritz et al. (1983) also measured one section in the June Lake area, which includes the "Backbone Ranges Formation." Krause (1979) measured multiple sections in the Sekwi Mountain area during his PhD thesis fieldwork, many of which include the upper part of the "Backbone Ranges Formation." MacDonald et al. (2013) measured multiple Ediacaran sections in the Sekwi Mountain area, some of which are capped by the "Backbone Ranges Formation." In the northeastern part of NTS 105P, near the Godlin River, measured sections document that the Backbone Ranges Formation s*ensu stricto* is present, is significantly more than 250 m thick, and displays its typical, shore-proximal three members (MacNaughton et al. 2008).

1.2.1.2 Sekwi Formation

The Sekwi Formation (Handfield 1968) is a carbonate-dominated unit known for its lithological diversity, trilobite faunas, and zinc-lead showings (Handfield 1968, Fritz 1972, Fischer and Pope 2012). The type section, located beside near June Lake, was revisited by Fritz (1972) and comprehensively sampled for trilobite fossils. Fritz (1976, 1978, 1979) also measured 35 other Sekwi Formation sections in NTS 105P, and adjacent areas. Fritz's (1982) Vampire Formation type section also contains the base of the Sekwi Formation. Cecile (1982) described the Hess River Formation, which overlies the Sekwi Formation in the Misty Creek embayment, and many of Cecile's (1980) sections also record the uppermost Sekwi Formation based on 38 sections. Chan et al. (2019) published an isopach map for the Sekwi Formation included 38 sections across the Mackenzie Mountains, showing that the Sekwi Formation ranges from approximately 150 to 1150 m thick.

1.2.1.3 Rockslide Formation

The Rockslide Formation (Gabrielse et al. 1973) outcrops in the southern Sekwi Mountain-June Lake area and is laterally equivalent to the Hess River Formation (Roots et al. 2012). Fritz (1976, 1978, 1979) referred to recessive rocks overlying the Sekwi Formation as “post-Sekwi dark shale and platy limestone;” these strata have subsequently been assigned to the Rockslide Formation (MacNaughton 2011). Exposures of this unit in the southernmost part of NTS 105P between the Keele and Natla rivers probably represent strata of the Rockslide Formation based on their relatively high fossil content at various stratigraphic levels, because the Hess River Formation is sparsely fossiliferous, except for its base (Fritz 1976, 1978, 1979). Pratt (1992) measured 2 sections in NTS 105P, where the Rockslide Formation is ~150-200 m thick.

1.2.2 Wrigley Lake Area (NTS 95M)

1.2.2.1 Backbone Ranges Formation

Gabrielse et al. (1973) formalized the Backbone Ranges Formation and erected its type section in central NTS 95L (Gabrielse et al. 1973 section 12, northeastern Backbone Ranges), south of the Wrigley Lake map area (Gabrielse et al. 1973; MacNaughton and Fallas 2021). Exposures of the Backbone Ranges Formation documented in the Wrigley Lake area are similar to the type section in that they exhibit its characteristic tripartite organization, although the formation is generally thinner (Gabrielse et al. 1973). This is mainly due to the upper, sandstone member being significantly thinner, although the middle carbonate-dominated and lower sandstone member also taper. Aitken (1989) measured one section [Aitken (1989) Section A]

~10 kilometres south of the Redstone River, the uppermost part of which records ~100 m of siltstone and sandstone of the Backbone Ranges Formation.

1.2.2.2 Sekwi Formation

Fine-grained, recessive-weathering strata that Gabrielse et al. (1973) originally included in the uppermost Backbone Ranges Formation were reassigned to the Sekwi Formation by Fritz (1981), a decision also followed by MacNaughton and Fallas (2021). In the Wrigley Lake area, the Sekwi Formation differs from most other areas in that it consists mostly of dolostone and maroon/purple-weathering siltstone, and averages ~100 m thick (Gabrielse et al. 1973; MacNaughton and Fallas 2021). Chan et al.'s (2019) isopach map for the Sekwi Formation included four sections in the Wrigley Lake area, in which the Sekwi Formation ranged from ~30 to ~120 m thick. The Sekwi Formation in this area is characteristically fossiliferous (trilobite faunas), distinguishing it from the Backbone Ranges Formation which does not contain body fossils (Fritz 1981).

1.2.2.3 Rockslide Formation

Gabrielse et al. (1973) first described the Rockslide Formation and erected its type section in the Wrigley Lake area [Gabrielse et al. (1973) section 16; west-central Wrigley Lake area]. In NTS 95M, strata of the Rockslide Formation typically consist of fossiliferous, dark-grey-weathering limestone and are ~200-300 m thick (Gabrielse et al. 1973). Exposures in easternmost areas are more poorly fossiliferous, and in southwestern NTS 95M the Rockslide Formation may also contain black, calcareous shale at its base. Pratt (1992) section R is also in the Wrigley Lake area, and is ~250 m thick, consisting of siltstone, limestone, and dolostone.

1.3 Purpose of Thesis

The purpose of this thesis is twofold: (1) to update the taxonomy of Fritz's (1972) Sekwi Formation type section trilobite succession and improve the biostratigraphic synthesis for Laurentia, and the Selwyn basin particularly, and (2) to use trilobite biostratigraphy as an aid to determine the geological history of the Redstone arch and adjacent, basinal areas during the lower and middle Cambrian. Despite recent work on trilobite faunas from the Great Basin of Nevada, California and Arizona (Webster 2011, Hollingsworth 2011), the biostratigraphic scheme for the lower Cambrian of Laurentia is in need of revision owing to its reliance on large-scale, genus-based trilobite zones, of which the integrity is often adversely affected by the taxonomic revision that most olenelline groups have been subjected to over the last half century (Webster 2011, Palmer and Repina 1993, Lieberman 1999). The Redstone arch has long been recognized as a key element of Laurentian paleogeography (Gabrielse 1967) but its detailed evolution and the precise nature of its influence on Selwyn basin deposition remain poorly known.

This thesis contains three chapters: (1) an introductory chapter, (2) a chapter dealing with the trilobite taxonomy of two Sekwi Formation sections (sections 2 and 10, Fritz 1972, 1976), including discussion of their biostratigraphic utility augmented with a limited amount of stable carbon isotope data, and (3) a chapter containing descriptions of trilobite collections from sections close to the Redstone arch and their biostratigraphic implications for the development of the Redstone arch, as well as a discussion of the available lithostratigraphic evidence for tectonism.

1.4 References

Blusson, S.L. 1971. Sekwi Mountain map-area, Yukon Territory and District of Mackenzie. Geological Survey of Canada. Paper 71-22, 17 pp.

Blusson, S.L. 1972. Geology, Sekwi Mountain, Northwest Territories and Yukon Territory. Geological Survey of Canada. Map 1333A. 1 sheet.

Chan, W.C., MacNaughton, R.B., and Fallas, K.M. 2019. Isopach maps for the Sekwi Formation (Cambrian Series 2), Mackenzie Mountains, Northwest Territories and Yukon. Geological Survey of Canada, Open File 8371, 18 pp.

Cecile, M.P., Morrow, D.W., and Williams, G.K. 1997. Early Paleozoic (Cambrian to early Devonian) tectonic framework, Canadian Cordillera. Bulletin of Canadian Petroleum Geology, **45**:54–74.

Davidson, A. 2008. Late Paleoproterozoic to mid-Neoproterozoic history of northern Laurentia: an overview of central Rodinia. Precambrian Research, **160:**5-22.

Gabrielse, H. 1967. Tectonic Evolution of the Norhtenr Canadian Cordillera. Candadian Journal of Earth Sciences, **4**:271-298.

Gordey, S.P., and Anderson, R.G. 1993. Evolution of the northern cordilleran miogeocline, Nahanni map area (105I), Yukon and Northwest Territories. Geological Survey of Canada Memoir 428. 214 pp.

Fischer, B.J., and Pope, M.C. 2011. Lower Cambrian carbonate succession. *In* Geology of the central Mackenzie Mountains of the northern Canadian Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories special volume 1, 142-149.

Fritz, W.H. 1972. Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Bulletin 212. 58 pp.

Fritz, W.H. 1976. Ten stratigraphic sections from the Lower Cambrian Sekwi Formation, Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 76-22. 42 pp.

Fritz, W.H. 1978. Fifteen stratigraphic sections from the Lower Cambrian of the Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 77-33. 19 pp.

Fritz, W.H. 1979. Eleven stratigraphic sections from the Lower Cambrian of the Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 78-23. 19 pp.

Fritz, W.H. 1980. International Precambrian-Cambrian boundary working group's 1979 field study to Mackenzie Mountains, Northwest Territories, Canada. *In* Current Research, Part A, Geological Survey of Canada Paper **80-1A**:41-45.

Fritz, W.H., 1981. Two Cambrian stratigraphic sections, Eastern Nahanni map area, Mackenzie Mountains, District of Mackenzie. *In* Current Research, Part A. Geological Survey of Canada. Paper 81- 1A. pp. 145-156.

Fritz, W.H., 1982. Vampire Formation, a new Upper Precambrian(?)/Lower Cambrian Formation, Mackenzie Mountains, Yukon and Northwest Territories. *In* Current Research, Part B. Geological Survey of Canada. Paper 82-1B. pp. 83-92.

Fritz, W.H., Narbonne, G.M., and Gordey, S.P. 1983. Strata and trace fossils near the Precambrian-Cambrian Boundary, Mackenzie, Selwyn, and Wernecke mountains, Yukon and Northwest Territories. *In* Current Research Part B, Geological Survey of Canada, Paper 83-1B, 356-375 pp.

Gabrielse, H., Blusson, S.L., and Roddick, J.A. 1973. Geology of flat river, Glacier Lake, and Wrigley Lake map areas, District of Mackenzie and Yukon Territory. Geological Survey of Canada. Memoir 366. 153 pp.

Gordey, S.P., and Anderson, R.G. 1993. Evolution of the northern cordilleran miogeocline, Nahanni map area (105I), Yukon and Northwest Territories. Geological Survey of Canada. Memoir 428. 214 pp.

Handfield, R.C. 1968. Sekwi Formation, a new lower Cambrian formation in the southern Mackenzie Mountains, District of Mackenzie (95L, 105I, 105P). Geological Survey of Canada, Paper 68-47, 23 pp.

Hollingsworth, J.S. 2011. Lithostratigraphy and biostratigraphy of Cambrian Stage 3 in western Nevada and eastern California. In: Cambrian stratigraphy and paleontology of northern Arizona and southern Nevada. The 16th field conference of the Cambrian Stage subdivision working group. Edited by Hollingsworth, J.S., Sundberg, F.A., and Foster, J.R. Museum of northern Arizona, Bulletin no. 67, 26-42.

Krause, F.F. 1979. Sedimentology and stratigraphy of a continental terrace wedge: the lower Cambrian Sekwi and June Lake formations (Godlin River Group), Mackenzie Mountains, Northwest Territories, Canada. Unpublished PhD thesis, University of Calgary, Calgary, Alberta, Canada. 252 pp.

Lieberman, B.S. 1999. Systematic revision of the Oleneloidea (Trilobita, Cambrian). Bulletin of the Peabody Museum of Natural History, **45**: 150 pp.

MacDonald, F.A., Strauss, J.V., Sperling, E.A., Halverson, G.A., Narbbonne, G.M., Johnston, D.T., Kunzmann, M., Schrag, D.P., and Higgins, J.A. 2013. The stratigraphic relationship between the Shuram carbon isotope excursion, the oxygenation of Neoproterozoic oceans, and the first appearance of the Ediacaran biota and bilaterian trace fossils in northwestern Canada. Chemical Geology, **362**:250-272.

MacNaughton, R.B., Dalrymple, R.W., and Narbonne, G.M. 1997. Multiple orders of relative sea-level change in an earliest Cambrian passive-margin succession, Mackenzie mountains, northwestern Canada. Journal of Sedimentary Research, **67**:622-637.

MacNaughton, R.B., Roots, C.F., and Martel, E. 2008. Neoproterozoic-(?) Cambrian lithostratigraphy, northeast Sekwi Mountain map area, Mackenzie Mountains, Northwest Territories: new data from measured sections. Geological Survey of Canada, Current Research 2008-16, 15 pp.

MacNaughton, R.B. 2011. Lowest Paleozoic siliciclastic succession. *In* Geology of the central Mackenzie mountains of the northern Canadian Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories Special Volume 1, 131-141.

MacNaughton, R.B., and Fallas, K.M. 2021. Neoproterozoic-Cambrian stratigraphy of the Mackenzie Mountains, Northwestern Canada, part 4: a stratigraphic reference section for the Ediacara-Cambrian transition in NTS 95-M (Wrigley Lake map area). Geological Survey of Canada. Open File 8839. 56 pp.

McCausland, P.J.A., Van der Voo, R., and Hall, C.M. 2007. Circum-Iapetus paleogeography of the Precambrian-Cambrian transition with a new paleomagnetic constraint from Laurentia. Precambrian Research, **156:**125-152.

Palmer, A.R., and Repina, L.N. 1993. Through a glass darkly: taxonomy, phylogeny, and biostratigraphy of the Olenellina. The University of Kansas Paleontological Contributions, **3**:1-35.

Webster, M. 2011. Trilobite biostratigraphy and sequence stratigraphy of the Upper Dyeran (traditional Laurentian “Lower Cambrian”) in the southern Great Basin, U.S.A. *In* Cambrian Stratigraphy and Paleontology of Northern Arizona and Southern Nevada. Edited by J.S. Hollingsworth, F.A. Sundberg, and J.R. Foster. Museum of Arizona Bulletin 67. pp. 121–152.

Chapter 2 - Biostratigraphy, systematic paleontology, and chemostratigraphy of the Sekwi Formation (Sekwi Mountain area, NTS 105P, Northwest Territories, Canada) and its implications for Laurentian correlation

2.1 ABSTRACT

Trilobites are the basis for biostratigraphy of the Cambrian of Laurentia. Historically, the biostratigraphic scheme for the lower Cambrian of Laurentia has consisted of three genus-based assemblage zones, which are, from oldest to youngest: the *Fallotaspis*, *Nevadella*, and *Bonnia-Olenellus* Zones. These biozones were established based on trilobites sampled from the Sekwi Formation type section (Northwest Territories, Canada). Critically, this section spans Cambrian stages 3-4, preserving some of the earliest trilobites in Laurentia. In the half century since the original study of the Sekwi Formation type section trilobite collections there have been dramatic changes in the state of trilobite taxonomy and the understanding of the stratigraphic ranges of the earliest trilobites. Numerous attempts have been made to modify or replace the existing biostratigraphic scheme for the lower Cambrian of Laurentia. This study documents several species-based trilobite biozones in the lower Sekwi Formation that previously had been best known from the Esmeralda County/White Inyo region of Nevada and California. A new, genus-based assemblage zone, the *Elliptocephala* Zone, is proposed for the lower Dyeran. Limited chemostratigraphic data ($\delta^{13}C_{vpdb}$) provides evidence for three globally recognized stable carbon isotope excursions in the Sekwi Formation: (1) the MICE, (2) AECE, and (3) the ROECE. The AECE is associated with the base of the *Elliptocephala* Zone. Species-based trilobite biozones offer better precision than large-scale, genus-based assemblage biozones, but are adversely affected by the high provinciality of species, as compared to genera (Palmer 1998). The

complementary and simultaneous use of genus-based and species-based biozones may offer dividends compared to using one to the exclusion of the other.

2.2 INTRODUCTION

The biostratigraphic scheme for the lower Cambrian of Laurentia is in need of revision, due to a need to develop a functional global chronostratigraphic subdivision, continual taxonomic revision of the olenellinae, and successive discoveries of ever-older trilobite assemblages (Babcock et al. 2011, Hollingsworth 2011, Webster 2011). Exposures of lower Cambrian rocks in the southern Great Basin (Arizona, California, and Nevada) and the Selwyn basin (Northwest and Yukon territories) have served as the primary reference sections for the establishment of lower Cambrian trilobite biozones in Laurentia (Fritz 1972, Hollingsworth 2011, Webster 2011) together with minor amounts of data from the Appalachians (Webster and Landing 2016). Fritz (1972) published descriptions of trilobite assemblages from the Sekwi Formation type section, and his tripartite, genus-based, trilobite assemblage zones (*Fallotaspis*, *Nevadella*, and *Bonnia-Olenellus* zones) have been widely used throughout the past half century. However, the utility of these biozones is adversely affected by taxonomic issues and imprecision owing to being defined by genera (Webster 2011).

This study reevaluates Fritz's (1972) Sekwi Formation type section collections and additional trilobite collections from Fritz (1976) section 2 (~193 km northwest of section 10, the Sekwi Formation type section) and compares both assemblages to biotas elsewhere in Laurentia [Arizona, California, and Nevada (Hollingsworth 2011 and Webster (2011) and British Columbia (Fritz 1992); Fig. 2-1]. These biostratigraphic data are complemented by limited $\delta^{13}C$ chemostratigraphic data. A synthesis of biostratigraphy and chemostratigraphy is necessary to develop the best possible chronostratigraphic scales for the Cambrian Period at both global and regional levels.

2.3 GEOLOGICAL BACKGROUND

2.3.1 REGIONAL GEOLOGY

2.3.1.1 SELWYN BASIN

The Selwyn basin (Fig. 2-2) was a long-lived, deep-water, primarily Paleozoic (late Neoproterozoic to Devonian) basin that is now mainly preserved in present-day Yukon and Northwest Territories (Cecile et al. 1997, Gordey and Anderson 1993) but occupied the northern margin of Laurentia during the Cambrian (Davidson 2008, McCausland et al. 2007). The Selwyn basin contains past-producing sedimentary exhalative/clastic-dominant (SEDEX/CD) base-metal deposits at several stratigraphic levels (upper Cambrian to lower Devonian) and carbonate-hosted Zn and Au deposits are present in the adjacent shallow-water epicratonic strata to the northeast(Goodfellow 2007). During much of the Cambrian, two elongate, north-trending arches (from south to north: Redstone and Mackenzie arches) separated the Selwyn basin from a contemporaneous shallow-water intracratonic basin to the northeast (Dixon 1997, Sommers et al. 2020).

2.3.1.2 SEKWI FORMATION

The Sekwi Formation (Handfield 1968) is a heterogeneous, carbonate-dominated lower Cambrian unit known for its trilobite faunas, lateral and vertical lithological variability, and zinc-lead showings (Fritz 1972, Fischer and Pope 2012). Characterized mainly by orange and grey dolostone, limestone, and sandy limestone/dolostone, the Sekwi Formation outcrops throughout the Mackenzie Mountains and represents a carbonate ramp (Dilliard et al. 2010).

The Sekwi Formation type section is in the Sekwi Range (63°33’N, 128°44’W) and consists of ~700 m of bright orange, yellow, red, and grey-weathering dolostone and limestone as well as sandy dolostone and sandstone. Minor amounts of fissile siltstone are present throughout the type section (Handfield 1968). Handfield (1968) divided the Sekwi type section into three informal “subunits:” (1) a ~110 m thick lower part consisting of mottled brown and grey limestone, orange-weathering dolostone, and minor interbedded fissile siltstone; (2) a ~290 m thick middle part consisting of sandy, orange-weathering dolostone with minor highly texturally mature, cross-bedded arenite beds; and (3) a ~300 m thick heterogeneous upper part consisting of orange, grey, and brown-weathering limestone and dolostone, some of which is oolitic. Handfield (1968) also documented archaeocyathan bioherms throughout the lower and middle subunits of the Sekwi Formation.

Across the Mackenzie Mountains, the Sekwi Formation is >50 to 1105 m thick (Chan et al. 2019). Dilliard et al. (2007, 2010) divided the Sekwi Formation into seven regionally correlatable unconformity-bounded sequences (S0-S6; Fig. 2-3). The lowermost two sequences, S0 (<50 to >400 m thick) and S1 (100 to >275 m thick), occupy approximately the lower half of the Sekwi Formation (*Fallotaspis* and *Nevadella* zones). S0 includes the uppermost part of the underlying Vampire Formation and records deep subtidal environments. S1 represents inner ramp to basinal deposits. Sequences S2-S6 record smaller-scale (40 to 150 m thick), shallower environments, each consisting of basal subtidal carbonate facies that shallow upwards to peritidal carbonate caps.

The Sekwi Formation conformably overlies fine-grained siliciclastics of the Vampire Formation, but may also overlie arenite of the Backbone Ranges Formation in eastern (=shoreward) areas with a conformable (Fischer and Pope 2012; Fig 2-2) or disconformable

(MacNaughton and Fallas 2021) contact. Deep-water calciturbidites of the Hess River Formation conformably overlie the Sekwi Formation throughout most of the Sekwi Mountain area, although in southern areas (NTS 105P) it is conformably overlain by the Rockslide and Avalanche formations, both lateral equivalents of the Hess River Formation.

The Sekwi Formation was deposited during Cambrian Age 3 to Aage 4 (Fritz 1972, 1976, 1978, 1979; Scott et al. 2022; Fig. 2-3). The lowermost (typically ~10 m) of the Sekwi Formation was deposited during the *Fallotaspis* Zone biochron, although the *Fallotaspis* Zone is absent in shoreward sections (Fritz 1976, 1978, 1979). The rest of the lower half of the Sekwi Formation accumulated during the *Nevadella* Zone, and the upper part was deposited during the *Bonnia-Olenellus* Zone biochron (Fritz 1972, 1976, 1978, 1979; Fig. 2-3). The Sekwi/Hess River formational contact is diachronous and spans the middle and upper parts of the *Bonnia-Olenellus* Zone (Scott et al. 2022).

Dilliard et al. (2007) published a $\delta^{13}C$ curve for the Sekwi Formation (Fig. 2-3). At least three carbon isotope excursions are present in Dilliard et al.'s (2007) $\delta^{13}C$ data, which probably represent the Cambrian Arthropod Radiation Excursion (CARE), Mingxinsi Carbon Isotope Excursion (MICE), and Archaeocyathan Extinction Isotope Excursion (AECE). The very uppermost strata of the Sekwi Formation in some sections may contain the Redlichiid-Olenellid Extinction Isotope Excursion (ROECE), although the stratigraphic position of this excursion is probably somewhat variable because of the diachroneity of the Sekwi-Hess River formational contact (Scott et al. 2022).

2.3.2 LOWER CAMBRIAN BIOSTRATIGRAPHY OF LAURENTIA

Trilobites are the biostratigraphic standard for the Cambrian Period, and formalized, trilobite-biostratigraphic schemes for Laurentia have existed since the late 19th century. Walcott (1890) established the *Olenellus* Zone, the base of which was defined as where *Olenellus* and its accompanying fauna appear (Fig. 2-4). Walcott (1890) considered this biozone to occupy the majority of the lower Cambrian and referred all underlying strata to the Precambrian. Walcott (1910) revised his (1890) olenellid taxonomy and introduced a new, quadripartite trilobite zonal scheme: (1) the *Nevadia* Zone, (2) the *Elliptocephala* Zone, (3) the *Callavia* Zone, and (4) the *Olenellus* Zone (Fig. 2-4). These zones were not defined by their eponymous genera but by various trilobite species, and problematically mingled both Laurentian and Avalonian species, hampering their utility.

Resser and Howell (1938) erected several biostratigraphic zones based on faunas from the southern Appalachians (the *Obolella*, *Bonnia*, *Kootenia*, *Olenellus*, and *Kochiella* zones, in ascending order; Fig. 2-4). Very little detail on what characterized these zones was given by Resser and Howell (1938). Later, Howell et al. (1944) modified this scheme, amalgamating the *Bonnia* and *Kootenia* zones into a singular *Bonnia* Zone, and re-naming the *Kochiella* Zone the *Syspacephalus* Zone (Fig. 2-4). These biozones were defined by multiple genera, but also problematically included both Laurentian and Avalonian trilobite genera. Resser and Howell's (1938) biostratigraphic scheme and Howell et al.'s (1944) modifications were not widely adopted by other workers. Rasetti (1951) rejected Howell et al.'s (1944) zonal scheme on several grounds, including: (1) the presence/absence of many defining taxa being because of facies and favourable/unfavourable paleoenvironments rather than being the result of a meaningful time interval; (2) the overall poor exposure of Cambrian rocks in the type areas used by Howell et al.

(1944); and (3) the structural complexity of the southern Appalachians. Lochman (1952) applied Howell et al.'s (1944) zonal scheme to lower Cambrian strata near Sonora, Mexico, but had reservations about the *Olenellus* Zone, suspecting that its stratigraphic extent was much greater that Howell et al. (1944) maintained.

Deiss (1940) erected the *Olenellus-Bonnia* Zone based on faunas from the St. Piran and Mt. Whyte formations in British Columbia, Canada. Rasetti (1951) maintained Deiss's (1940) zonal concept but inverted the name, referring to it as the *Bonnia-Olenellus* Zone. The termination of this biozone was considered by Rasetti (1951) to correspond to the end of the lower Cambrian (Fig. 2-4).

Fritz (1972) documented the *Bonnia-Olenellus* Zone *sensu* Deiss (1940) and Rasetti (1951) in the Sekwi Formation (Mackenzie Mountains, Northwest Territories, Canada) and recognized two pre-*Olenellus* trilobite assemblages: the *Fallotaspis* (older) and *Nevadella* (younger) zones (Fig. 2-4). These three biozones (in ascending order: the *Fallotaspis, Nevadella*, and *Bonnia-Olenellus*) were genus-based assemblage zones and have been widely used in the decades since their original erection by Deiss (1940), Rasetti (1951), and Fritz (1972).

The *Fallotaspis* Zone was based on a *Fallotaspis*-dominated assemblage of trilobites from the Anti-Atlas Mountains, Morocco, originally described by Hupé (1952). Despite this, basal strata of the Sekwi Formation assigned by Fritz (1972) do not contain *Fallotaspis* but do contain *Parafallotaspis*, a morphologically similar genus. Comparisons between the North American and Moroccan "*Fallotaspis*" assemblages are controversial, for a variety of reasons:

1) The stratigraphic relationship between *Parafallotaspis* and *Fallotaspis* is unclear. Fritz (1972) maintained that *Fallotaspis* and *Parafallotaspis* co-occurred at an

undescribed section northwest of the Sekwi type section (GSC locations 84300-84303). However, Fritz (1976) published this section (section 2) and did not include *Fallotaspis* in his faunal list. Fritz (1980) also documented *Fallotaspis* sp. in the Cassiar Mountains of British Columbia. South of the Canadian cordillera, *Fallotaspis* has been documented in the Campito Formation (Hollingsworth 2011), but the taxonomy of these *Fallotaspis* species is contentious (see below).

2) The comparisons between North American and Moroccan occurrences of *Fallotaspis* are controversial. Geyer (1996) confirmed the presence of *Fallotaspis* in the White Inyo Mountains of California. However, Lieberman (2002) reassigned trilobites from the same area that had previously been assigned to *Fallotaspis* to *Archaeaspis*. If occurrences of *Fallotaspis* in North America and Morocco are not congeneric, already tenuous comparisons between the two assemblages become impossible.
3) *Fallotaspis* is stratigraphically wide-ranging in Morocco (Geyer 1996). The base of Hupé's (1952) *Fallotaspis* Zone corresponds to the occurrence of *Fallotaspis tazemmourtensis* Hupé 1953 but other species of *Fallotaspis* have a wide stratigraphic range throughout the Moroccan lower Cambrian (Geyer 1996). In North America, *Fallotaspis* is confined to Cambrian Stage 3, which is probably a more restricted stratigraphic range.

Because of these issues, Palmer and Repina (1993) suggested that the *Fallotaspis* Zone only be used informally, and in the sense of an interval containing a fallotaspidid-dominated trilobite assemblage.

The *Nevadella* Zone was considered by Fritz (1972) to be dominated by *Nevadella*, *Holmia*, and *Bradyfallotaspis*. The eponymous trilobite genus, *Nevadella*, mainly occurs in the upper part of the zone; the lower part is dominated by *Nevadia*. The taxonomy of these two genera is controversial, and many species assigned to either genus have overlapping diagnostic features (Lieberman 2001, Abe et al. 2010). These taxonomic ambiguities also led Palmer and Repina (1993) to suggest that usage of the *Nevadella* Zone be informal, and in the sense of a nevadiid-dominated stratigraphic interval.

The base of the *Bonnia-Olenellus* Zone (also referred to by some authors as the *Olenellus* Zone) was originally defined by the appearance of *Olenellus* (Fritz 1972). Fritz (1991) expanded the definition of the biozone, defining its top as slightly above the last occurrence of *Olenellus*. *Proliostracus* and *Wanneria* generally occupy the middle part of the biozone. *Bonnia* occurs in the upper part of the biozone; numerous small, smooth ptychopariids such as "*Antagmus*" and "*Onchocephalus*" co-occur with *Zacanthopsis* in the upper part of the biozone as well (Fritz 1972, 1991). Much like the underlying *Nevadella* and *Fallotaspis* zones, the *Bonnia-Olenellus* Zone has a number of issues that affect its integrity and utility. These are as follows:

1) The *Bonnia-Olenellus* Zone spans a very long-time interval relative to most other Cambrian trilobite biozones, and is generally depicted as occupying the entirety of Cambrian Stage 4 (Peng et al. 2020). This makes it difficult to determine the chronology of events that occur on timescales that are less than ~millions of years, necessitating subdivision. Fritz and Yochelson (1987) suggested that *Salterella*, a cone-like Cambrian problematicum, characterized the middle part of the biozone. Palmer and Repina (1993) suggested that *Wanneria* defines the middle of the *Bonnia-Olenellus* Zone.

2) *Olenellus*, one of the eponymous genera of the *Bonnia-Olenellus* Zone and historically the most important genus that defines it, has undergone extensive revision over the past half century (Palmer and Repina 1993, Lieberman 1999), and its true stratigraphic range is now poorly constrained.

Webster (2011) suggested that the *Bonnia-Olenellus* Zone be abandoned. It is because of these limitations that the "*Fallotaspis*", "*Nevadella*", and "*Bonnia-Olenellus*" zones will be referred to informally when used in the present tense throughout the rest of this thesis.

Palmer and Halley (1979) documented trilobites in the Carrara Formation (Nevada and California) and applied the *Bonnia-Olenellus* Zone to the lower part of the unit, although they referred to it only as the *Olenellus* Zone. Palmer and Halley (1979) also established three zonules in the upper part of the *Olenellus* Zone. These were, in ascending order, the *Olenellus multinodus*, *Bristolia*, and *Olenellus arcuatus* zonules. These zonules were not contiguous but had undefined gaps separating them. Palmer (1964) had previously established two olenellid-dominated faunules in the Pioche Shale, which also occur in the upper part of the *Bonnia-Olenellus* Zone. These are, in ascending order, the *Fremontia fremonti*-*Bristolia britsolensis* and *Olenellus gilberti*-*Paedumias clarki* faunules.

Hollingsworth (2007) established a pre-*Fallotaspis* trilobite biozone in the Andrews Mountain Member of the Campito Formation (Nevada), which he named the *Fritzaspis* Zone (Fig. 2-4). The *Fritzaspis* Zone is a genus-based assemblage zone, contains the oldest known trilobite assemblage in North America, and may be correlatable with the oldest known trilobite assemblages in Morocco and Siberia. The base of the *Fritzaspis* Zone is defined by the first appearance of its eponymous genus. Other genera in the *Fritzaspis* Zone include *Profallotaspis*?, *Amplifallotaspis*, and *Repinaella*.

Genus-based biozones such as the "*Fallotaspis*", "*Nevadella,*" and "*Bonnia-Olenellus*" zones offer some advantages because the geographic range of a genus is always greater than that of any of its species. This results in the probability of a genus being present at any given location being greater than any of its species. This ameliorates issues associated with provinciality, but at the cost of precision. As a result, modern efforts to solve the ambiguities and issues associated with the "*Fallotaspis*", "*Nevadella,*" and "*Bonnia-Olenellus*" zones have mainly consisted of establishing finer resolution, species-based trilobite biozones (Hollingsworth 2011; Webster 2011). Although it is a genus-based assemblage zone, the *Fritzaspis* Zone has not been subject to any attempts at modification, probably because it was established relatively recently, is only documented in western Nevada, and contains a sparse, poorly preserved fauna.

Hollingsworth (2011) modified the *Fallotaspis* Zone based on data from the Campito Formation (Esmeralda embayment, Nevada and California) by defining its base as the first appearance datum of *Archaeaspis*. Hollingsworth (2011) maintained that the base of the *Fallotaspis* Zone contained a thin (~decimetre scale) *Archaeaspis* subzone. The remainder of the *Fallotaspis* Zone in the Campito Formation includes a variety of species of *Fallotaspis,* the first species of which appears only a few metres above the last occurrence of *Archaeaspis*. Other trilobite genera in the *Fallotaspis* Zone in the Campito Formation include *Daguinaspis*, *Cirquella*, *Cambroinyoella*, *Paranevadella*, *Parafallotaspis*, *Nevadia*, and *Judomia* as well as some questionably assigned trilobite genera such as aff. *Montezumaspis*, aff. *Selindella*, and *Bradyfallotaspis*?. Although an improvement over Fritz's original conception of the "*Fallotapsis*" Zone, this scheme by Hollingsworth (2011) still represents an eclectic consortium of trilobite genera. Critically, some of these taxa are distinctive of the overlying *Nevadella* Zone, such as *Nevadia*, *Bradyfallotaspis*?, and aff. *Montezumaspis*.

Hollingsworth (2011) also erected five species-based trilobite biozones throughout the same stratigraphic interval in the upper Campito and lower Poleta formations (Nevada and California) as the "*Nevadella*" Zone. These biozones are, in ascending order, the *Esmeraldina rowei*, *Grandinasus patulus*, *Avefallotaspis maria,* and *Nevadia addyensis* zones (Fig. 2-4). The base of each zone is defined by the first appearance datum of its eponymous species, and the top by the eponymous species of the succeeding biozone. The only exception to this is the *Nevadella eucharis* Zone, the base of which is defined by either the first appearance datum of *Nevadella eucharis* or *Nevadella perfecta*, and the top of which corresponds to the extinction of nevadiid trilobites.

Webster (2011) erected six species-based biozones occupying the same stratigraphic interval as the upper "*Bonnia-Olenellus*" Zone. The base of each of these biozones is also defined by the first appearance datum of its eponymous species, and the top by the first appearance datum of the succeeding eponymous trilobite. They are in ascending order: the *Arcuolenellus arcuatus*, *Bristolia mohavensis*, *Bristolia insolens*, *Peachella iddingsi*, *Bolbolenellus euryparia*, and *Nephrolenellus multinodus* zones (Fig. 2-4. The top of the terminal species-based biozone, the *Nephrolenellus multinodus* Zone, corresponds to the extinction of olenellid trilobites in Laurentia. There is some conceptual and taxonomic overlap between Webster's (2011) species-based zonal scheme and the zonules/faunules of Palmer and Halley (1979) and Palmer (1964). The *Arcuolenellus arcuatus* Zone encompasses the *Olenellus arcuatus* Zonule of Palmer and Halley (1979) and the undefined interval overlying it. The base of the *Bristolia mohavensis* Zone corresponds to the base of Palmer and Halley's (1979) *Bristolia* Zonule, and both the *Bristolia insolens* and *Peachella iddingsi* zones are contained in the *Bristolia* Zonule. The *Bolbolenellus euryparia* Zone comprises the upper part of the *Bristolia*

Zonule as well as the undefined interval overlying it. The terminal species based biozone of the Dyeran, the *Nephrolenellus multinodus* Zone, corresponds exactly to Palmer and Halley's (1979) *Olenellus multinodus* Zonule. It should be noted that from a practical standpoint, the bases of Hollingsworth's (2011) and Webster's (2011) species-based biozones are probably defined by the first occurrence (FO) of its eponymous taxon instead of its FAD.

The most important trilobite group in Laurentian lower Cambrian trilobite biostratigraphy are the olenellids, whose extinction marked the traditional lower-middle Cambrian boundary in Laurentia. Olenellid trilobites were endemic only to Laurentia, and historically were assumed to have a synchronous extinction with paradoxidid and redlichiid trilobites in Gondwana and Baltica (Sundberg et al. 2020). Recent work (Sundberg et al. 2020, Sundberg et al. 2022) has falsified this assumption, and demonstrated that these groups of trilobites had significant temporal overlap. This indicates that the traditional lower-middle Cambrian boundary in Laurentia differs from its position in other paleocontinents. (For clarity, usage of the term "lower" and "middle" Cambrian in this chapter and Chapter 3 refers solely to traditional Laurentian lower (Waucobian Series and pre-trilobite Cambrian) and middle (Lincolnian Series) Cambrian and should not be applied to other paleocontinents.)

2.4 MATERIALS AND METHODS

2.4.1 Paleontology

Archival trilobite specimens (n=867; 258 from section 2 and 609 from section 10) were identified to the lowest possible taxonomic level. Only the general collection from Fritz (1972, 1976) section 10 was available owing to pandemic-related delays, because the type collection from this location is separately curated. Trilobite specimens were whitened with ammonium chloride sublimate and photographed with a Canon EOS T7i with a Tamron 90 mm lens under either a ring light or high-angle incident LED lighting. Photographs of each specimen were stacked and brightness and contrast were altered to enhance clarity using Adobe Photoshop 2022.

2.4.2 Stable Isotope Geochemistry

Samples (section 2: n=29; section 10: n= 50 and 15 duplicates) for stable carbon and oxygen isotope analysis were drilled from the matrix of fossil samples. Powders were drilled using a Dremel™ drill fitted with a tungsten carbide drill bit. Lime mudstone matrix was targeted under a binocular microscope to avoid potential contamination from allochems, and ~0.5 mg of powder was sampled in glass vials. Samples were analyzed at the Stable Isotope Laboratory in the Department of Geological Sciences of the University of Manitoba, MB. The laboratory analyzed two international calcite standards (NBS-18 and IAEA-603) during the beginning, middle, and end of each sample suite. Using these standards, the laboratory calculated a calibration line by least squares linear regression. One calibrated internal standard (CHI, $\delta^{13}C$= -8.01 +/- 0.06‰ VPDB and $\delta^{18}O$= -11.62 +/- 0.04‰, n=12) was analyzed with the unknown samples. Further details can be found in Appendix 2B.

2.5 RESULTS

2.5.1 Stable Carbon Isotope Chemostratigraphy

2.5.1.1 Section 2

Section 2 exhibits a $\delta^{13}C_{vpdb}$ curve with values ranging from 1.0‰ to -3.4‰ (Fig. 2-5a, A-C, Table 1). The lowermost data points (GSC location 84299) have values of ~1.0‰. The data point from GSC location 84314 has the most negative value of -3.4‰. $\delta^{18}O_{vpdb}$ values for these data points are somewhat more negative than most others (~24.0‰ and -13.0‰, respectively), implying that those values may have been altered by diagenesis (Marshall et al., 1997). R^2 values for the covariance plot of $\delta^{13}C_{vpdb}$ vs $\delta^{18}O_{vpdb}$ are 0.05, implying that overall, very little diagenetic alteration has affected the $\delta^{13}C_{vpdb}$. GSC locations 84319 to 84325 also exhibit negative $\delta^{13}C_{vpdb}$ values ranging from -2.0‰ to -1.3‰. The remaining data points fluctuate between ~0.50‰ to ~-0.50‰, with one pronounced negative data point close to the Sekwi-Hess River formational contact (GSC location 84399, -1.3‰) that is followed by moderately positive values of ~0.90‰ and ~0.70‰.

2.5.1.2 Section 10

Section 10 exhibits a $\delta^{13}C_{vpdb}$ curve with values ranging from 1.0‰ to -4.0‰ (Fig. 2-5b, D-F; Table 1). Lowermost data points also exhibit moderately high $\delta^{18}O_{vpdb}$ values (GSC location 73025, -12.8‰), implying that diagenesis may have affected the base of the Sewki Formation at section 10 as well (Marshall et al. 1997). The remaining $\delta^{18}O_{vpdb}$ values tend to cluster around -10‰. R^2 values for the covariance plot of $\delta^{13}C_{vpdb}$ vs $\delta^{18}O_{vpdb}$ are 0.28 which is higher than that of section 2 but still acceptably far from 1, implying that diagenetic alteration has not substantially modified section 10's carbon and oxygen isotope record. $\delta^{13}C_{vpdb}$ values at section 10 are initially somewhat positive (0.2‰) and subsequently reach negative values close to -1.0‰. Moderately positive $\delta^{13}C_{vpdb}$ values return at GSC locations 73034, 73035, and 73038, with GSC locations 73036 and 73037 briefly returning to moderately negative values. This is followed by a substantial sampling gap (~200 m, equivalent to roughly the upper half of the "*Nevadella*" Zone at section 10). After this, GSC locations 73040 and 73041 exhibit strong negative $\delta^{13}C_{vpdb}$ values of -4.0‰ and -3.4‰. The remainder of sampled GSC locations in the section oscillate between ~-1.0‰ to 1.0 ‰.

2.5.2 SYSTEMATIC PALEONTOLOGY

Class Trilobita Walch 1771

Order Agnostida Salter 1864

Discussion. The affinity of agnostids to polymerid trilobites is controversial, and agnostids have been interpreted as being derived, possibly paedomorphic trilobites (Fortey 2001, Fortey and Theron 1995) or more closely related to mandibulate arthropods (Edgecombe 2017). Recent work has also suggested that agnostids are artiopods, and closely related to polymerid trilobites (Moysiuk and Caron 2019). Agnostids are pragmatically considered to be trilobites herein and attempts to argue for a proper placement of agnostids lie outside of the scope of this work.

Suborder Eodiscina Kobayashi 1939

Family EODISCIDAE Raymond 1913

Genus *Pagetides* Rasetti 1945

Discussion. Blaker and Peel (1997) summarized the historical debate over which eodiscinids ought to be assigned to *Pagetides* and emended Rasetti's (1945) original definition of the genus, synonymizing *Neopagetina* Pokrovskaya in Chernysheva 1960 and *Pagetides* Rasetti 1945. The emended Blaker and Peel (1997) definition of *Pagetides* is adhered to in this paper.

Pagetides spinulus Fritz 1972

Appendix 2A, Plate 3, A-P

Pagetides spinulus Fritz 1972, p. 10, plate 8, figs. 1-12.

Material. 37 cranidia and 29 pygidia.

Description. Fritz (1972) adequately describes this species.

Discussion. This species bears the hallmark features of *Pagetides* as per Blaker and Peel's (1997) definition and Fritz' (1972) original definition, including: (1) a narrow glabella with two pairs of furrows, (2) an occipital ring that extends into a spine, (3) very short palpebral lobes, (4) minute librigenae, and (5) a semi-circular pygidium with a narrow axis that consists of up to seven rings that does not contact the posterior border furrow (Blaker and Peel, 1997). *Pagetia* Walcott 1916a is a similar genus to *Pagetides* but Pagetia lacks a posterior occipital spine that is an extension of the occipital lobe and has well-defined radial markings on its cranidial border.

Occurrence. GSC locations 73027, 73030, 73032, 73033, 73034, and 73036. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Family YUKONIIDAE Zhang 1980

Genus *Yukonides* Fritz 1972

Discussion. Fritz (1972) erected *Yukonides*, which remains monospecific and can be distinguished from similar Yukoniids chiefly by a narrow glabella and pronounced eye tubercles positioned on the cephalic margin.

Yukonides lacrinus Fritz, 1972

Appendix 2A, Plate 3, Q-Y

Yukonides lacrinus Fritz 1972, p. 10, plate 8, figs. 1-12.

Yukonides lacrinus? Fritz 1973, p. 11, plate 3, figs. 31-34.

Material. 11 cranidia and 12 pygidia.

Description. Fritz (1972) adequately describes this species.

Discussion. Fritz (1973) figured material that he questionably assigned to *Yukinides lacrinus* because of some minor morphological differences and poor preservation. The morphological differences included 1) an absence of pits close to the posterior edge of the anterior border, 2) smaller ocular tubercles, and 3) a pygidial axis that has nodes rather than spines on its axial rings. The pits present on the type material of *Y. lacrinus* are quite subtle, and their absence in Fritz' (1973) material could be an artifact of preservation. The latter two differences are minor. Fritz' (1973) material is therefore tentatively synonymized with the Fritz (1972) type material. Cotton and Fortey (2005) apparently came to a similar conclusion, as they listed Fritz' 1972 and 1973 material as synonymous [see table 1, Cotton and Fortey (2005)].

Occurrence. GSC locations 73035, 73037, and 73038. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Order Redlichiida Richter 1932

Suborder Olenellina Walcott 1890

Family ARCHAEASPIDIDAE Repina 1979

Genus *Bradyfallotaspis* Fritz 1972

Bradyfallotaspis fusa Fritz 1972

Appendix 2A, Plate 7, L

Bradyfallotaspis fusa Fritz 1972, p. 19, plate 3, figs. 1-7.

Material. 3 cephala.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC locations 73027 and 73030. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Bradyfallotaspis patula Fritz 1972

Appendix 2A, Plate 7, M

Material. 1 partial cephalon.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73030. Section 10, (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Family FALLOTASPIDIDAE Hupé 1953

Genus *Parafallotaspis* Fritz 1972

Parafallotaspis grata Fritz 1972

Appendix 2A, Plate 1, G-L

1972 *Parafallotaspis grata* Fritz; p. 28, Pl. 1, fig. 1-8.

Material. 19 partial cephala.

Description. Fritz (1972) adequately describes this species.

Discussion. This material is identical to *Parafallotaspis grata* Fritz 1972. *Parafallotaspis* is currently monospecific, and *P. grata* can readily be distinguished from similar fallotaspidid trilobite genera such as *Fallotaspis* by the following features: 1) a prominent plectrum that contacts the preglabellar ridge, 2) parafrontal bands extending from the anterior portion of the ocular lobes that merge with the plectrum, 3) an interocular area that is slightly greater than the half-width of the extraocular area at the midline of the ocular lobe (wider than most other fallotaspidids), and 4) a posterior margin that is swept slightly back or straight.

Occurrence. GSC locations 84300, 84301, and 84303. Section 2 (Fritz 1976). GSC location 73025, Fritz Section 10. Sekwi Formation, "*Fallotaspis*" Zone.

Indet. Fallotaspidid?

Appendix 2A, Plate 5, P

Material. 1 complete and 1 partial cephalon.

Description. Length of cephalon equal to approximately ¾ width. Glabella overall parallel-sided, LA broadly curved relative to nevadiid-like glabellae but still pointed. Three glabellar furrows present: S3 shallow, straight, extends nearly to middle of glabella; S2 somewhat deeper but constrained to outer margin of glabella; S1 deepest and of equivalent extent to S3. All glabellar furrows parallel and directed back at ~40° angle. LA comprises over 1/3 length of glabella exclusive to the occipital lobe. Preglabellar field equivalent to ¼ length of LA. Anterior and lateral borders slightly thicker than length of preglabellar field, convex, and of equal width throughout. Ocular lobes originate from antero-lateral corner of LA and initially present as parafrontal band, initially directed backwards until tangent is parallel to axis at posterior of L2 and terminating parallel to occipital furrows. Occipital furrows deep initially but shallow towards axis. Occipital ring bears small node. Interocular area subequal to extraocular area and slightly convex. Posterior margin thin, equal to ~1/3 width of anterolateral border. Posterior margin sub-transverse.

Discussion. This species bears a somewhat nevadiid-like glabella but maintains a thick parafrontal band that is defined by the projection of the anterior part of the ocular lobes, a feature that is characteristic of fallotaspidid (Palmer and Repina 1993). *Avefallotaspis maria* McMenamin 2001 also bears nevadiid-like features alongside a parafrontal band, and McMenamin classified *A. maria* as a fallotaspidid. This species is probably somewhat more definitively fallotaspidid-like than *A. maria* based on its relatively wide interocular area, although neither species are perfect fits for either fallotaspididae or nevadiidae. McMenamin (2001) also claimed that *A. maria* represents a fallotaspidid that convergently developed a nevadiid-like anterior glabellar lobe because of similar selective pressures to that which shaped nevadiids. Specifically, this adaptation could have improved digestion. This explanation appears to be a just-so-story, and it could just as easily be stated that *A. maria* is a nevadiid that convergently developed fallotaspidid-like features. The affinity of both this indeterminate fallotaspidid? and *A. maria* is ambiguous.

Occurrence. GSC location 84305. Fritz Section 2 (1976). Sekwi Formation, "*Nevadella*" Zone.

Indet. Fallotaspidoids

Appendix 2A, Plate 1, A-F

Material. 46 partial cephala and one associated opisthothorax.

Description. Cephala with broadly curved anterior glabellar lobes, faintly incised glabellar furrows, and a wide interocular area (~1/3 width of glabella). Preglabellar field ~1/2 length of anterior glabellar lobe; antero-lateral border slightly convex and ~1/3 length of preglabellar field.

Discussion. Samples from the basalmost strata of the Sekwi Formation contain numerous fragmentary and/or highly compacted cephala. Most lack a strongly developed plectrum and other features that would allow confident assignment to *Parafallotaspis grata*. Although the specimens assigned to "Indet. Fallotaspidoid material" herein could foreseeably have belonged to multiple species, all specimens apparently lack a parafrontal band or projection from the anterior portion of the ocular lobes and a plectrum. Most of these cephalic fragments also possess glabellar furrows that are dissimilar to *Parafallotaspis grata*, although this could be due to the compacted nature of the fossils. These specimens are too incomplete and poorly preserved to be confidently assigned to any fallotaspidoid family.

Occurrence. GSC locations 84299, 84301, 84302, 84303, and 84304. Fritz Section 2 (1976). Sekwi Formation, "*Fallotaspis*" Zone.

Family HOLMIIDAE Hupé 1953

Genus *Holmiella* Fritz 1972

Discussion. Hollingsworth (2006) modified Fritz' (1972) definition of *Holmiella* to include *Holmiella millerensis* Hollingsworth 2006, which is disparate from the type, *Holmiella preancora* Fritz 1972, in that it has an exceptionally wide extraocular area. This most recent diagnosis is followed herein.

Holmiella falcuta Fritz 1972

Appendix 2A, Plate 6, A-P, Plate 7, A-G

Holmiella falcuta Fritz 1972, p. 26-27, plate 7, figs. 7-17.

Material. 32 cephala and 12 pygidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC locations 73034, 73035, 73037, 73038, and 73039. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Holmiella preancora Fritz 1972

Appendix 2A, Plate 7, H-K

Holmiella preancora Fritz 1972, p. 25-26, plate 4, figs. 1-13.

Material. 7 cephala and 2 pygidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC locations 73027, 73030, and 73033. Section 10 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Genus *Montezumaspis* Hollingsworth 2006

Montezumaspsis? sp. 1

Appendix 2A, Plate 5, E-I

Material. 13 partial cephala and one associated hypostome.

Description. Cephalic width slightly greater than ½ cephalic length. Anterior margin more sharply curved, curvature becomes broader towards lateral margin of cephalon. Anterior and lateral border of uniform width (approximately ¼ length of LA), broadly convex sagittaly. Anterior and lateral border furrow shallow, of uniform depth throughout. Posterior margin transverse from axis to genal area (approximately 1/3 half-width of cephalon away from axis) and then directed slightly forward from genal area to margin. No metagenal spine evident. Pre-glabellar field equal in width to anterior border. Sides of glabella parallel, L1 and L2 slightly constricted relative to L3 and LA, which expand outwards. LA slightly under 1/3 glabellar length, L3-L1 of sub-equal length. S3 and S2 shallow, curved; tangent of curve is approximately

30° relative to transverse line across cephalon. S3 straight, deeper than and angled similarly to S3 and S2. S3 and S2 not connected across glabella, S3 connected across the glabella by shallow, transverse line. S0 of similar depth to S3, angled at approximately 40° relative to transverse line. Ocular lobes separated from glabella by shallow, axial furrow. Curvature of ocular lobes uniform, slightly divergent, terminate at midpoint of occipital lobe. Width of extraocular area approximately twice that of interocular area.

Tentatively assigned hypostome poorly preserved but oval-like in shape, with a raised, middle body that is also oval-shaped that joins the main body along shallow, uniform furrows. Borders not fully preserved, although the border does appear to widen posteriorly, and may terminate without wrapping around the posterior, leaving what appears to be a small, posterior cleft parallel to the axis.

Discussion. These cephala are most comparable to either *Montezumaspis* or *Palmettaspis* and can be distinguished from *Esmeraldina* by the presence of a relatively pronounced pre-glabellar field. The following characteristics support assignment within *Montezumaspsis*: 1) A posterior margin that is transverse to sub-transverse and genal angles that are less advanced compared to all known species of *Palmettaspis* and 2) Ocular lobes that terminate parallel to some part of the occipital ring, as opposed to a more anterior segment of the glabella, which is the case with *Palmettaspis*. This species is not confidently assigned to *Montezumaspis* because the material present consists of incomplete cephala. Furthermore, some of the cephala that have been assigned to this species have been differentially compacted, resulting in some specimens apparently having glabellar furrows that are continuous across the glabella or genal/posterior angles that appear to differ. Taphonomy is known to affect features such as these and assigning these cephala to the same species is probably a reasonable assumption.

Occurrence. GSC locations 84307 and 84309. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Montezumaspsis? sp. 2

Appendix 2A, Plate 5, J-K

Material. 2 partial cephala.

Description. Cephalic length ~4/5 that of width. Anterior margin very sharply and evenly curved, becoming more broadly curved and pointed almost directly back at postero-lateral margin. Anterior border slightly convex and equal to ~1/4 length of LA. Anterolateral border furrow shallow and poorly defined. Posterior margin too poorly preserved to comment on. Glabellar margins overall straight. LA margins taper forward uniformly; front of LA abruptly curved, giving it the appearance of a blunt point. L3 and L2 each ~1/2 length of LA; lateral margins very slightly curved. L3 very slightly wider (transversely) than L2. L1 slightly longer, lateral margins also slightly curved and angled very slightly inwards. L0 similarly shaped to L1. S3 faint; convex anteriorly; oriented inwards. S2 parallel and more strongly incised. S1 straight; deep and broad relative to S3 and S2; directed inwards at ~30° relative to transverse line. S0 parallel to S1 but slightly more pitted. Ocular lobes originate from posterior corner of LA; separated from glabella by faint, axial furrow. Maximal distal extent from axis of ocular lobes parallel to middle of L1; posterior tip of ocular lobe parallel to middle of L0 and directed slightly inwards. Interocular area very slightly convex; equal to ~1/2 width of glabella. Extraocular area convex; equal in width to glabella at maximum extent.

Discussion. These cephala are similar to Montezumaspis? sp. 1 save for the following differences: 1) an overall thinner cephalon, 2) a thinner glabella with a more pointed anterior glabellar lobe, 3) a smaller interocular area, and 4) ocular lobes that are of lesser curvature. The morphological differences between this species and *Montezumaspis*? sp. 1 are relatively minor, and the same discussion as above applies to the affinity of *Montezumaspis*? sp. 2.

Occurrence. GSC locations 84307 and 84309. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Genus *Esmeraldina* Resser and Howell 1938

Esmeraldina? sp.

Appendix 2A, Plate 5, L

Material. 2 partial cephala and one tentatively assigned partial cephalon (GSC location 84312).

Description. Length of cephalon approximately 2/3 width. Anterior and lateral borders gently convex in transverse cross-section and quite wide, averaging approximately 1/8 cephalic length. Anterior and lateral border furrow shallow, of consistent depth throughout excepting the posterior ¼ of cephalic length where they shallow and terminate. Pre-glabellar field virtually absent; space in between glabella and anterior border occupied by furrow. Ocular lobes crescentic, originate roughly at have length of cephalon and terminate parallel to posterior 1/5 of cephalic length. Width of interocular area unclear. Extraocular area thin (equivalent to 1/12 cephalic width) and convex; appears as ridge separated from ocular lobes by a pronounced furrow and bounded on the other side by lateral border furrow. Genal spines appear directed outwards initially, base of genal spines wide. Length of genal spines unclear.

Discussion. The three cephala assigned to this species are incomplete and lack detail on the glabella, interocular area, and posterior. The wide antero-lateral border does compare to *Esmeraldina* sp. aff. *rowei* Abe et al. 2010, as does the convex shape of the extraocular area. This species differs from *Esmeraldina* sp. aff. *rowei* Abe et al. 2010 in its smaller cephalic length:width ratio, and wider, shallower antero-lateral border furrows.

Occurrence. GSC locations 84311 and 84312. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone

Family NEVADIIDAE Hupé 1953

Genus *Nevadella* Raw 1936

Discussion. *Nevadella* and *Nevadia* are closely related, morphologically similar genera and there has been considerable historical debate over their taxonomy. Whittington (1989) suggested that *Nevadella* ought to be dropped altogether, and that all representatives of *Nevadella* should be subsumed by *Nevadia*. Fritz (1992) recommended that the two genera be kept separate at least temporarily and listed several criteria to distinguish *Nevadia* from *Nevadella* based on the lectotype of *Nevadia weeksi* Walcott 1910: 1) a wider cephalon, 2) a shorter glabellum, 3) narrower anterolateral borders, 4) a swept back posterior margin, and 5) longer ocular lobes. Lieberman (2001) also maintained *Nevadia* and *Nevadella* as separate genera and listed numerous cephalic features that could be used to distinguish the two, some of which correspond to Fritz' (1992) criteria. Lieberman's (2001) cephalic criteria include 1) *Nevadella* possessing a longer LA than *Nevadia*, 2) S2 and S0 are both convex anteriorly in *Nevadella*, whereas in *Nevadia* they are both straight, and *Nevadella* lacks a visible intergenal ridge opposite the middle of the ocular lobe, whereas *Nevadia* has a prominent intergenal ridge. Abe et al. (2010) largely reiterated Lieberman's (2001) criteria and highlighted the need for formal revision of the two genera. Lieberman's criteria are generally followed in this paper with some caveats (see discussion under *Nevadia addyensis*). In general, *Nevadella* is a nevadiid with a long LA, narrow cephalon, narrow anterolateral borders, and short ocular lobes relative to *Nevadia*. Species of *Nevadia* also often have swept-back posterior margins.

Nevadella bacculenta Fritz 1972

Appendix 2A, Plate 4, A

Nevadella bacculenta Fritz 1972, p. 22-23, plate 5, figs. 1-9.

Material. 1 cephalon and 3 genae.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73030. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Nevadella eucharis Walcott 1913

Appendix A, Plate 5, A

Callavia eucharis Walcott 1913, p. 315, plate 53, fig. 1.

Nevadella eucharis Raw 1936, p. 249, 250.

Nevadella eucharis Poulsen 1959, p. O196.

Nevadella eucharis Best in Kielan 1960, p. 89.

Nevadella eucharis Fritz 1992, p. 24, plate 4, figs. 1-3, fig. 7d.

Material. 1 complete cephalon and 3 partial cephala.

Description. Fritz (1992) adequately describes this species.

Discussion. This material is virtually identical to the material described in Fritz (1992*)*. *Nevadella perfecta* Walcott 1913 appears very similar to *N. eucharis* but can be discriminated chiefly by ocular lobes that are initially directed more strongly backwards than outwards, a pronounced metagenal ridge, and relatively advanced genal spines (Fritz 1992). In addition, *N. perfecta* material figured in Fritz (1992) and Walcott (1913) generally appear to have glabellar furrows that are prominently conjoined across the axis, while the glabellar furrows of *N. eucharis* do not conjoin or do so more subtly.

Occurrence. GSC location 84315. Fritz Section 2 (1976). Sekwi Formation, "*Nevadella*" Zone, *Nevadela eucharis* Zone.

Nevadella faceta Fritz 1972

Appendix 2A, Plate 4, D-H

Nevadella faceta Fritz 1972, p. 23-24, plate 3, figs. 8-14.

Material. 11 cephala and 3 genae.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC locations 73027, 73032, 73034, 73035, 73036, and 73037. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Nevadella cf. *N. keelensis* Abe et al. 2010

Appendix 2A, Plate 5, M-O

cf. *Nevadella keelensis* Abe et al., 2010, p. 1448, fig. 3c, d.

Material. 1 complete cephalon and 13 partial cephala.

Description. Cephalic convexity low (transversely). Width of cephalon slightly greater than ½ cephalic length. Sides of glabella straight and convergent; LA tapers to a blunt point. Three glabella furrows present, all of moderate depth and shallowing towards the axis. S3 and S2 faint, straight; S1 slightly convex anteriorly and deeper. All glabellar furrows are at a ~40° angle relative to transverse line and directed backwards. Occipital furrow deeper, slightly curved, angled backwards. Occipital ring bears very slight node at posterior. Ocular lobes uniformly curved, narrow, originating from the posterior part of L0 and terminating parallel to the anterior of the occipital lobe. Interocular area thin, approximately ¼ width of extraocular area at maximal thickness. Anterior and lateral parts of cephalic border of uniform width, approximately 1/5 length of LA. Posterior part of cephalic border moderately thicker at margins between genal spine and metagenal area, of similar width as anterior and lateral border inwards. Border furrow shallow and uniform throughout. Genal spines directed outwards, tapering, length relative to cephalon unclear. No metagenal spine evident, although a slight swelling is present in the metagenal area. Extraocular area bears extremely faint genal caeca.

Discussion. This species bears a strong resemblance to *Nevadella keelensis* Abe et al., 2010, save for a few features: 1) a plectrum is not present on any of the cephala assigned to this species, 2) the ocular lobes of *N. keelensis* are somewhat thicker, whereas this species has narrow, more crescentic ocular lobes, 3) the cephalic border of *N. keelensis* is moderately thicker, and 4) genal caeca are not evident on *N. keelensis*. The latter feature may be due to preservation rather than an actual morphological difference between these two taxa.

Occurrence. GSC location 84305. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Nevadella cf. *N. bacculenta* Fritz 1972

Appendix 2A, Plate 4, I

cf. *Nevadella bacculenta* Fritz 1972, p. 22-23, plate 5, figs. 1-9.

Material. 1 partial cephalon.

Description. Cephalon wide, width probably over twice cephalic length (margins of cephalon not present). Sides of glabella convergent, L1 to L3 slightly concave. LA tapering, elongate, appears as dull point. S3 shallow, S2 somewhat deeper, and S1 the most deeply incised. All glabellar furrows directed backwards; S3 and S2 inclined at ~30° angle relative to transverse line across cephalon, S1 inclined moderately more sharply (~45°). Ocular lobes originate at midpoint of LA and are crescentic in shape, diverging strongly initially with tangent parallel to axis across from L2. Ocular lobes terminate parallel to midlength of posterior glabella lobe (S1). Interocular area approximately 1/5 extraocular area at widest point, flat, inclined very slightly towards axis. Preglabellar field short, approximately 1/3 length of LA. Anterior border wide (approximately 1/3 length of LA), of consistent width throughout. Marginal furrow shallow, of same depth both anteriorly and laterally. Extraocular area bears faint venations that appear as slight, sub-parallel lines that radiate outwards.

Discussion. The cephalon assigned to this species is incomplete, precluding specific designation. Other species of *Nevadella* in this collection possess much narrower cephala than this species. The posterior margin of this cephalon is also absent, inhibiting comparison. The portions of this cephalon that remain are, however, comparable to *N. bacculenta*. *N. bacculenta* differs in that it has ocular lobes slightly closer to the glabella, granules on its glabella, a well-developed plectrum, and a slightly longer pre-glabellar field.

Occurrence. GSC location 84312. Fritz Section 2 (1976). Sekwi Formation, "*Nevadella*" Zone.

Nevadella sp.

Appendix 2A, Plate 5, B-C

Material. 13 partial cephala.

Description. Small, incomplete, poorly preserved cephala bearing a relatively long LA, concave-sided glabellae, and relatively wide interocular areas.

Discussion. These cephala are too incomplete and poorly preserved to be assigned to any known species of *Nevadella*, although they do appear to bear the hallmark traits of the genus. Namely, LA is elongate and S0 appears convex anteriorly (see list of criteria in Lieberman 2001).

Occurrence. GSC location 84314. Fritz Section 2 (1976). Sekwi Formation, "*Nevadella*" Zone.

Nevadella sp. 2 Fritz 1972

Appendix 2A, Plate 4, B and C

Nevadella sp. 2 Fritz 1972, p. 24-25, plate 5, figs. 12-15.

Material. 1 cephalon and 3 associated hypostomata.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC locations 73030, 73033, 73037. Fritz Section 10 (1976). Sekwi Formation, "*Nevadella*" Zone

Genus *Nevadia*

Discussion. See discussion under *Nevadella*.

Nevadia addyensis Okulitch 1951

Appendix A, Plate 4, J and K

Nevadia addyensis Okulitch 1951, p. 406, plate 62, figs. 1 and 2.

Nevadella sp. Nelson 1976, p. 36, plate 4.

Nevadia parvoconica Fritz 1992, p. 22-24, plate 2, figs. 7-9, fig. 7b.

Nevadia fritzi Lieberman 2001, p. 105-106, fig. 4, 1 and 2.

Material. 2 large, mostly complete cephala and 4 small, incomplete cephala.

Description. Width of cephalon slightly less than twice cephalic length, closely approximating half circle. L0 to L3 convergent, sides of glabella overall slightly concave; posterior half of LA straight, anterior half convergent, terminates as dull point. Occipital ring bears a slight node. Glabellar furrows of moderate depth, shallowing slightly towards axis. S3 to S1 straight, inclined backwards at roughly 40° relative to transverse line across width of cephalon. S3 connected across the axial midline, all other glabellar furrows discrete. S0 convex anteriorly; slope of tangent to S0 sub-parallel to angle of other glabellar furrows. Ocular lobes originate at posterior of LA and form a crescent that terminates parallel to the posterior of L3. Interocular area exceedingly thin (approximately 1/8 extraocular area at widest point). Preglabellar field approximately 1/3 length of LA and occupied by a well-defined plectrum. Anterior border wide, approximately 1/4 length of LA. Lateral border of similar width; anterior and lateral border furrows shallow and of consistent depth throughout. Posterior border ½ the thickness of anterior border; posterior border furrow of similar depth as lateral/anterior border furrows. Metagenal ridge present but quite faint, originates from posterior tip of ocular lobes and terminates at 1/3 length of posterior margin away from glabella. Posterior margin between axis and intergenal area transverse; posterior margin becomes slightly swept back between intergenal area and margins of cephalon. Extraocular area bears genal caeca.

Discussion. Okulitch (1951) distinguished *Nevadia addyensis* from *Nevadia weeksi* based on the former trilobite's relatively longer and narrower glabella and ocular lobes that are relatively close to the glabella and separated from the glabella by axial furrows. Hollingsworth (2011) regarded *Nevadia parvoconica* Fritz 1992 as being a junior subjective synonym of *N. addyensis*. In addition, Hollingsworth (2011) also subsumed *Nevadia fritzi* Lieberman 2001 within *N. addyensis* and stated that one nevadiid identified in Lieberman (2001, fig. 3.2) as *N. weeksi* was *N. addyensis* instead. The latter reassignment (Lieberman 2001, fig. 3.2) appears less plausible than the others on the basis that that cephalon differs in some features commonly observed in *N. addyensis*: it has a sub-transverse posterior margin, a relatively wide posterior portion of the glabella that tapers much more rapidly, and an anterior glabellar lobe that appears to initially expand outwards and reach a width greater than that of L3 before tapering forwards. It seems unlikely that the totality of these features is due to compaction. Morphological variation between *N. addyensis* Okulitch 1951, *N. parvoconica* Fritz 1992, and *N. fritzi* Lieberman 2001 seems in accordance with variation that one would expect in the same species, and this author agrees that those taxa ought to be subsumed in *N. addyensis*, although such reassignment should be done after formally examining type collections rather than solely based on published images. It is unclear as to whether or not Hollingsworth viewed type specimens in order to justify the taxonomic re-evaluation published in Hollingsworth (2011). However, it is with the standards for morphological variation originally suggested by Hollingsworth (2011) in mind that this material is assigned to *N. addyensis*. This material does have a more sharply tapering L0 and a slightly longer pre-glabellar field than other material that has been assigned to *N. addyensis*. This is regarded as being an acceptably minimal amount of variation to warrant assignment to *N. addyensis*. Okulitch (1951) also stated that *N. addyensis* does not possess glabellar furrows that connect across the glabella. This does not seem to be the case in his figured material, as the specimen in plate 62.1 (Okulitch 1951) does appear to possess an S3 than connects shallowly across the axis. This is also the case with the other species that have been synonymized with *N. addyensis* and the material herein, and this trait is undoubtedly variable depending on compaction.

Lieberman (2001) included *Nevadia addyensis* in *Nevadella*. This author maintains *Nevadia* in its original genus, chiefly because of its relatively long pre-glabellar field.

Occurrence. GSC location 84313. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone, *Nevadia addyensis* Zone.

Family OLENELLIDAE Walcott 1890

Genus *Olenellus* Hall 1861

Olenellus cf. *O. clarki* (Resser 1928)

Appendix 2A, Plate 15, Q-S

cf. *Paedumias clarki* Resser 1928, p. 9, plate 3, figs. 1, 2.

cf. *Paedumias clarki* Riccio 1952, p. 33, plate 9, figs. 1-4.

cf. *Olenellus clarki* Mount 1976, p. 175, fig. 6.

cf. *Olenellus clarki* Palmer and Halley 1979, p. 68, plate 3, figs. 1-5.

cf. *Olenellus clarki* Mount 1980, p. 27, fig. 6.

cf. *Olenellus clarki* Lieberman 1999, p. 18, fig. 3, 2-5

Material. 4 partial cephala.

Description. Cephalon approximates half circle. Anterior margin moderately curved; anterolateral border equal to ~1/4 length of LA, thickening slightly at posterolateral corner. Anterolateral border furrow narrow and well-defined. Posterior margin transverse throughout initial 2/3 length from axis and then contacts metagenal area as slight bump. Genal angle ~25° relative to transverse line. Posterior border slightly less thick than anterolateral border. Front of LA strongly rounded; lateral margins directed outwards at ~15° angle relative to axis. L3 slightly less than 1/3 length of LA; margins directed ~20° away from axis; anterior and posterior margins curved. L2 V-shaped; of same length as L3. L1 equal to slightly less than ½ length of LA; margins slightly convex. L0 of similar length to L1 and ring-shaped. S3 narrow; moderately deep, overall u-shaped (convex side backwards-facing), merging across the axis. S2 pit-like close to the axis and sub-transverse close to the axis, convex anteriorly distal from the axis and more narrow. S1 convex anteriorly (tangent at ~45° relative to axis), deep, and wider than S3 and S2. S0 similar to S1 but deeper and broader. Ocular lobes originate from the postero-lateral corners of LA and are separated from the glabella by a faint furrow that is slightly divergent (outwardly) from the axis, reaching maximum distal extent from the axis parallel to the middle of L2 and terminating parallel to S0. Interocular area ~1/6 width of glabella. Extraocular area slightly convex and equal in width to glabella.

Discussion. Similar to *Olenellus clarki* Resser 1928 in most aspects, excepting: 1) an S2 that is joined across the axis, 2) relatively more robust genal spines, 3) a more slightly more advanced genal angle, and a genal area that is slightly closer to the axis, 4) no plectrum is evident [material assigned to this species figured in Palmer and Halley (1979) appear to bear plectra, although it is not stated in their description], and 5) a narrower extraocular field. These differences can probably be considered to fall outside of variation within a species. Despite this, this species remains quite close to *O. clarki* Resser 1928.

Occurrence. GSC location 84338. Section 2 (Fritz 1976). Hess River Formation, "*Bonnia-Olenellus*" Zone.

"*Olenellus puertoblancoensis*" Lochman 1952

Appendix 2A, Plate 17, A-I

Paedumias puertoblancoensis Lochman in Copper, 1952, p. 94, Plate 19, figs. 9-16.

Olenellus puertoblancoensis Fritz 1972, p. 14-15, Plate 17, figs. 1-7.

Material. 20 cephala, 1 partial thorax, and 1 gena.

Description. Fritz (1972) describes this species in detail.

Discussion. *O. puertoblancoensis* specimens figured by Fritz (1972), although quite close to *O. transitans* Walcott 1910 can more plausibly be said to be distinct from it because of the following features: 1) a longer preglabellar field, 2) a sub-transverse rather than swept-back posterior margin, and 3) longer ocular lobes. It is possible that the same could be said of Lochman's (1952) type material, but with a lower degree of certainty. The *Olenellus puertoblancoensis* type material described in Lochman (1952) is problematic because it consists mainly of juvenile individuals, and the few fully mature cephala that were figured and described by Lochman (1952) are fragmentary. It is therefore difficult to assess the differences between this material and Lochman's (1952) type specimens. Furthermore, as is stated in Lochman (1952), the few apparent differences between *O. puertoblancoensis* and *O. transitans* are minimal and could foreseeably have resulted from compaction.

It should also be noted that, as is the case in virtually every species of *Olenellus*, S2 is slit-like and confined to the interior of the glabella in *O. puertoblancoensis*, resulting in a fused L2 and L3. One immature cephalon [Plate 1, fig. 1, Fritz (1972)] does not bear this feature, indicating that either it is not *O. puertoblancoensis* or that *O. puertoblancoensis* developed that feature later in its ontogeny.

Occurrence. GSC locations 73068, 73069, 73070, 73071, and 73072. Section 10 (Fritz 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Olenellus cf. "*O. puertoblancoensis*" Lochman 1952

Appendix A, Plate 17, N

cf. *Olenellus puertoblancoensis* Fritz 1972, p. 14-15, Plate 17, figs. 1-7.

Material. 1 partial cephalon.

Description. Cephalon semi-circular. Lateral borders 1/6 length of LA, of consistent thickness throughout. Pre-glabellar field of considerable length for *Olenellus*, equal to roughly 2/3 length of LA. LA long, equalling slightly under ½ total length of glabella, occipital ring exclusive. LA divergent anteriorly throughout posterior half and then convergent anteriorly, terminating as dull point. L3 appears "curved" overall, imparting a chevron shape. Sides of L3 angled outwards (~20°) relative to sagittal line. L2 constricted relative to other lobes, side slightly convex and parallel. LA also chevron-shaped, but with sides directed inward at ~30° relative to sagittal line. S3 deep distal from axis and shallower medially, directed outwards at ~40° relative to transverse line, slightly convex anteriorly and joined across the midline. S2 straight and deep distally. S1 roughly as deep as S2, directed outwards at ~40° relative to transverse line. Occipital ring slightly wider than LA, sides convex. Occipital furrows roughly as deep as S1 and S2, directed outwards at ~35° relative to transverse line. Interocular area slightly convex, width equivalent to under 1/3 width of extraocular area. Ocular lobes bear slight longitudinal furrow and originate from postero-lateral corner of LA, tangent to curvature initially directed strongly backwards and shallowing just before S3. Ocular lobes reach most distal extent parallel to S1 and terminate parallel to middle of occipital ring. Posterior border sub-transverse, of equivalent width to lateral border. Posterior border furrow of equivalent depth to lateral border furrow. No metagenal spine evident. Genal spines slightly advanced, base of medium width, originate parallel to middle of occipital ring, length equal to half-length of cephalon.

Discussion. This cephalon most resembles *O. puertoblancoensis* Lochman 1952 and differs in the following features: 1) a relatively long pre-glabellar field and 2) S3 is joined across the axis. This material is somewhat closer to *O. puertoblancoensis* than *O. transitans* because it lacks a swept-back posterior margin (see discussion for *O. puertoblancoensis* above). This cephalon is held in open nomenclature for similar reasons as discussed above.

Occurrence. GSC location 84340. Section 2 (Fritz 1976). Hess River Formation, "*Bonnia-Olenellus*" Zone.

Olenellus sp. 5 Fritz 1972

Appendix 2A, Plate 17, J-M

Olenellus sp. 5 Fritz 1972, pg. 19, plate 20, figs. 9-14.

Material. 5 cephala and 2 genae.

Discussion. *Olenellus* sp. 5 is clearly *Olenellus*-like and can be maintained in that genus. Fritz (1972) considered *Olenellus* sp. 5 to be very close to *O. puertoblancoensis*, and details on the differences between these two taxa can be found in Fritz (1972, pg. 19). In addition to those differences, *Olenellus* sp. 5 consistently bears a more pronounced S2 furrow between the merged L3 and L2, the outer portion of which is shallow, narrow, and directed inwards at roughly a 40° angle relative to the axis. Contrastingly, the S2 of *Olenellus puertoblancoensis* is more pit-like, and its outer portion is poorly defined. These differences seem sufficient to merit a different species designation than *O. puertoblancoensis*. Of all the species Fritz (1972) assigned to an indeterminate species of *Olenellus,* this is the only one that should remain assigned to that genus.

Occurrence. GSC locations 73073 and 73074. Section 10 (Fritz 1972). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Olenellus? sp.

Appendix 2A, Plate 13, E

Material. 1 worn cephalon.

Description. Cephalon length slightly under 2/3 width. Anterior border approximately 1/6 length of LA, of consistent thickness until parallel to S3. Lateral border overall thicker, increasing slightly parallel to S3 and reaching maximum thickness at above genal area. Anterior and lateral border furrows of similar thickness as anterior border. Pre-glabellar field absent. LA approximately 1/5 total width of cephalon, slightly divergent anteriorly at posterior-most 1/5 of length, convergent at anterior 4/5 of length and terminating as a dull, blunt point. L3-L0 and glabellar furrows poorly visible due to effacement, although S3 and S2 appear arcuate and do not appear to connect medially. Ocular lobes quite wide (transversely), equal to slightly more than 1/3 transverse width of LA. Ocular lobes originate from postero-lateral corners of glabella and terminate close to the posterior border, presumably parallel to the occipital ring. Interocular area thin, equal to less than ¼ width of extraocular area. Posterior border of same thickness as lateral border distal to axis, tapers somewhat inward. Posterior border furrow of equivalent depth and width to anterior and posterior border furrows. Posterior margin overall swept back at 10° angle relative to transverse line across cephalon. Intergenal area bears small bumps rather than spines and occurs just over 2/3 cephalic half width away from axis. Genal angle slightly advanced, genal spines directed outwards at roughly 10° relative to sagittal line. Genal spines short (less than half cephalic length).

Discussion. Fritz (1976) originally designated this trilobite as aff. *Olenellus puertoblancoensis* (Lochman 1952) in his faunal list. Conspicuous differences between this specimen and the material figured in Lochman in Cooper 1952 and Fritz (1972) include wider ocular lobes and a smaller interocular area. These features are disparate from *O. puertoblancoensis*, and the general effacement of this specimen necessitates a cautious generic assignment.

Occurrence. GSC location 84330. Fritz Section 2 (1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Family "LAUDONIIDAE" Harrington 1956

Genus *Fritzolenellus* Lieberman 1998

Discussion. More recent work has modified Lieberman's (1998, 1999) definition of *Fritzolenellus*. Notably, Lieberman (1999) maintained that *Fritzolenellus* does not exhibit a parafrontal band in dorsal view. Stein (2008) figured several specimens of *Fritzolenellus* *lapworthi* Peach and Horne 1892 that exhibit a parafrontal band, and several specimens figured in Fritz (1992) also exhibit a parafrontal band dorsally (e.g., Fritz (1992), plate 7, fig. 1). This is in contradiction to Lieberman's (1999) definition. A parafrontal band is a diagnostic criterion of *Fritzolenellus* and is considered to be an important characteristic herein, although its expression may vary because of compaction and mode of preservation. More detailed discussion can be seen under the discussions of the species assigned to this genus, as well as the discussion for *Elliptocephala walcotti* Lieberman 1999.

Fritzolenellus cf. *F. truemani* (Walcott 1913)

Appendix 2A, Plate 10, A-G

cf. *Olenellus truemani* Walcott 1913, p. 316, plate 54, figs. 2, 6, and 8.

cf. *Olenellus truemani* Walcott 1916b, pg. 253, plate 17, figs. 2-10.

cf. *Olenellus truemani* Fritz 1992, p. 15, plate 6, figs. 1-4, plate 7, figs. 1-6, text fig. 6b.

cf. *Fritzolenellus truemani* Lieberman 1999, p. 95-96, fig. 17.1.

Material. 4 complete cephala, 1 complete early stage meraspid cephalon, and 9 incomplete cephala.

Description. Length of cephalon slightly greater than ½ width. Width of anterior and lateral borders equal to ~1/6 length of LA, antero-lateral border broad and shallow throughout. Preglabellar field present, marked by plectrum; equal to 2/5 length of LA on small cephala and slightly less than ¼ length of LA on larger specimens. LA comprises 1/5 width of cephalon, equal to ½ length of glabella (occipital ring exclusive); front strongly rounded imparting a "bullet shape;" postero-lateral corners divergent anteriorly. L3-L1 overall "V-shaped." L3 short, equal in width to LA at widest extent. L2 constricted, sides divergent anteriorly. L1 longer than both L3 and L2, sides divergent posteriorly. Glabellar furrows generally strongly incised. S3 chevron-shaped, connected across axis; S2 relatively faint, very slightly convex anteriorly; S1 deeper, also convex anteriorly. Sides of occipital ring sub-parallel, length equal to that of L1. Occipital furrows sub-transverse and deep. Ocular lobes bear faint ocular furrow; originate from postero-lateral corner of LA and contact L3; reach most distal extent from axis parallel to S1 and terminate parallel to anterior 1/3 point of occipital ring. Interocular area sub-equivalent to width of ocular lobe, equal to slightly less than 1/3 width of extraocular area. Anterior half of interocular area flat, posterior half sloped backwards. Posterior border slightly thinner than antero-lateral border; posterior border furrow faint. Posterior margin sub-transverse until 2/3 cephalic half-width away from axis and then directed forwards, resulting in an advanced genal area. Genal spines initiate parallel to anterior portion of occipital lobe, base of moderate thickness, length equal to as much as half that of cephalon. No intergenal spines evident.

Length of early-stage meraspid cephalon ½ width. Pre-glabellar field equal to 1/3 length of LA, marked by plectrum. Length of LA subequal to combined length of L3-L1. LA wider (~1/4 width of cephalon at widest point) than L3-L1; postero-lateral corners divergent, front broadly curved. Margins of glabella from L1-L2 straight, parallel; margins of L3 slightly wider and divergent anteriorly. Orientation and morphology of glabellar furrows unclear. Occipital ring short, sides parallel. Ocular lobes reach most distal extent parallel to L1, terminate parallel to middle of occipital ring. Interocular area convex and equal in width to ½ width of extraocular area. Genal spines advanced relative to adult cephala; base parallel to L2. Length of genal spines equal to ½ length of cephalon. Posterior margin sub-transverse from axis to ½ cephalic half-width from axis and advanced from that point outwards. Metagenal area marked by pair of slight, metagenal spines that are directed outwards.

Discussion. This species closely compares to material in Fritz 1992 designated as *Olenellus truemani*. *Olenellus truemani* Walcott 1913 has been reassigned to *Fritzolenellus* (Lieberman 1998, 1999) and is quite disparate material assigned to from *Olenellus truemani* by Fritz (1972), which Lieberman (1999) assigned to *Elliptocephala*. Differences between the material in this study and the specimens of *Fritzolenellus truemani* illustrated in Fritz 1992 include: 1) thinner antero-lateral borders, 2) A longer pre-glabellar field that bears a plectrum, 3) ocular lobes that terminate farther back, and 4) a posterior margin that is sub-transverse and then directed forwards, rather than sub-transverse to swept-back.

cf. *Olenellus truemani* described by Blaker and Peel 1997 is also quite similar to this species and differs mainly in 1) an S3 that is not conjoined across the axis, 2) Small intergenal swellings or spines are present, and 3) a posterior margin in which the area between the axis and intergenal area closest to the intergenal area is directed backwards. cf. *Olenellus truemani* Blaker and Peel would probably be reassigned to *Fritzolenellus* if re-evaluated and appears to bear more resemblance to *O. truemani* Fritz 1992 rather than *O. truemani* Fritz 1972, despite the direct comparison made with the former in Blaker and Peel (1997). Notably, late-stage meraspid and early-stage protaspid material illustrated in Blaker and Peel (1997) bears some resemblance to the *Fritzolenellus* morphotype *sensu* Laibl et al., 2021 and also strongly resemble the early-stage protaspid in this paper. Namely, both possess genal spines with bases parallel to the posterior tip of the ocular lobes and a posterior margin that is directed forwards. One salient difference between the material in Blaker and Peel (1997) and the *Fritzolenellus* morphotype is that the intergenal spines in juvenile cf. *O. truemani* are directed outwards rather than straight back. Regardless, it is probable that cf. *O. truemani* Blaker and Peel 1997 should be reassigned to *Fritzolenellus*.

Occurrence. GSC location 84316. Section 2 (Fritz 1976). Sekwi Formation, lower "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Fritzolenellus sp. 1 Fritz 1972

Appendix 2A, Plate 11, D-K

Olenellus sp. 1 Fritz 1972, p. 17, plate 10, figs. 6-16.

Material. 12 cephala, 7 genae, and 3 hypostomata.

Description. Fritz (1972) adequately describes this species.

Discussion. Fritz (1972) provided several criteria to distinguish between this species and *Olenellus puertoblancoensis* and maintained that *Olenellus* sp. 1 and *O. puertoblancoensis* are morphologically close. In addition to the features Fritz (1972) outline, it should also be noted that the glabella of *Olenellus* sp. 1 differs from *O. puertoblancoensis* in that S2 is convex, separating L1 and L2. *O. puertoblancoensis* has a slit-like S2 and L1 and L2 are merged. Virtually every species of *Olenellus* possesses a merged L1 and L2, making this species dissimilar to the genus in general, and possibly only superficially similar to *O. puertoblancoensis*. *Fritzolenellus* lacks a merged S2 and S3, and this material is a better match for *Fritzolenellus* than *Olenellus*.

Occurrence. GSC location 73043. Section 10 (Fritz 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Fritzolenellus? sp.

Appendix 2A, Plate 11, C

Material. 1 complete cephalon and 1 partial cephalon.

Description. Length of cephalon roughly equivalent to 2/3 width. Anterior and lateral border equal to ¼ length of LA, of consistent width throughout. LA equal to ½ length of glabella, occipital ring exclusive. Preglabellar field 1/5 length of LA. Entirety of LA convergent anteriorly, tapers as dull point. L3 as wide as LA, L2 constricted slightly. S1 and S0 parallel, of moderate depth distally, not connected across axial midline. Width of interocular area equal to 1/3 width of extraocular area. Ocular lobes originate at postero-lateral corner of LA, reach maximum outward extent parallel to L2, and terminate parallel to anterior of L0. Posterior border somewhat thicker than anterior and lateral borders, posterior border furrow of similar depth to antero-lateral border furrow. Posterior directed back from axis to metagenal area (~2/3 cephalic half-length away from axis), genal area slightly advanced. Metagenal area bears small bump instead of spine. Genal spines originate parallel to anterior of L0 and are of moderate width.

Discussion. These cephala are poorly preserved but appear to be more similar to *Fritzolenellus truemani* Walcott 1913 than the type of *Olenellus*, *O. thompsoni* Hall 1859. Namely, the lateral margins of LA and L0 a roughly parallel to one another, and the posterior tips of the ocular lobes are slightly more anterior. Other hallmark features of *Fritzolenellus* include an L2 and L3 that are distinctly separated by S2, whereas in *Olenellus* L2 and L3 merge. The glabella of the complete cephalon assigned to this species is damaged, and these features are absent as a result. This species is therefore held in open nomenclature because of uncertainty arising from damage.

Occurrence. GSC location 84318, Section 2 (Fritz 1976). Sekwi Formation, lower "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Genus *Lochmanolenellus* Lieberman 1998

Lochmanolenellus sp.

Appendix 2A, Plate 10, H-L

Material. 11 incomplete cephala and 4 meraspid cephala.

Description. Length of cephalon equal to 2/3 width. Width of anterior and lateral borders equal to 1/6 length of LA; antero-lateral border convex and high-standing, deflected slightly around LA. Antero-lateral border furrow narrow but deep. Lateral border thickens somewhat towards the genal area. LA contacts anterior border furrow; LA equal to slightly less than 1/3 width of cephalon, convex and high-standing compared to other glabellar lobes. LA overall oval-shaped (with long axis of oval perpendicular to axis of cephalon), with postero-lateral corners of LA divergent anteriorly, and front broadly curved. L3 thin, chevron-shaped; margins less well-separated from ocular lobes by axial furrow; L2 V-shaped and somewhat thicker; L1 only partially preserved leaving its thickness indeterminate, sides appear to merge seamlessly with interocular area. Glabellar furrows strongly incised; all directed outwards at ~25° angle relative to transverse line, and none conjoin across the axis. S3 slightly convex anteriorly, relatively shallow; S2 straight, somewhat deeper, S1 slightly convex anteriorly and of moderate depth. Ocular lobes directed outwards, originating from poster-lateral corners of LA, reaching maximal distal extent parallel to L2 and terminating parallel to end (?) of L1. Ocular lobes consist of convex inner band raised above the rest of ocular lobes, separated from outer band by ocular furrow that extends throughout the length of the ocular furrows and shallows posteriorly. Extraocular platform bound tightly to outer ocular lobe and of similar height to outer band. Interocular area equal to less than half extraocular area. Genal angle advanced; base of genal spines parallel to S2. Genal spines initially directed outwards, broadly curved, and directed inwards or straight back along posterior half of spine. Posterior border slightly lesser thickness than that of anterior border; posterior border furrow narrow. Posterior margin transverse (?) from ~3/5 cephalic half-width distance away from axis to axis; posterior margin along genal angle follows line with 45° from sagittal line. No intergenal swellings or spines evident. A faint, posterior ocular line is visible on some specimens which appears to be directed at a ~10° line from transverse line and terminate close to the intergenal area. The surface of one large partial cephalon bears a faint, polygonal meshwork on its surface. Some polygons bear slight pustules in the centre.

Length of meraspid cephala equal to ¾ length. Anterior margin more sharply curved than in adult cephala; antero-lateral border equal to ¼ width LA. Glabella straight, parallel-sided from L0 to L3; LA wider, ovoid in a similar manner to adult cephala but thinner transversely. Occipital ring bears faint node. Ocular lobes terminate parallel to anterior of L1. Posterior margin sub-transverse until parallel (sag.) with posterior tip of ocular lobes, advanced until genal area. Small, posterior spines evident at mid-way point of advanced portion of posterior margin. Base of genal spines parallel to posterior of L2; genal spines initially directed outwards until curving straight back at half-way point.

Discussion. Fritz (1976) originally designated this material as *Laudonia*? sp, and these cephala can now be designated as *Lochmanolenellus* Lieberman 1998 based on the presence of an extraocular platform, a cephalic surface ornamented with a polygonal meshwork in which polygons bear pustules, and genal spines with bases parallel to L2 (Webster and Bohach, 2014). This species of *Lochmanolenellus* is unique from other representatives of its genus in several aspects, including 1) a glabella in which L3 is not distinctly separated from the ocular lobes by the axial furrow, 2) L1 is not distinctly separated from the interocular area by an axial furrow, and 3) no pronounced intergenal spines or swellings. Webster and Bohach (2014) modified Lieberman's (1998) criteria for *Lochmanolenellus* and, among other things, added the presence of an extraocular platform as being a characteristic of *Lochmanolenellus*. The outer ridge present on the outer band of the ocular lobes of these specimens is probably the same structure, although its expression differs in this case in that it is tightly fused to the ocular lobe and relatively high-standing rather than a somewhat discrete bulge located in the extraocular area. This state is also disparate from other known species of *Lochmanolenellus*.

Occurrence. GSC location 84316. Section 2 (Fritz 1976). Sekwi Formation, lower "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Family "WANNERIIDAE" Hupé 1953

Genus *Elliptocephala* Emmons 1844

Elliptocephala laxocules (Fritz 1972)

Appendix 2A, Plate 14, D-Q

Olenellus laxocules Fritz 1972, pg. 13, plate 11, figs. 7-21.

Elliptocephala laxocules Lieberman 1999, pg. 60, fig. 12.6

Material. 19 cephala and 1 hypostome.

Description. Fritz (1972) adequately describes this species.

Discussion. *Elliptocephala laxocules* can be distinguished from other species of *Elliptocephala* chiefly by the presence of a pre-glabellar field and a relatively small interocular area.

Occurrence. GSC location 73046. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Elliptocephala paraoculus (Fritz 1972)

Appendix 2A, Plate 15, A-H

Olenellus paraoculus Fritz 1972, pg. 14, plate 15, figs. 8-22.

Elliptocephala paraoculus Lieberman 1999, pg. 60.

Material. 41 cephala, 1 genae, and 2 hypostomata.

Description. Fritz (1972) adequately describes this species.

Discussion. *Elliptocephala paraoculus* can be easily distinguished from other species of *Elliptocephala* by its narrow interocular area and an anterior glabellar lobe that contacts the anterior border.

Occurrence. GSC locations 73058, 73059, 73060, 72061, 73064, and 73065. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Wanneria* Subzone.

Elliptocephala sequomalus (Fritz 1972)

Appendix 2A, Plate 14, A-C

Olenellus sequomalus Fritz 1972, pg. 15-16, plate 12, figs. 14-25.

Elliptocephala sequomalus Lieberman 1999, pg. 57, fig. 12.2.

Material. 5 cephala.

Description. Fritz (1972) adequately describes this species.

Discussion. *Elliptocephala sequomalus* is somewhat like *E. laxocules* in that it also possesses a pre-gabellar field. *E. sequomalus* differs in that it has a larger interocular area and a swept-back posterior margin, as opposed to *E. laxocules* which has a narrow interocular area and a sub-transverse posterior margin.

Occurrence. GSC location 73049. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Wanneria* Subzone.

Elliptocephala walcotti (Lieberman 1999)

Appendix 2A, Plate 9, A-K*Olenellus truemani* Fritz 1972, pg. 16, plate 9, figs. 1-14.

Elliptocephala walcotti Lieberman 1999, pg. 58-59, fig. 12.3.

Material. 19 cephala, 1 pleura, and 1 hypostome.

Description. Fritz (1972) and Lieberman (1999) adequately describe this species.

Discussion. Fritz (1972) originally held this species as being conspecific with *Fritzolenellus truemani* (Walcott 1913). Later, Fritz (1992) repudiated that original designation, but maintained both species in *Olenellus*. Lieberman (1998) erected *Fritzolenellus* and established *Fritzolenellus truemani* (Walcott 1913) as the type species. Later, Lieberman (1999) argued for the placement of *Olenellus truemani* (Fritz 1972) in *Elliptocephala*, redubbing the species *E. walcotti*. *Olenellus truemani* (Walcott 1913) and *Olenellus truemani* (Fritz 1972) are therefore neither congeneric nor conspecific as per Lieberman (1999).

Given recent refinements to the concept of *Fritzolenellus* (Stein 2008) and the documentation of the ontogeny of *Elliptocephala* and *Fritzolenellus* (Laible et al. 2021), Lieberman's (1998) designation may no longer be tenable. The list of features that Lieberman (1999) listed to argue for *Elliptocephala walcotti*'s generic designation are as follows: 1) *E. walcotti* has an anterior cephalic border width adjacent to very front of the cephalon that is equal to 50-60% of the sagittal width of L0 as opposed to equal to L0, 2) *E. walcotti* has a prominent parafrontal band, while *F. truemani* does not, 3) The ocular lobes of *E. walcotti* extend to parallel to S0, whereas those of *F. truemani* extend to the medial area of L1, 4) *E. walcotti* lacks lateral lobes on its L0, while *F. truemani* has lateral lobes on L0, 5) the interocular area of *E. walcotti* is evenly sloped from the ocular lobe to the glabella, while the interocular area of *F. truemani* is arched, 6) *E. walcotti* possesses a conjoined S0, and *F. truemani* does not, and 7) the genal ridge of *E. walcotti* is more developed than that of *F. truemani.*

Many of these features allow for inclusion in *Fritzolenellus* or are probably not significant from a diagnostic standpoint. Lieberman's (1999) points are addressed here, in the same order: 1) The anterior cephalic margin length of *Fritzolenellus* varies from species to species, with *F. lapworthi* exhibiting a substantially shorter anterior cephalic margin (Stein 2008, Laibl et al. 2021). Furthermore, that feature is liable to be strongly affected by compaction, 2) *F. truemani*, as figured in Fritz (1992), does appear to exhibit a parafrontal band, as does *F. lapworthi* (Stein 2008, Laibl 2021). This feature is probably an important diagnostic feature of *Fritzolenellus*, contradicting Lieberman's (1999) original criteria. 3) *F. lapworthi* exhibits ocular lobes that are parallel to S0 or the anterior portion of L0, indicating that this feature is variable in the genus and may not be useful for distinguishing between *Fritzolenellus* and *Elliptocephala*, 4) Other representatives of *Fritzolenellus* aside from the type including *F. lapworthi* and *F. reticulatus* Peach 1894 appear to bear lateral swellings on L0 that are sometimes separated from the rest of L0 by a faint, marginal furrows parallel to the axis (e.g. Stein 2008 Fig. 3, A; Laibl et al. 2022 Fig. 7, A) , indicating that that feature may actually be useful for distinguishing between the two genera, 5) the interocular area of *E. walcotti* does evenly sloped rather than convex, but this feature may also be readily altered by compaction, and probably shouldn't be given high priority from a phylogenetic standpoint, 6) All species currently assigned to *Fritzolenellus* do appear to lack a conjoined S0, whereas those assigned by Lieberman (1999) to *Elliptocephala* (including *E. truemani*) do not, indicating that that feature may remain useful for distinguishing between the two genera, and 7) This author does not see any significant differences in the development of the genal ridge between *E. walcotti* and *F. truemani*, or any other species assigned to either genera. Anecdotally, the development of the genal ridge in olenellids appears to vary within species at times, and in this case may not be useful to discriminate.

Secondly, one immature cephalon figured by Fritz (1972, Plate 9, fig. 5) appears more like documented *Fritzolenellus* instars than it does to *Elliptocephala* instars. Specifically, the immature cephalon possesses 1) pronounced pits on its anterior glabellar lobe, and 2) genal spines that are rear facing rather than splayed slightly outwards, as is the case in equivalently developed juvenile *Elliptocephala* cephala (Whittington 1957). Both species' immature cephala appear similar and belong to the *Fritzolenellus* morphotype (Laibl et al. 2021), but these characteristics may still indicate that *Elliptocephala walcotti* ought to be reassigned to *Fritzolenellus*.

The issues with Lieberman's (1999) rationalization for including *E. walcotti* in *Elliptocephala* indicate that the criteria for discriminating between *Elliptocephala* and *Fritzolenellus* need to be further refined and re-evaluated and that there is at least tentatively an argument for including *E. walcotti* in *Fritzolenellus*. The former notion is favoured herein, mainly because of the presence of a parafrontal band and the similarities between the immature cephalon figured by Fritz (1972; Plate 9, fig. 5) and the *F. lapworthi* meraspids figured in Laibl et al. (2021). Further cladistic work is required to satisfactorily resolve this issue.

Fritz (1972) held that *Olenellus praenuntius* Cowie 1968 was synonymous with *E. walcotti* Walcott 1913. Several differences between Cowie's (1968) and Walcott's 1913 type material are evident, two of which were noted by Fritz: 1) S3 and S2 cross the axial midline, and 2) hypostomata of *Olenellus praenuntius* Cowie 1968 bear 6 sets of postero-lateral spines as opposed to 7 on equivalently sized hypostomata of the type specimens. In addition, the hypostome figured in Fritz (1972, plate 9, fig. 9) differs from the hypostome figured in Cowie (1968, plate 1, fig. 5,6) in that it is less bulbous. Cephala figured in Cowie (1968, plate 1, figs. 1-4, 7-10) also appear to have variably pronounced metagenal spines and pre-glabellar field lengths in a manner that does not closely correspond to ontogeny (see plate 1, figs. 1 and 4 in particular). Lieberman (1999) also did not consider *Olenellus praenuntius* to be conspecific with *E. walcotti*, and erected *Elliptocephala praenuntius* Cowie 1968. This designation is much more plausible than Cowie's 1968 material being conspecific with *E. walcotti*.

Occurrence. GSC location 73040. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Elliptocephala cf. *E*. sp. 2 (Fritz 1972)

Appendix 2A, Plate 15, N

Material. 1 partial cephalon.

Description. Similar in overall proportions to *Elliptocephala* sp. 2 Fritz 1972 except for the following differences: 1) A chevron shaped L3 and an S2 that traces the shape of L3, as opposed to the transverse glabellar lobes and furrows of *Elliptocephala* sp. 2 Fritz 1972, and 2) no obvious intergenal ridge.

Discussion. The posterior portion of this cephalon is incomplete, but the differences seem substantial enough to maintain this trilobite separate from *Elliptocephala* sp. 2 Fritz 1972.

Occurrence. GSC location 84333. Section 2 (Fritz 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Elliptocephala sp. 2 (Fritz 1972)

Appendix 2A, Plate 15, I-L

Olenellus sp. 2 Fritz 1972, pg. 17-18, plate 13, figs. 6-18.

Material. 11 cephala and 8 genae.

Description. Cephala approximate half circle. Antero-lateral cephalic border convex, equal to ~1/4 length of LA, and of consistent width throughout. Preglabellar field equal to length of LA, marked by plectrum. Anterior of LA pointed, merges seamlessly with plectrum; glabella parallel-sided, straight. L3-L0 all of sub-equivalent length (~1/2 length of LA). Glabellar furrows narrow, sub-transverse on small cephala. Large cephala bear anteriorly rounded S3 that connect across the axial midline. S2 rounded anteriorly but does not connect across the axial midline. S1 and S0 straight, slightly deeper, and inclined at 30° relative to transverse line. L0 bears node. Ocular lobes originate from postero-lateral corner of LA, reach maximal distal extent from axis parallel to L2, and terminate parallel to S0. Interocular area equal to slightly more than 1/3 extraocular area. Intergenal ridge present and quite pronounced, extending from posterior tip of ocular lobes and contacting the intergenal area. Posterior margin swept back, intergenal swelling present 2/3 cephalic half width away from axis. Genal spines narrow.

Discussion. Fritz (1972) considered this species to be morphologically similar to *Olenellus puertoblacnoensis*. This species is not particularly *Olenellus*-like and appears to match the criteria for *Elliptocephala* better in that it possesses a pronounced intergenal ridge. In addition, *Elliptocephala* sp. 2 lacks a fused L3 and L2 and has a pronounced plectrum. The former feature appears across all species of *Olenellus*, and the latter is atypical of *Olenellus*.

Occurrence. GSC locations 73057, 73062, and 73065. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Elliptocephala? sp. 1

Appendix 2A, Plate 15, P

Material. 2 partial cephala.

Description. Anterior two lobes of glabella very slightly wider than posterior two lobes and occipital ring. Posterior portion of LA just above convergence with ocular lobes only slightly convergent as to appear sub-parallel. LA equal to 2/5 length of glabella (occipital ring exclusive), terminates as dull point. L3 short, chevron-shaped; L2 slightly longer, also chevron-shaped, margins slightly convergent anteriorly; L1 more ring-like in shape. S3 slightly curved (convex anteriorly), shallow, and deepest distally. S2 straight to very slightly arcuate. S1 convex anteriorly, of moderate depth, and wide relative to other glabella furrows. No glabellar furrows connected across axis; all glabellar furrows angled inwards at ~25° relative to sagittal line. Margins of occipital ring parallel, length of occipital ring slightly greater than L2. Occipital ring bears medial node. Occipital furrows sub-transverse, deep relative to all other glabellar furrows. Ocular lobes originate from postero-lateral corner of LA, reach most distal extent parallel to L2, and terminate parallel to anterior-most point of occipital ring. Ocular lobes consist of high-standing, convex inner band that is separated from a lower-standing outer band by an ocular furrow that runs lengthwise through the lobe and terminates gradually and slightly before the posterior tip of the ocular lobes. Interocular area of slightly greater width than ocular lobe; anterior half flat and slightly angled inwards towards axis, posterior half sloped posteriorly.

Discussion. These cephala correspond closely to Lieberman's (1999) definition of *Elliptocephala* on the basis of 1) An LA approximately 3/2 the length of L0 + L1 with distal margins that are somewhat distal from the margins of L0, 2) an S3 and S2 that are convex anteriorly, 3) an L3 and L2 that are not fused, 4) distal margins of L2 that are divergent anteriorly, and 5) margins of L3 that merge with the ocular lobes. This species differs from Lieberman's (1998) criteria for *Elliptocephala* in that rather than having a posterior portion of its LA that diverges anteriorly the entire LA tapers forwards and terminates roughly at the anterior border. These cephala match many of the other criteria for *Elliptocephala*, so it has been placed in that genus in open nomenclature. *Wanneria* differs more strongly from these cephala in that it possesses a wider glabella that more dramatically obstructs the anterior border and does not uniformly taper anteriorly. This species highlights the need for Lieberman's (1998, 1999) olenellid taxonomy to be updated and refined.

Occurrence. GSC location 84339. Section 2 (Fritz 1976). Hess River Formation, "*Bonnia-Olenellus*" Zone.

Elliptocephala? sp. 2

Appendix 2A, Plate 13, R

Material. 3 partial adult cephala and 3 meraspid cephala.

Description. "Wanneriid" with cephalon approximating half-circle, a pre-glabellar field equivalent to 1/3 length of LA, an anterior glabellar lobe that appears as a dull point, ocular lobes closely spaced to glabellar margins, and a transverse posterior margin bearing short, thin genal spines.

Meraspid cephala differ from adult cephala in that they have a slightly higher length to width ratio than ~1:2 and less extraocular space.

Discussion. Although incomplete, these cephala are distinct from the other "wanneriids" described herein because of their relatively long pre-glabellar field and a lengthier anterior glabellar lobe. Most "wanneriids" possess broadly curved, "squat" anterior glabellar lobe that either contacts and deflects the anterior border or terminates quite close to the border. The meraspids assigned to this species appear very morphologically similar to adults, although a full ontogenic series is lacking.

Occurrence. GSC location 84335. Fritz Section 2 (1976). *Bonnia-Olenellus* Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Genus *Wanneria* Walcott 1910

Discussion. Lieberman (1998, 1999) assigned two species (*W. logani* and *W. parvifrons*) that had previously been assigned to *Wanneria* to *Elliptocephala*, leaving the genus monotypic. This taxonomy differs in that these species are at least provisionally still considered to belong to *Wanneria*. Several features seem to unite *W. logani* Walcott 1910, *W. parvifrons* Fritz 1972, and the type, *W. walcottana* Wanner 1901: 1) An LA that is moderately wider than the remainder of the glabella and more ovoid in shape, expanding rapidly laterally, 2) an anterior glabellar lobe that contacts and often deflects the anterior border, and 3) a pronounced transocular furrow (sensu Webster and Bohach 2014) coupled with an ocular surface that terminates before the contact of the ocular lobe and LA, imparting a "stalk-like" appearance to the ocular lobes. It should be noted that the type of *Wanneria*, *W. walcottana*, does appear to bear these structures but most published specimens of it are compacted, leaving some uncertainty. It is with these features in mind that *W. parvifrons* and *W. logani* are retained in *Wanneria*. In addition, *E. paraoculus* has similar glabellar proportions to 1) and may bear a highly effaced transocular furrow. However, the configuration of its ocular lobes is different, so it is tentatively maintained in *Elliptocephala*.

Wanneria logani (Walcott 1910)

Appendix 2A, Plate 13, G-N

Olenellus logani Walcott 1910, pg. 333, plate 41, figs. 5,6.

Wanneria nathorsi Poulsen 1932, pg. 40, plate 12, figs 1-13.

Wanneria logani Poulsen 1958, pg. 16.

Wanneria logani Fritz 1972, pg. 29, plate 14, figs. 1-14, plate 16, figs. 1-7.

Wanneria logani Fritz 1991, pg. 17, plate 3, figs 16-17.

Elliptocephala logani Lieberman 1999, pg. 70, fig. 12.5.

Material. 23 cephala, 9 genae, and 1 pleurae.

Description. Fritz (1972) adequately describes this species.

Discussion. *Wanneria logani* is morphologically similar to *Wanneria parvifrons* but differs in that it has a narrower cephalon and more robust genal spines. The anterior glabellar lobe of *W. logani* is also swollen dorsally, whereas the anterior glabellar lobe of *W. parvifrons* when seen in side view slopes downwards anteriorly.

Occurrence. GSC locations 73049, 73050, 73051, 73053, 73054, 73055, 73062, and 73064. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Wanneria parvifrons Fritz 1972

Appendix 2A, Plate 13, O

Wanneria parvifrons Fritz 1972, pg. 30, pl. 13, figs. 1-5.

Wanneria sp. 1 Fritz 1991, pg. 18, plate 3, fig. 2.

Elliptocephala parvifrons Lieberman 1999, pg. 60-61, fig. 12.6.

Material. 1 partial cephalon.

Description. Fritz (1972) adequately describes this species.

Discussion. Although incomplete, this cephalon appears to bear many of the hallmark features of *Wanneria parvifrons*, including: 1) a relatively wide cephalon (length roughly ½ width) with a transverse posterior margin such that it approximates a half-circle, 2) a broadly curved, relatively small anterior glabellar lobe, and 3) a relatively constricted L2, imparting a rather slender posterior portion of the glabella (although *W. logani* is somewhat similar in this aspect).

Lieberman (1999) assigned *Wanneria* sp. 1 Fritz 1991 to *Wanneria parvifrons*. This designation is followed in this paper as well, although the specimen figured in Fritz (1991) is partial and should be assigned to *W. parvifrons* cautiously.

Occurrence. GSC locations 84336. Fritz Section 2 (1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Wanneria cf. *W. parvifrons* Fritz 1972

Appendix 2A, Plate 13, P, Q

cf. *Wanneria parvifrons* Fritz 1972, pg. 30, pl. 13, figs. 1-5.

cf. *Wanneria* sp. 1 Fritz 1991, pg. 18, plate 3, fig. 2.

cf. *Elliptocephala parvifrons* Lieberman 1999, pg. 60-61, fig. 12.6.

Material. 3 partial cephala

Description. Similar to *W. parvifrons* save for the following aspects: 1) slightly advanced genal angles, 2) genal spines that are directed more strongly outwards, 3) an anterior border that is more strongly deflected by LA, and 4) a wider cephalon.

Discussion. These differences seem too great to warrant inclusion in *W. parvifrons*, and this species is tentatively kept in open nomenclature.

Occurrence. GSC location 84335, 84337. Fritz Section 2 (1976). *Bonnia-Olenellus* Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Wanneria? sp.

Appendix 2A, Plate 15, M

Material. 2 cephala.

Description. Cephalon approximates half-circle. Anterior and lateral borders both convex and relatively high-standing, width equal to 1/3 length of LA. Anterior and lateral border furrow pronounced and deep. Pre-glabellar field present and minute. LA equal to slightly under half length of glabella (occipital ring exclusive), equal to ¼ width of cephalon at widest point, front broadly curved. L3 chevron shaped, width slightly less than LA. L2 and L1 ring-shaped, slightly constricted relative to LA and L3. S3 convex anteriorly, tangent to apex of curve sub-transverse. S2 also convex anteriorly, tangent to apex of curve inclined slightly inwards, joined across axis. S1 very slightly arcuate, almost appearing straight, inclined inwards at ~25°. Occipital ring ring-shaped, slightly wider than L1, occipital furrow transverse, deep relative to other furrows, deepest distally. Ocular lobes thick, base occupying posterior 1/3 of LA at origin, terminating parallel to anterior portion of occipital ring and reaching maximal distal extent from axis parallel to L2. Interocular area thin, equal to less than ¼ width of extraocular area at widest point. Posterior border approximately ½ thickness of antero-lateral border; posterior border furrow shallower and less pronounced than antero-lateral border furrow. Posterior margin transverse until 2/3 cephalic half-width away from axis; distal 1/3 cephalic half-width from axis advanced resulting in genae being parallel to posterior of L1. No metagenal spine or bump evident. Genal spine width and length unknown.

Discussion. This species appears to have the general proportions of *Wanneria* but does not have an LA that contacts the anterior border. Other species of *Wanneria* also lack a posterior border that flexes anteriorly; all other known species of *Wanneria* have fully transverse posterior margins. These differences make the assignment of this species to *Wanneria* questionable.

Occurrence. GSC location 84331. Fritz Section 2 (1976). *Bonnia-Olenellus* Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Family uncertain

Genus *Gabriellus* Fritz 1992

Gabriellus? sp.

Appendix 2A, Plate 15, O

Material. One partial cephalon.

Description. LA overall rounded in shape, equal in length to roughly 2/5 of total glabellar length (occipital ring exclusive). L3 and L2 sub-equal in size and thin compared to LA, collectively comprising 1/3 length of glabella. L1 larger than L3 or L2, but less long than LA. S3 straight (?), inclined outwards at ~30°. S2 and S1 parallel to S3 but convex anteriorly. Occipital ring parallel-sided, no occipital node evident; occipital furrows transverse and deep distally. No glabellar or occipital furrows appear to conjoin medially. Ocular lobes directed nearly straight back, exhibiting minimal curvature. Ocular lobes terminate parallel to the posterior of the occipital ring. Interocular area absent; ocular lobes separated from the glabella by axial furrows.

Discussion. This partial cephalon is mostly incomplete, and detailed genus/species assignment is impossible. Nevertheless, this specimen appears to resemble *Gabriellus* in that the ocular lobes are extremely close to the margins of the glabella. In the case of this trilobite, the ocular lobes are so close to the glabella that the interocular area is gone and only axial furrows separate the glabella from the ocular lobes. This species differs from *Gabriellus lanceatus* Fritz 1992, which has ocular lobes that terminate shortly before the occipital furrow rather than close to the posterior of the occipital ring, a bullet-shaped rather than rounded anterior glabellar lobe, and a chevron-shaped anterior glabellar furrow. Olenelloid gen. and sp. indet Whittington 1989 was also assigned by Fritz (1992) to *Gabriellus*. It is unclear how comparable that specimen is to this material because the glabella of the specimen figured in Whittington (1992) is partially crushed into the hypostome.

Occurrence. GSC location 84334. Fritz Section 2 (1972, 1976). *Bonnia-Olenellus* Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Indet. olenellid sp. 1

Appendix 2A, Plate 5, D

Material. 1 partial cephalon

Description. Cephalon roughly semi-circular in shape. Anterol-lateral border convex, width equal to 1/5 length of LA. Length of pre-glabellar field equal to width of border. Sides of glabella appear parallel, LA is well-rounded. Ocular lobes crescentic, lack ocular furrows. Ocular lobes originate from postero-lateral corner of LA and terminate just before the posterior border. Width of interocular area ½ that of extraocular area at widest point. Posterior border slightly thinner than antero-lateral border. Genal spines directed outwards, slightly advanced, thin.

Discussion. This species is likely a holmiid but lacks enough satisfactorily preserved material to be assigned to an olenellid family.

Occurrence. GSC location 84306. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Indet. olenellid sp. 2

Appendix 2A, Plate 6, A-B

Material. 3 partial cephala

Description. Length of cephalon roughly 2/3 width. Anterior and lateral border slightly convex, width is consistent throughout and equivalent to ¼ length of LA. Pre-glabellar field equal in width to anterior border. Sides of L1 straight, convergent anteriorly; sides of L2-L3 also straight but divergent anteriorly, resulting in an overall hourglass-like shape of the glabella. Front of LA broadly curved, length of LA equivalent to ¼ length of glabella, occipital lobe inclusive. L3 short compared to other glabellar lobes, all other glabellar lobes of sub-equal length but lesser than LA. S3 and S2 convex anteriorly, parallel; both of moderate depth and not connected across the axial midline. S1 straight, inclined at roughly 35° relative to transverse line across cephalon, joined across axial midline. Sides of L0 rounded, S0 deep relative to other furrows, does not join across axial midline. Ocular lobes originate from postero-lateral corners of LA, reach most outward point parallel to posterior of L2 and terminate parallel to anterior of L0. Ocular lobes bear ocular furrow throughout entirety of length. Interocular area equal to approximately ½ width of extraocular area at widest point.

Discussion. This olenellid appears morphologically disparate from other *Nevadella* Zone olenellids. The three partial cephala present in this collection do not preserve any posterior features, prohibiting the assignment of a new genus.

Occurrence. GSC location 84308. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone.

Indet. olenellid sp. 3

Appendix 2A, Plate 11, A

Material. One large, partial cephalon.

Description. Cephalon wide, l:w ratio unclear. Anterolateral border of moderate and consistent thickness, approximately ¼ length of LA. Antero-lateral border furrow shallow, depth greatest at anterior of cephalon and shallower at margins. Pre-glabellar field present but thin. LA elongate, appears as dull point. S2 shallow, straight; S1 deeper, straight, parallel to S2. S0 straight and deep relative to S1 and S2. Visible glabellar furrows do not appear to conjoin medially. Ocular lobes originate at postero-lateral corner of LA and remain close to glabella, resulting in a thin interocular area (~1/5 width of extraocular area). Base of genal spines wide, genal spines directed outwards at approximately 30° relative to sagittal line. Borders and genal spines bear faint lines sub-parallel to curvature of border/spine.

Discussion. Fritz (1976) originally designated this trilobite *Olenellus* sp. in his faunal list. This cephalon is incomplete and compacted but appears to have some characteristics that do not match the criteria for *Olenellus*, including: 1) Posterolateral corners of LA that converge instead of diverging anteriorly and 2) Genal spines that are directed outwards at an angle greater than 10-20°. The incompleteness of the singular cephalon assigned to this species precludes designation to any known olenellid genera or species.

Occurrence. GSC location 84317. Section 2 (Fritz 1976). Sekwi Formation, lower "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Indet. olenellid sp. 4

Appendix 2A, Plate 13, F

Material. 1 effaced cephalon.

Description. Cephalon semi-circular. Pre-glabellar field present, equal to slightly over 1/3 length of LA. LA broadly curved, equal to just under half length of glabella, occipital ring exclusive. L3 very thin, (~1/6 length of LA), chevron-shaped. L2 twice the length of L3, sides directed at shallow angle anteriorly. L1 slightly constricted relative to other glabellar lobes. S3 arcuate, convex anteriorly; S2 straight, shallow, transverse; S1 deeper, directed 30° anteriorly relative to transverse line. Sides of occipital ring parallel, probably convex, occipital furrow the same depth as S1 and transverse. No glabellar furrows appear to join medially. Width of interocular area equal to slightly more than 1/3 width of extraocular area. Ocular lobes reach most distal extent from axis parallel to S1, terminate parallel to anterior of occipital lobe. Posterior appears directed slightly back. Genal spines exceedingly thin, short (~1/4 length of entire cephalon).

Discussion. Fritz (1976) originally designated this cephalon as *Olenellus* sp. in his faunal list. This cephalon does not appear particularly *Olenellus*-like and lacks an anteriorly divergent posterior of LA.

Occurrence. GSC location 84332. Section 2 (Fritz 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Indet. olenellid sp. 5

Appendix 2A, Plate 11, B.

Material. 1 cephalon.

Description. Length of cephalon slightly more than ½ width of cephalon. Cephalic border convex, equal to ¼ length of LA. Antero-lateral border furrow shallow, uniform throughout. Pre-glabellar field slightly wider than anterior border. Glabella parallel-sided, equal to ~¼ width of cephalon. LA broadly curved, merges smoothly with extraocular and pre-glabellar area. Two extremely shallow glabellar furrows visible: S2 present as shallow, central pits; S1 directed slightly back at ~20° relative to transverse line. L3 and L2 merged and only partially separated by S2; both equal in length to L1. Occipital furrow sub-transverse, occipital ring parallel-sided. No occipital node is evident. Ocular lobes originate from postero-lateral area of LA, reach maximum distance from axis parallel to S1, and terminate slightly behind the occipital furrow. Interocular area virtually absent; ocular lobes separated from glabella by broad, deep axial furrows. Posterior margin swept slightly back until slight metagenal spine ~2/3 distance from axis. Posterior margin sub-transverse from metagenal area to genal area. Genal spines present; length unclear.

Discussion. Fritz collected this cephalon but did not describe it, nor did he denote GSC location in Fritz (1972, 1976). This is probably because this cephalon is quite morphologically disparate from most olenellids and singular, making it useless for the purpose of correlation. *Gabriellus* has a similar configuration of the ocular lobes in that it essentially lacks an interocular area but differs in that its posterior margin is advanced. The general effacement of this cephalon and the resultant virtual absence of glabellar furrows sets this species apart from almost every known olenellid.

Occurrence. GSC location 73046. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Order Corynexochida Kobayashi 1935

Family DORYPYGIDAE Kobayashi 1935

Genus *Bonnia* Walcott 1916a

Bonnia columbensis Resser 1936

Appendix 2A, Plate 16, L-N; Plate 18, H-P

Corynexochus senectus Walcott 1916a, pg. 319, plate 55, figs. 7, 7a-c. [non. Plate 56, figs. 1, 1a-g]

Corynexochus senectus Walcott 1917, pg. 66, plate 9, figs. 2, 2a-c. [non. pl. 9, figs. 1, 1a-d]

Bonnia columbensis Resser 1936, pg. 9.

Bonnia columbensis Lochman 1947, pg. 69.

Bonnia fieldensis Rasetti 1951, pg. 82.

Bonnia copia Fritz 1968, pg. 194, plate 36, figs. 17-24.

Bonnia columbensis Fritz 1972, pg. 32, plate 18, figs. 1-13.

Bonnia columbensis Fritz 1991, pg. 21-22, in text fig. 5, k, l, plate 7, figs. 1-12, plate 8, figs. 1-20, plate 9, figs. 1-15.

Bonnia columbensis Sundberg and Webster 2021, pg. 1247-1250, fig. 6, 1-22.

Material. 13 cranidia and 21 pygidia.

Description. Fritz (1972, 1991) adequately describes this species.

Occurrence. GSC location 73073, Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, undefined interval.

Bonnia laterispina Fritz 1972

Appendix 2A, Plate 16, A-G

Bonnia laterispina Fritz 1972, pg. 33, plate 15, figs. 1-7.

Bonnia laterispina Fritz 1972, pg. 22-23, in text fig. 5a, b, plate 3, figs. 7-15.

Material. 4 cranidia, 5 partial cranidia, 1 pygidium, 3 partial pygidia, and 1 worn, questionably assigned pygidium.

Description. Fritz (1972, 1991) adequately describes this species.

Discussion. *Bonnia laterispina* can be distinguished from other species of *Bonnia* chiefly by its relatively deep glabellar furrows, a glabella that reaches its maximal width 1/3 length away from the anterior, a pygidium in which the anterior two axial rings are well defined and the others poorly differentiated, and a pygidial border that bears three short spines that decrease in length posteriorly.

Occurrence. GSC locations 84334, 84335, and 84336. Section 2 (Fritz 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Wanneria* Subzone.

Bonnia sp. 2 Fritz 1972

Appendix 2A, Plate 16, K

Bonnia sp. 2 Fritz 1972, pg. 34, plate 16, figs. 16-18.

Material. 2 cranidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73067. section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Bonnia sp.

Appendix 2A, Plate 16, H-J

Material. 3 cranidia, 1 partial cranidium, 3 pygidia, and two partial pygidia.

Description. Cranidium length equal to slightly more than ½ width. Anterior border upturned, convex; anterior border furrow deep, of consistent depth, and wide. Glabella comprises 1/3 width of cranidium. Sides of glabella straight until anterior 1/5 glabellar length, where it rounds and terminates. Axial furrows shallow. Glabellar front broadly curved. Two glabellar furrows evident: posterior pair slightly arcuate, convex anteriorly, tangent to apex of curve inclined at ~40° relative to transverse line; second pair present at half-length of glabella, parallel to first pair. Occipital ring short sagittaly, of equal length at all points. Occipital furrow transverse, deep distally and shallow towards axis. Palpebral area convex in cross-section transversely, equal to 1/5 width of glabella. Eye ridges faint, contact glabella close to anterior 1/5 length. Palpebral lobes narrow, crescent-shaped, equal to slightly over ¼ length of cranidium, centered parallel to middle of glabella. Palpebral furrows of equivalent depth to axial furrows but wider. Posterior area equal in width to glabella at base. Posterior border equal in width to anterior border;

posterior border furrow of slightly greater width and depth than axial furrows. Some cranidia bear irregular, short ridges as ornamentation.

Pygidium approximates half-circle. Axis tapers slightly posteriorly, composed of articulating half-ring, five well-defined axial rings and terminal piece. Ring furrows of moderate and consistent depth. Pleural field broadly convex. Three pairs of pleural ribs present: anterior two ribs average same thickness as axial rings, widen slightly distally; posterior rib slightly thinner. Interpleural furrows deep, equal to ~2/3 length of axial rings. Border wide, border furrow shallow. Posterior part of border bears small notch. Two marginal spines present: first located at antero-lateral corner and hook-like in shape, second appears as small swelling parallel to the anterior of middle pleural rib.

Discussion. Fritz (1976) designated this species as *Bonnia* sp. (two pairs of spines) in his faunal list. *Bonnia tatondukensis* Palmer 1968 is similar in gross aspect to this species and has a pygidium that bears two pairs of spines but differs in that it lacks glabellar furrows altogether. Bohach (1997) also figured a trilobite (plate 29, figs. 7-13; plate 30, figs. 1-4) that is similar to this species in that it bears two pairs of marginal spines and shallow glabellar furrows but has a pygidium with a higher length to width ratio, an additional pygidial ring, and an additional pleural rib.

Occurrence. GSC location 84339. Fritz Section 2 (1976). Hess River Formation, "*Bonnia-Olenellus"* Zone.

Genus *Bonnima* Fritz 1991

Bonnima sp. nov.

Appendix 2A, Plate 16, O-R

Bonnia sp. 3 Fritz, 1972, pg. 35, plate 17, figs. 8, 9, 11-12.

Material. 8 cranidia and 1 tentatively assigned pygidium.

Description. Pygidium of low relief, axis of same height as maximum height of pleural area. Outline approximates half-circle, with length being slightly greater than ½ width. 5 axial rings present, each separated by faint, transverse furrows. Furrow separating terminal piece from posterior axial ring shallower, terminal ring blunt and broadly curved, terminating at posterior border. Lateral and posterior borders narrow, furrow separating them from pleural area narrow and shallow as to almost be absent. Axial furrows narrow, shallow. Pleural field consists of 4 ribs, each marked a medial, longitudinal pleural furrow that is narrow and shallow. Interpleural furrows narrow, shallow, and uniform from axis to margins. Anterior slightly damaged, leaving no evidence of an articulating half-ring or a "semi-detached" anterior pleural segment.

Discussion. Fritz (1991) erected *Bonnima*, which is similar to *Bonnia* in general proportions but differs chiefly in that it has low relief and furrows that are generally absent or poorly visible. The associated pygidium (GSC location 73068) was not recorded in Fritz (1972) but is probably attributable to *Bonnima* sp. nov. because of its morphological similarity to internal pygidial moulds of *B. semidiscoidea* Fritz 1991. This pygidium therefore warrants description, although Fritz (1972) already adequately describes the cranidium.

The material originally assigned to *Bonnia* sp. 3 by Fritz (1972) matches the definition of *Bonnima* more closely than *Bonnia*. The effaced, smooth, low relief cranidium matches perfectly. This species of *Bonnima* does have a more pronounced pygidial border than the type species, although it should be noted that internal pygidial moulds of *Bonnima semidiscoidea* display wider borders than pygidia that are preserved externally. An articulating half-ring and a "semi-detachable" anterior pleural segment also characterize the pygidia of *Bonnima*- these features are regrettably absent in the pygidium assigned to *Bonnima* sp. nov. Nevertheless, it seems plausible that the associated pygidium belongs to the same species as the cranidia figured herein, and that this material represents a new species that is of closer affinity to *Bonnima* than *Bonnia*.

Occurrence. GSC locations 73068 and 73071. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Genus *Kootenia* Walcott 1889

Kootenia diutina, Fritz 1972

Appendix 2A, Plate 1, M-V; Plate 2, A-R

Kootenia diutina Fritz, 1972, pg. 36-37, plate 2, figs. 1-13.

Material. 79 cranidia, 50 pygidia, 3 librigenae, and 8 hypostomata.

Description. Fritz (1972) adequately describes this species.

Discussion. Fritz (1991) suggested that the definition of *Bonnia* ought to be modified, and that such modifications might necessitate *Kootenia diutina* being included in the genus. This suggestion arose from two species known from relatively little and incomplete material that were described from the Illtyd Formation (Fritz 1991) and designated as *Bonnia*? sp. 2 and *Bonnia*? sp. 3. Each of these taxa possess deep interpleural furrows and numerous pygidial marginal spines, which is atypical of *Bonnia*. If these species were to be confidently placed in *Bonnia*, the inclusion of species with those features could warrant *Kootenia diutina* also being included in *Bonnia*. Although that designation may be valid, *Kootenia diutina* is provisionally kept as is because there is too little data on *Bonnia*? sp. 2 and *Bonnia*? sp. 3 Fritz 1991 to warrant a re-evaluation of *Bonnia*. In addition, such a re-evaluation would necessitate an extremely low initial stratigraphic occurrence of *Bonnia*, and a considerable gap between the FAD of *Bonnia* and later occurrences of the genus.

Occurrence. GSC locations 73026, 73027, 73030, 73032, 73033, 73034, 73035, 73036, 73037, 73038, and 73039. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Genus *Ogygopsis* Walcott 1889

Ogygopsis? sp.

Appendix 2A, Plate 19, D

Material. One partial cranidium.

Description. Dorypygid cranidium of low convexity with a large (~1/2 width of cranidium), parallel-sided glabella that converges along the anterior 1/3 of glabellar length. Front of glabella broadly curved. S3-S1 not evident. Occipital ring poorly preserved but separated from rest of glabella by shallow, transverse occipital furrow.

Discussion. This cranidium is considered to be a more likely match with *Ogygopsis* than other dorypygids based on the absence of glabellar furrows and the presence of a parallel-sided glabella of low convexity. *Bonnia* often possesses glabellar furrows. Cranidia of *Kootenia* often appear similar to those of *Ogygopsis*, and the two genera are distinguished mainly by *Kootenia* possessing a pygidium in which the entire margin is spinous. No such pygidia are observed in this collection, so an assignment to *Ogygopsis* is considered more likely. Caution must be exercised when dealing with incomplete material, however, and this cranidium is assigned to *Ogygopsis* tentatively.

Occurrence. GSC location 84341, Section 2 (Fritz 1976). Hess River Formation, upper "*Bonnia-Olenellus*" Zone.

Family ORYCTOCEPHALIDAE Beecher 1887

Discussion. Oryctocephalid classification herein follows that of Sundberg (2014).

Genus *Goldfieldia* Palmer 1964

Goldfieldia pacifica Palmer 1964

Appendix 2A, Plate 17, O-Q

Goldfieldia pacifica Palmer 1964, pg. 8-9, plate 1, figs. 14, 16-18.

Oryctocephalus? sp. Fritz 1972, pg. 37, plate 19, figs. 20, 21.

Goldfieldia kunshanensis Zhang and Zou 1985?, pg. 262, plate 2, fig. 15.

Goldfieldia pacifica Yuan et al. 2002, pg. 113, 244, plate 28, fig. 11.

Goldfieldia pacifica Sundberg 2014, pg. 574-578, fig. 6, 1-26, fig. 7, 1-5.

Material. 9 cranidia, 2 partial cranidia, 3 partial thoraxes, and one partial thorax with pygidium.

Description. Outlines of cranidia subtrapezoidal, length equal to ~3/5 width. Cranidium of overall low convexity. Anterior border thin, "wire-like," convex, and upturned; curvature of anterior margin extremely broad, almost appearing straight excepting a slight "cleft" at the axis.

Anterior border furrow thin, extremely shallow. Length of glabella slightly less than total length of cranidium, width equal to 1/5 to ¼ total width of cephalon (at L1 and LA, respectively); area between anterior border and front of glabella marked by shallow medial sulcus. Sides of glabella straight, L1 somewhat thinner than other glabellar furrows, sides parallel, rest of glabella expands very slightly anteriorly. Glabella separated from rest of cranidium by straight, thin, axial furrows that are significantly deeper than anterior border furrow. Front of glabella follows curvature of anterior margin save for interruption by medial sulcus. Glabellar furrows pit-like, generally deepest closest to the axis and shallowing outwards. S4 relatively shallow, sub-transverse; S3 deeper, sub-transverse; S2 similar in appearance to S3; S1 triangular. No glabellar furrows conjoin across the axis. Sides of occipital ring parallel, occipital furrows appear straight to very slightly arcuate and slightly inclined inwards. Ocular ridges of moderate height and width, contact the glabella parallel to S4 and cut across by axial furrows. Palpebral lobes of similar height and width as ocular ridges, slightly arcuate, length equal to 1/3 total length of cranidium, anterior parallel to anterior of L3, posterior tip parallel to posterior of L2. Palpebral furrows thin, moderately deep. Palpebral area equivalent to width of L1. Posterior area equal to 5/4 width of glabella at widest extent. Posterior border thick, convex; posterior border furrow of moderate depth. Anterior portion of facial sutures angled very slightly outwards along anterior 1/3 of cranidium; angled slightly more outwards parallel to palpebral lobes; posterior portion of facial suture slightly rounded, angled outwards on average at 40° relative to transverse line.

Thorax consists of 13 segments and tapers slightly posteriorly. Pleurae curved, appearing slightly convex anteriorly; individual pleurae are of fairly consistent width until termination as antero-laterally directed pleural spine. Pleural furrows are located closer to anterior of pleurae, directed adaxially and into pleural spines, of slight depth. Axial furrows on thorax are narrow and of slightly less depth than axial furrows on cranidium. Pygidium tapering, ill-defined from thorax; consists of two rings and a terminal piece. Pygidial spines directed posteriorly.

Discussion. Palmer (1964) defined the anterior margin of *Goldfieldia pacifica* as being gently curved. Sundberg (2014) also maintained that trait in his descriptions, and none of his figured material appears to bear the same clefted anterior margin as the material herein. In all other aspects the material in this paper seems to match *G. pacifica*, and it would seem imprudent to maintain this material as being disparate on the basis of one minor feature. Sundberg (2014) also assigned *Oryctocephalus*? sp. Fritz 1972 to *G. pacifica*. Although fragmentary, the material in Fritz (1972) does appear to be a close match for *G. pacifica*. If it is accepted that the material in this paper is also *G. pacifica*, its presence in the Selwyn basin is much better substantiated.

Occurrence. GSC location 84340. Section 2 (Fritz 1976). Hess River Formation, upper "*Bonnia-Olenellus*" Zone.

Family ZACANTHOIDIDAE Swinnerton 1915

Genus *Zacanthopsis* Resser 1938

Zacanthopsis stribuccus Fritz 1972

Appendix 2A, Plate 19, A-C

Zacanthopsis stribuccus Fritz 1972, pg. 38, plate 16, figs. 19, 20.

Material. 1 cranidia and 3 questionably assigned cranidia.

Description. Fritz (1972) adequately describes this species.

Discussion. 3 incomplete cranidia are tentatively assigned to this species and one mostly complete cranidium is assigned with confidence. Fritz originally assigned one cranidium and another tentatively assigned cranidium to this species from GSC locations 73067 and 73074, respectively. In addition, it appears as though there are other cranidia in Fritz' (1972, 1976) Section 10 collection that satisfy the criteria for *Z. stribuccus* from GSC locations 73068 and 73073.

Occurrence. GSC locations 73068 and 73073. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Order Ptychopariida Swinnerton 1915

Discussion. Some workers have suggested that Ptychopariida is either paraphyletic or polyphyletic (Fortey 1997, Adrain 2011), and historically the order has been treated as a wastebasket taxon (Adrain 2011). Recent iterations of high-level trilobite taxonomy have abandoned the ordinal concept of Ptychopariida and placed many of its families in order Aulacopleurida or as having uncertain affinity (Adrain 2011). Others have criticized this scheme, and tentatively retained Ptychopariida as an order (Chatterton 2020). Resolving the status of trilobites historically placed in Ptychopariida is outside of the purview of this work, and Ptychopariida is cautiously and pragmatically maintained herein.

Family PTYCHOPARIIDAE Matthew 1887

Discussion. Many Cambrian "ptychoparioid" (early librostomate trilobites genera) are either poorly defined, based on problematic type material, morphologically similar, known from partial remains, or some combination of these issues. Many authors have attempted to resolve these issues at least partially (Sundberg and McCollum 2000, Sundberg and Webster 2022). "Ptychoparioid" genera in this paper are referred to in open nomenclature because of the abundance of critical issues that affect the taxonomic integrity of the group.

Genus "*Antagmus*" Resser 1936

"*Antagmus*" *truncatus* Fritz 1972

Appendix 2A, Plate 18, B-D

Antagmus truncatus Fritz 1972, pg. 40-41, plate 19, figs. 1-10.

Material. 4 cranidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73073. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Genus "*Piaziella*" Lochman 1947

"*Piaziella*" *pia* (Walcott 1917)

Appendix 2A, Plate 18, A

Ptychoparia pia Walcott 1917, pg. 93, plate 12, fig. 8.

Antagmus pia Resser 1937, pg. 1.

Piaziella pia Lochman 1947, pg. 69, figs. 4-6

Piaziella pia Rasetti 1951, pg. 236, plate 8, figs. 3-5.

Piaziella pia Fritz 1972, pg. 42-43, plate 19, figs. 11-19.

Material. 1 cranidium.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73073. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Genus "*Poulsenia*" Resser 1936

"*Poulsenia*" sp. 1 Fritz 1972

Poulsenia sp. 1 Fritz 1972, pg. 41, plate 11, figs. 3-6.

Material. 1 partial cranidium.

Description. Fritz (1972) adequately describes this species.

Discussion. This specimen is unfigured. *Poulsenia* sp. 1 Fritz 1972 is adequately figured (plate 11, figs. 3-6b) and the partial cranidium in this collection does not add any additional morphological data.

Occurrence. GSC location 73048. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone. *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone.

Genus "*Proliostracus*" Poulsen 1932

"*Proliostracus*" *annosus* Fritz 1972

Appendix 2A, Plate 12, E-L

Proliostracus annosus Fritz 1972, pg. 44, plate 10, figs. 17-22.

Material. 8 cranidia and 1 latex cast of the holotype cranidial mould (section 10), and numerous silicified material in silt (GSC locations 84327 and 84328).

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73044. Sections 2 and 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Zone.

"*Proliostracus*" cf. *P. contractus* Fritz 1972

Appendix 2A, Plate 12, Q, R

cf. *Proliostracus contractus* Fritz 1972, pg. 45, plate 10, figs. 1-5.

Material. 34 cranidia.

Description. Cephalon of overall low convexity. Length of cephalon equal to 4/5 width. Anterior border inflated, wide, convex; length equal to slightly more than ¼ total length of glabella. Glabella parallel-sided, front abruptly truncated, length comprises 2/3 length of cephalon excluding occipital ring, width comprises slightly less than 1/3 total width. Three pairs of glabellar furrows present: S3 and S2 shallow, sub-transverse; S1 shallow, overall sub-transverse, faintly bifurcated. Occipital ring incomplete, situated below glabella, bears small node. Occipital furrow deep relative to S3-S1, sub-transverse. Pre-glabellar and axial furrows broad, deep. Ocular ridges narrow, moderately well-defined; palpebral lobes narrow, slightly crescentic, length equal to ~1/3 length of glabella and centered parallel to ½ point of glabella. Palpebral area equal to 2/3 width of glabella, convex and raised above anterior border. Posterior border furrow deep, broad; posterior border incomplete. Facial suture line divergent posteriorly and slightly rounded outwards from anterior to palpebral lobes, directed slightly more outwards along palpebral lobes, and directed strongly outwards past palpebral lobes to posterior.

Discussion. This species differs from *Proliostracus contractus* chiefly in the orientation of the anterior most glabellar furrow, which is directed anteriorly on *P. contractus* and transversely in this material. *P. contractus* also has a slightly narrower palpebral area and longer palpebral lobes. These differences render the species described herein disparate from *P. contractus*, although both species are quite close.

Occurrence. GSC location 84325. Section 2 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Zone.

"*Proliostracus*" *depressus* Fritz 1972

Appendix 2A, Plate 11, L-O

Proliostracus depressus Fritz 1972, pg. 45-46, plate 9, figs. 15-20.

Material. 8 cranidia.

Description. Fritz (1972) adequately describes this species.

Discussion. *Proliostracus depressus* is similar to *Proliostracus contractus*. Details on the differences between these two species can be found in Fritz (1972, pg. 45).

Occurrence. GSC location 73040. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Zone.

"*Proliostracus*" sp.

Appendix 2A, Plate 12, M-P

Material. 4 partial cranidia and 1 tentatively assigned compacted cranidium (GSC loc. 84324).

Description. Small cranidia bearing wide axial, preglabellar, and posterior border furrows and a parallel-sided glabella that tapers and terminates abruptly. S3 shallow, narrow, sub-transverse; S2 inclined slightly backwards and of similar depth to S3; and S1 slightly deeper, transverse. Preglabellar swelling of similar width to terminus of glabella. Occipital furrow deeper than glabellar furrows, transverse, shallows towards axis. Ocular line faint, arcuate; palpebral lobes narrow, crescentic, equal to slightly over 1/3 length of glabella. Palpebral area equal to ¾ width of glabella at widest extent.

Discussion. The incompleteness of the material assigned to this species prohibits confident assignment to a given species of *Proliostracus*, although the wide, deep axial and pre-glabellar furrows coupled with the abruptly truncating glabella and the presence of a pre-glabellar swelling are indicative of the genus.

Occurrence. GSC locations 84323 and 84324. Section 2 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Zone.

Genus "*Syspacephalus*" Resser 1936

"*Syspacephalus*" *vapidus* Fritz 1972

Appendix 2A, Plate 18, E-G

Syspacephalus vapidus Fritz 1972, pg. 47, plate 20, figs. 1-8.

Material. 23 cranidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73075. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Bonnia-Olenellus*" Zone.

Genus “*Variopelta*” Fritz 1972

“*Variopelta*” *laevis* Fritz 1972

Appendix 2A, Plate 12, A-D

Material. 19 cranidia.

Description. Fritz (1972) adequately describes this species.

Occurrence. GSC location 73045. Section 10 (Fritz 1972, 1976). Sekwi Formation, “*Bonnia-Olenellus*” Zone, *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Zone.

Family SOLENOPLEURIDAE Angelin, 1854

Genus *Keeleaspis* Fritz 1972

Keeleaspis stupenda Fritz 1972

Appendix 2A, Plate 7, N-Q; Plate 8, A-F

Material. 8 cranidia, 5 pygidia, and 3 librigenae.

Description. Width of cranidium equal to ½ length. Cranidia highly convex, mainly due to high-standing glabella. Anterior margin high-standing, convex, length equal to ½ length of anterior glabellar lobe. Anterior border furrow deep, width equal to half of length of anterior border excepting where the glabella impinges on it slightly. Sides of glabella straight to very slightly concave, convergent; anterior of glabella broadly curved. S3 shallow, straight, inclined slightly backwards as to be almost transverse; S2 deeper, straight, inclined backwards at ~40° relative to transverse line; S1 more deeply incised, sub-parallel to S1, terminates at roughly 1/3 width of glabella. Occipital furrow broad, deep, and transverse. Occipital ring long, equal to anterior glabellar lobe in length, posterior margin curved. Palpebral area slightly convex, width equal to ¾ width of glabella. Ocular ridge pronounced, slightly curved; originates slightly above S3 and terminates slightly below S3. Palpebral lobes crescentic, centered opposite midpoint of glabella. Palpebral furrow shallow, narrow. Posterior border furrow shallow and broad relative to anterior border furrow. Posterior border thinner than anterior border, of uniform width until parallel with palpebral lobes and then expanding outwards. Posterior margin transverse until parallel with palpebral lobes, and then slightly advanced. Orientation of facial sutures generally poorly preserved, but apparently convergent from posterior to palpebral lobes and directed slightly more inwards and convex from palpebral lobes to anterior.

Pygidium small, length equal to ~1/2 width at widest point. Axis consists of a protrusive articulating half-ring, 3 axial rings, and a terminal piece. Anterior axial ring separated from second axial ring by a well-defined ring furrow that shallows towards the axis. Second ring furrow shallower, less well-defined; third axial furrow virtually absent such that the posterior most axial ring and terminal piece are not strongly separated. Terminal piece broadly curved, directly contacting the posterior border. Anterior border poorly defined; anterior margin of pygidium is swept back and convex anteriorly. Anterior border furrow narrow, of moderate width; follows outline of anterior border. Pleural area bears two well-defined pleural ribs separated by a thin, moderately deep pleural furrow. Pleural ribs bear faint interpleural furrows. Postero-lateral margin of sub-equivalent width as articulating half-ring, somewhat well-defined compared to anterior border but separated from pleurae by only a faint border furrow. Posterior margin very broadly curved. Marginal spines are not evident.

Discussion. Fritz (1972) erected *Keeleaspis* and described *K. stupenda* and *K. pustula*, and erected *K. gratia* as the type species. However, *K. gratia* was not formally described by Fritz (1972), and if any subsequent publications did so, the author is unaware. By convention, *K. stupenda* is the type species (Hollingsworth 2005) because it was the first species of *Keeleaspis* described by Fritz (1972), and *K. gratia* is a *nomen nudum*.

Occurrence. GSC locations 73027, 73032, 73033, 73034, 73036, 73037, and 73038. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Keeleaspis pustula Fritz 1972

Appendix 2A, Plate 8, G-J

Material. 4 cranidia and 1 librigena.

Description. Fritz (1972) adequately describes this species.

Discussion. The differences between *K. pustula* and *K. gratia* are discussed above. Fritz (1972) listed criteria for distinguishing between *K. pustula* and *K. stupenda*. The most salient difference between *K. pustula* and other species of *Keeleaspis* is its ornamentation, which consists of relatively widely spaced pustules as opposed to smaller, closely spaced pustules that are characteristic of the prosopon of *K. gratia* and *K. stupenda*.

Occurrence. GSC locations 73033, 73037, 73038, and 73039. Section 10 (Fritz 1972, 1976). Sekwi Formation, "*Nevadella*" Zone.

Indet. trilobite family

Indet. trilobite sp. 1

Appendix 2A, Plate 5, Q

Material. 4 partial cephala

Description. Sides of glabella straight, margins parallel from L1 to L3. Anterior of LA strongly curved. 3 pairs of glabellar furrows present, none of which connect across the glabella: S3 and S2 shallow, inclined backwards at roughly 15° relative to transverse line across cephalon, S1 deeper and sub-transverse. Ocular lobes originate from postero-lateral corner of LA and are separated from the glabella by a slight axial furrow. Curvature of ocular lobes slight from L3 to first half of L2, sharply curved inwards towards the axis at posterior of L2, terminate at anterior of L1. Interocular area thin (approximately 1/3 width of glabella at thickest point), slightly raised, slightly convex. Pre-glabellar field thin, approximately 1/5 length of LA and rises towards anterior border. Anterior border convex, raised slightly below the level of the glabella, approximately equal in thickness to pre-glabellar field.

Discussion. Fritz (1976) originally designated this species as cf. *Bergeroniellus* sp. What little material is present does appear to resemble *Bergeroniellus* in gross aspect in that it possesses a parallel-sided glabella, a relatively wide, broadly curved anterior margin, and ocular lobes that reach a relatively distal extent from the margins of the glabella. Other features appear to differ. Namely, in most species of *Bergeroniellus*, the ocular lobes are distinctly separated from the glabella by the axial furrows, whereas in this material the contact between the ocular lobes and the glabella is only faintly cut by the axial furrow. If dorsal facial suture lines are present on this taxon, they are not preserved, leaving their configuration unknown. The posterior of this taxon is also not preserved, leaving its affinity ambiguous. The presence of *Bergeroniellus* or a *Bergeronielllus*-like trilobite would also be unprecedented in Laurentia.

Occurrence. GSC location 84305. Section 2 (Fritz 1976). Sekwi Formation, "*Nevadella*" Zone

2.5.3 Biostratigraphic Results

2.5.3.1 Section 2

2.5.3.1.1. “*Fallotaspis*” Zone

At section 2, the “*Fallotaspis*” Zone (~35 m thick) is represented by numerous poorly preserved, indeterminate fallotaspidids and *Parafallotaspis grata* (Fig. 2-6, Tables 2 and 3).

2.5.3.1.2. “*Nevadella*” Zone

The “*Nevadella*” Zone at Fritz section 2 (~225 m thick) is represented by an indeterminate, tentatively assigned fallotaspidid, *Nevadella* cf. *N. keelensis*, indet. trilobite sp. 1, indet olenellid sp. 1, *Montezumaspis*? sp. 1, *Montezumaspis*? sp., *Esmeraldina*? sp. *Nevadella* cf. *N. bacculenta, Nevadia addyensis, Nevadella* sp. 2, and *Nevadella eucharis* (Fig. 2-6, Tables 2 and 3).

2.5.3.1.3. “*Bonnia-Olenellus*” Zone

The *Bonnia-Olenellus* Zone at Fritz section 2 (~900 m thick) is represented by a diverse assemblage of polymerid trilobites. These are as follows: *Fritzolenellus* cf. *F. truemani*, *Lochmanolenellus* sp., indet. Olenellid sp. 3, *Fritzolenellus*? sp., *Proliostracus* sp., *Proliostracus annosus*, *Olenellus*? sp., *Wanneria*? sp., Indet. Olenellid sp. 4, *Elliptocephala* cf. *E*. sp. 2 Fritz 1972, *Gabriellus*? sp., *Bonnia laterispina*, *Elliptocephala* cf. *E. parvifrons*, *Elliptocephala parvifrons*, *Olenellus* cf. *O. clarki* Resser 1928, *Elliptocephala*? sp. 1, *Elliptocephala*? sp. 2, *Bonnia* sp., *Olenellus* cf. *O. puertoblancoensis*, *Goldfieldia pacifica*, and *Ogygopsis*? sp (Fig. 2-6, Tables 2 and 3).

2.5.3.2. Section 10

2.5.3.2.1. “*Fallotaspis*” Zone

The *Fallotaspis* Zone at Fritz section 10 (~37 m thick) is represented by *Parafallotaspis grata* (Fig. 2-7, Tables 4 and 5).

2.5.3.2.2. “*Nevadella*” Zone

The *Nevadella* Zone at Fritz section 10 (~290 m thick) is represented by *Bradyfallotaspis fusa*, *Nevadella faceta*, *Nevadella* sp. 2 Fritz 1972, *Holmiella preancora*, *Holmiella falcuta*, *Pagetides spinulus*, *Yukonides lacrinus*, *Keeleaspis stupenda*, *Keeleaspis pustula*, *Kootenia diutina,* and *Bradyfallotaspis patula* (Fig. 2-7, Tables 4 and 5).

2.5.3.2.3. “*Bonnia-Olenellus*” Zone

The *Bonnia-Olenellus* Zone at Fritz section 10 (~400 m thick) is represented by *Elliptocephala walcotti*, *Elliptocephala laxocules*, *Ellitpocephala sequomalus*, *Elliptocephala logani*, *Elliptocephala paraoculus*, *Elliptocephala* sp. 2 Fritz 1972, *Olenellus puertoblancoensis*, *Olenellus* sp. 5 Fritz 1972, *Fritzolenellus* sp. 2 Fritz 1972, “*Proliostracus*” *depressus*, “*Proliostracus*” *annosus*, “*Variopelta*” *laevis*, “*Poulsenia*” sp. 1 Fritz 1972, “*Piaziella*” *pia*, “*Antagmus*” *truncatus*, “*Syspacephalus*” *vapidus*, *Zacanthopsis stribuccus*, *Bonnia columbensis*, *Bonnia* sp. 2 Fritz 1972, and *Bonnima* sp. nov (Fig. 2-7, Tables 4 and 5).

2.6 INTERPETATION

2.6.1 Chemostratigraphic Correlation

Stable carbon isotope data from the Sekwi and Hess River formations improve the understanding of their depositional ages. Carbon isotope chemostratigraphic results can be compared to the global composite stable carbon isotope curve for the Cambrian (Peng et al. 2020, Cramer and Jarvis 2020) and the established curve for the Sekwi Formation (Dilliard et al., 2007; Figs. 2-3, 2-5). Samples used for stable isotope analysis from this study (Table 1) could be sampled only from the matrix of trilobite-bearing samples, resulting in stable carbon isotope curves with sparse stratigraphic spacing (>0.5 to >>1 m) but exact calibration to biostratigraphic material. Comparison of stable carbon isotope chemostratigraphic data to trilobite biostratigraphic zones in the Cambrian is an ongoing task that is necessary to improve correlation in the Cambrian.

The Sekwi and Hess River formations have yielded stable carbon isotope curves (Dilliard et al. 2007, Turner 2015, Fig. 2-3) that are closely comparable to the established global curve (Cramer and Jarvis 2020). Previously, Dilliard et al.'s (2007) curve was incorporated into the 2012 Geological Timescale global curve (Saltzman and Thomas 2012). Dilliard et al. (2007) identified 8 isotope "cycles" in their curve. The most complete stable carbon isotope record for the lower Cambrian of the northern cordillera is probably Dilliard et al. (2007) Section 4 (see figs. 2-6, 2-8, and 2-9 in Dilliard et al. (2007); Figs. 2-3, 2-5, in this study) Three global excursions are present in that curve (Scott et al. 2022, Fig. 3): the Cambrian Arthropod Radiation Excursion (CARE), Mingxinsi Carbon Isotope Excursion (MICE), and Archaeocyathan Extinction Carbon Isotope Excursion (AECE). In addition, the onset of the Redlichiid-Olenellid Extinction Carbon Isotope Excursion (ROECE) is probably present at the top of Dilliard et al. (2007) Section 4 at the Sekwi-Hess River formational contact.

When compared to Dilliard et al.'s (2007) data, two to three globally recognized isotope excursions are present in the curves derived from sections 2 and 10 (Figs. 2-3, 2-8) The first of these is the MICE, which is exhibited in section 10 (=A in Fig. 2-9) but not section 2, where no carbonate samples were gathered from the equivalent interval. The MICE at section 10 consists of two positive peaks with a brief return to slightly negative values in its middle. The AECE (=B in Fig. 2-8) is probably present in the curves for both sections 2 and 10. Section 2 exhibits an interval with strongly negative values from -3.4‰ to -2.1‰ close to the middle of the Sekwi Formation, and section 10 exhibits negative values at roughly the same stratigraphic level (-4.0‰- -1.8‰; Figs. 2-3 and 2-8; Table 1). The onset of the ROECE may be present at the Sekwi-Hess River formational contact based on data from Dilliard et al. (2007). Dilliard et al. (2007) section 3 exhibits a strong negative trend close to the Sekwi-Hess River formational contact, and Dilliard et al. (2007) section 4 also exhibits a negative trend at a stratigraphically similar level, albeit one that is less pronounced. Data from this paper support the ROECE being close to the Sekwi-Hess River formational contact (Fig. 2-8). In addition to these three excursions, the CARE may be present in the base of the Sekwi Formation based on moderately positive values present in lowermost GSC locations (Table 1; GSC locations 84299 and 73025). However, these data points are not sufficient to warrant a strong designation, and there is evidence that the lower part of the Sekwi Formation is more diagenetically altered than the upper part.

Generally, the MICE is only partially expressed in the Sekwi Formation because of the presence of the sandy marker bed that occupies the boundary between the *Bonnia-Olenellus* and *Nevadella* zones (Figs. 2-3 and 2-8, Section 10). Comparisons between the MICE as expressed in the Sekwi Formation and units elsewhere globally are challenging. In the Sekwi Formation, it appears as though the MICE is confined to the *Nevadella* Zone. Dilliard et al. (2007) section 3 exhibits positive values from ~150 to 400 m, which is probably the best record of the MICE yet found in the Selwyn basin. Dilliard et al. (2007) exhibits similar values along the same stratigraphic interval, and section 10 also exhibits positive values, although the curve is more truncated at that section. Values from this section corroborate Dilliard et al.'s (2007) data. The MICE is recorded in South China in core from the Yangtze platform (Chang et al. 2017), Australia (Betts et al. 2018), and Siberia (Brasier and Sukhov, 1998). Chang et al.'s (2017) curve was incorporated into the GTS 2020 global curve (Cramer and Jarvis 2020, Peng et al. 2020). Compilations of Cambrian stable carbon isotope data typically depict the MICE as being largely a Cambrian Stage 4 phenomenon (Cramer and Jarvis 2020, Peng et al. 2020). Laurentian data contrasts with this, because the MICE appears to be almost wholly associated with the *Nevadella* Zone, which occurs in the undefined Stage 3 [Figs. 2-3 and 2-8; Dilliard et al. 2007]. This contrast could be for several reasons: (1) issues associated with Stage 3 still not being formally defined, (2) issues related to intercontinental correlation, (3) occurrences of the MICE not being exactly coeval, or (4) some combination of these factors.

Clear evidence of the AECE is not present in this study's dataset, and its presence is suggested only because of comparison to Dilliard et al.'s (2007) curve (Fig. 2-8). Notably, where present, its occurrence in the Sekwi Formation is consistently near the highest stratigraphic occurrence of archaeocyathan mounds (Dilliard et al. 2007). Biostratigraphically, the AECE is associated with the lower to upper *Bonnia-Olenellus* Zone. Although relatively few Sekwi Formation sections have stable carbon isotope data, the relationship between the last occurrence of archaeocythans and lower-middle *Bonnia-Olenellus* Zone trilobites does appear to be consistent throughout the Sekwi Formation (Fritz 1976, 1978, 1979; Dilliard et al. 2007, 2010), implying that the AECE is closely associated with the last occurrence of archaeocyathans in the Sekwi Formation throughout the Selwyn basin.

The ROECE is probably present above the Sekwi-Hess River formational contact at Fritz (1976) section 2 given the value of -1.3‰ ~50 m above the base of the Hess River Formation

(Table 1). The values surrounding that GSC location are moderately negative and all are within the *Bonnia-Olenellus* Zone, implying that the occurrence of the ROECE in the Sekwi Formation is slightly before the extinction of olenellid trilobites in Laurentia. The Sekwi-Hess River formational contact is diachronous, and spans through roughly half of Cambrian Stage 4, or through the middle to upper *Bonnia-Olenellus* Zone (Scott et al. 2022). The stratigraphic level of the ROECE is likewise variable, and can occur at the Sekwi-Hess River Formational contact or 100-200 m above it in lower strata of the Hess River Formation (Figs. 2-3, 2-5, 2-8). More stable isotope data and better sample coverage are needed to verify this hypothesis. Elsewhere in Laurentia, the occurrence of the ROECE appears to differ from that of the Sekwi Formation. In the Carrara Formation (California) and the Pioche Formation (Nevada), the ROECE closely corresponds to the extinction of olenellid trilobites (Faggeter et al., 2017). Data from Lin et al. (2019) from Nevada also correspond to the curves in Faggeter et al. (2017). The apparent presence of post-ROECE trilobites in the Hess River Formation at Fritz (1976) section 2 is probably due to either local differences in the expression of the ROECE or slight diachroneity in the extinction of olenellid trilobites throughout Laurentia. Lin et al. (2019) discussed differences in the expression of the ROECE in Nevada and South China sections. In Nevada, the ROECE consists of two notably negative crests (~-4.0‰) with moderately negative values between them. The expression of the ROECE in curves from South China is much more compact (Lin et al., 2019). It may be the case that although the ROECE is a globally correlatable excursion, local differences in its expression hamper its utility as a correlation tool.

2.6.2 Regional Biostratigraphic Correlation

2.6.2.1 “*Fallotaspis*” Zone

The lower “*Fallotaspis*” Zone of sections 2 and 10 preserves only *Parafallotaspis grata* and indeterminate fallotaspidid material (Figs. 2-6 and 2-7; Tables 2 and 4). In the Campito Formation (Nevada and California), *Parafallotaspis* occurs only in the upper part of the “*Fallotaspis*” Zone (Hollingsworth 2011), indicating that the lowermost part of the Sekwi Formation is correlatable with the middle of the Montenegro member of the Campito Formation. Furthermore, the extremely low thickness of the “*Fallotaspis*” Zone in the Sekwi Formation and the predominance of *Parafallotaspis grata* suggests that the full extent of the “*Fallotaspis*” Zone is not expressed in the Selwyn basin. This could indicate either that (1) environmental conditions during deposition of the underlying Vampire Formation were unsuitable for the presence of trilobites, (2) facies of the Vampire Formation were unsuitable for the preservation of trilobite carapaces, or (3) trilobites had not yet migrated to the Selwyn basin, and the first appearance of trilobites in the Esmeralda basin is substantially earlier than that of the Selwyn basin. The first hypothesis is regarded as being implausible because of the presence of *Cruziana*, an arthropod ichnofossil commonly attributed to trilobites, in the Vampire Formation (MacNaughton and Narbonne 1999). Part of the Vampire Formation was, therefore, probably deposited during “*Fallotaspis*” Zone and possibly the *Fritzaspis* Zone biochron, despite no diagnostic body fossils being preserved.

2.6.2.2 “*Nevadella*” Zone

2.6.2.2.1 Section 2

The "*Nevadella*" Zone at section 2 is ~225 m thick (Fig. 2-6). Two of Hollingsworth's (2011) species-based interval zones are diagnosable at section 2: the *Nevadia addyensis* and *Nevadella eucharis* zones. The base of the *Nevadia addyensis* Zone corresponds to the first occurrence (FO) its eponymous species, *Nevadia addyensis*, and its top is delineated by the FO of *Nevadella eucharis*. The *Nevadia addyensis* Zone is ~165 m thick at section 2 (Fig. 2-6), and the only species represented in it is its eponymous taxon. The base of the *Nevadella eucharis* Zone is delineated by the FO of *Nevadella eucharis*, and its top is defined by the extinction of nevadiid trilobites and the appearance of an olenellid trilobite assemblage consisting mainly of "Wanneriid" trilobites. The *Nevadella eucharis* Zone is ~50 m thick at section 2 (Fig. 2-6), and its assemblage also consists only of its eponymous taxon and *Nevadella* sp. 2.

The remainder of the "*Nevadella*" Zone assemblage (the lowermost, undivided ~70 m) consists of a more diverse assemblage of nevadiids, holmiids, and an indeterminate fallotaspidid. The lowest assemblage (GSC location 84305) consists of *Nevadella* cf. *N. keelensis* Abe et al. 2010, an indeterminate fallotaspidid, and an indeterminate trilobite that Fritz (1976) compared to *Bergeroniellus*. GSC location 84306 contains an indeterminate, worn olenellid of probable holmiid affinity. GSC locations 84307 and 84309 both contain *Montezumaspis*? sp. 1 and *Montezumaspis*? sp. 2, and GSC location 84308 contains an indeterminate olenellid. GSC location 84311 contains *Esmeraldina*? sp. GSC location 84312 also contains *Esmeraldina*? sp. and *Nevadella* cf. *N. bacculenta* Fritz 1972 (Fig. 2-6). This fauna differs from the lower species-based biozones of Hollingsworth (2011) (*Esmeraldina rowei*, *Grandinasus patula*, and *Avefallotaspis maria* zones) in many respects. However, the presence of *Esmeraldina*- and *Palmetaspis*/*Montezumaspis*-like assemblage in the lower half of the undivided "*Nevadella*" Zone at section 2 is comparable to assemblages in the *Esmeraldina rowei* and *Grandinasus* *patula* zones, suggesting that the interval may be broadly correlatable to those biozones. It is probably the case, however, that most of Hollingsworth's (2011) species-based biozones for the Montezuman are not diagnosable in the Sekwi Formation because of provinciality and a large scale "barren zone" between the *Avefallotaspis maria* and *Nevadia addyensis* zones (Hollingsworth 2011).

2.6.1.2.2 Section 10

The "*Nevadella*" Zone assemblage at section 10 is ~250 m thick and, strongly differs from section 2 (Fig. 2-7), consisting of an eodiscinid/dorypygid fauna coupled with nevadiids, holmiids, archaeaspidids, and ptychopariids. Section 2 lacks eodiscinids, dorypygids, archaeaspidids such as *Bradyfallotaspis*, and ptychopariids, and its nevadiid/holmiid fauna has no specific overlap. This is a striking faunal difference considering that the sections are only ~123 km apart (present-day; mainly along-strike). Section 10 also features a thick interval of sandstone and sandy dolostone (~120 m) in which no trilobite fossils are present in the upper "*Nevadella*" Zone, hampering comparisons with other Sekwi Formation sections and Montezuman trilobite assemblages elsewhere in Laurentia. In addition, the lower half of section 2 contains some silty intervals that are not present at section 10. This may partially explain the lack of faunal overlap between the Nevadella Zone assemblages at sections 2 and 10.

There is a variety of possible explanations for the differences in faunas between sections 2 and 10. (1) Depth-dependent faunal changes as a result of one section being farther basinward than the other. It should be noted that although the present-day locations of sections 2 and 10 are approximately along depositional strike of one another,their relative positions in the thrust-belt mean that one could record a substantially deeper (outboard) environment than the other, (2) Differences in post-mortem transportation to the eventual burial site of the trilobite fossils. (3)

Differences in diagenesis that differentially affected taphonomy. (4) Geographic barriers resulting in high degrees of endemism across relatively small distances. Explanations (1) and (4) are favoured herein, because the lower part of the Sekwi Formation is known to have been affected by normal faulting (Dilliard et al. 2010), which may have resulted in horst/graben structures that served as geographic barriers or produced laterally variable seafloor subenvironments. Other Sekwi Formation sections are known to contain "eccentric faunas" whose compositions differ dramatically from nearby localities. Fritz (1973) described "*Nevadella*" Zone trilobites from sections slightly north of the Intga River [~80 km west of the bulk of Fritz's (1976, 1978, 1979) and Dilliard et al.'s (2010) sections in the June Lake area]. The faunas recorded by Fritz (1973) are markedly different from most other "*Nevadella*" Zone trilobite assemblages in the area, consisting of eodiscines (*Serrodiscus mackenziensis*, *Yukonides*, two species of *Ekwipagetia*, and several species of *Pagetides*), *Bradyfallotaspis*, *Holmia*, *Judomia*? *absita*, *Nevadia*, and edelsteinaspidids such as *Labradoria* and *Anadoxides*. This assemblage has almost no specific or generic overlap with adjacent sections. Normal faulting may have produced geographic barriers (horsts and grabens) that resulted in endemism during the deposition of the lower half of the Sekwi Formation.

2.6.2.3 *Bonnia-Olenellus* Zone Subdivision and the *Elliptocephala* Zone (New)

Owing mostly to its large temporal span, the *Bonnia-Olenellus* Zone has been treated as having three informal subunits (Fritz 1991; Scott et al. 2022). A new biozone is proposed herein, the *Elliptocephala* Zone, which represents approximately the lower half of the *Bonnia-Olenellus* Zone in the Sekwi Formation and is divisible into two subzones. These subzones are, in ascending order, the *Fritzolenellus-Lochmanolenellus* Subzone and the *Wanneria* Subzone. Both are genus-based assemblage zones, and both are applicable mainly to the Selwyn basin and nearby areas, although they do have some utility elsewhere in Laurentia.

The base of the (new) *Elliptocephala* Zone is here defined by the first appearance datum (FAD) of *Elliptocephala*, but its base is more practically defined by the FO of *Elliptocephala*. In the Selwyn basin, the FO of *Elliptocephala* is consistently *Elliptocephala walcotti* (Fig. 2-7; although see taxonomic discussion above for commentary on its taxonomic status). This roughly corresponds to the base of the traditional "*Bonnia-Olenellus*" Zone (=base of undefined Stage 4; Fig. 2-4). *Bonnia laterispina* and "*Variopelta*" *laevis* occur throughout the middle of this biozone, and the small, smooth ptychopariid genus "*Proliostracus*" is also confined to this biozone (Figs. 2-6, 2-7). Where they occur, these taxa are also characteristic.

The lower subzone of the *Elliptocephala* Zone, the (new) *Fritzolenellus-Lochmanolenellus* Subzone, is a biostratigraphic interval in which representatives of *Fritzolenellus* and/or *Lochmanolenellus* occur (Figs. 2-6, 2-7). *Laudonia* may also occur in this subzone (Fig. 2-7), although currently *Laudonia* consists of only two species (Webster and Bohach 2014) and is of limited biostratigraphic utility. *Lochmanolenellus* appears to be confined to the lowermost part of the Dyeran, and in the Mount Robson area (British Columbia, Canada) *Lochmanolenellus pentagonalis* Webster and Bohach 2014 co-occurs with *Laudonia bispinata* Harrington 1956, *Fritzolenellus truemani*, *Mummaspis muralensis* Fritz 1992, *Mummaspis truncatooculatus* Fritz 1992, and *Mummaspis oblisooculatus* Fritz 1992 (Webster and Bohach 2014). These taxa are characteristic of the *Fritzolenellus-Lochmanolenellus* Subzone. Occurrences of *Lochmanolenellus* with some of these characterizing taxa in Nevada and Sonora support the idea that the genus, and the assemblage commonly accompanying it, are useful for correlation in the lower Dyeran, although Mexican occurrences of *Lochmanolenellus* are stratigraphically poorly constrained (Webster and Bohach 2014).

The base of the (new) *Wanneria* Subzone is defined by the FAD of any representative of its eponymous genus, and the top by the extinction of *Wanneria*. In the Selwyn basin, it is unclear whether *Wanneria* or *Elliptocephala* goes extinct first (Fritz 1972, 1976, 1978, 1979), and the top of the *Wanneria* Subzone and the *Elliptocephala* Zone is defined by the last occurrence (LO) of whichever of these genera occurs last. In the case of section 10, the first occurrence of *Wanneria* is the co-occurrence of both *W. logani* and *W. parvifrons* (Fig. 2-7). In section 10, *W. logani* has a significantly greater stratigraphic range than *W. parvifrons*, which is confined to GSC location 73049. Section 2 differs in that the first occurrence of *Wanneria* is *W.* cf. *W. parvifrons*, but *W. parvifrons* does appear ~15 m above that (Fig. 2-6).

Dyeran strata overlying the *Elliptocephala* Zone correspond to the upper "*Bonnia-Olenellus*" Zone of earlier usage. Considering modern revisions to the genus (Lieberman 1998, Palmer and Repina 1993, Webster and Landing 2016), the FAD of *Olenellus* is probably mid-Dyeran. It may be possible to establish an *Olenellus* Zone s*ensu novo* that is applicable at least to the Selwyn basin and adjacent areas. However, the first appearance of *Olenellus* in the Selwyn basin is poorly constrained, and revision to historical trilobite collections [e.g., faunal lists in Fritz (1976, 1978, 1979)] as well as new collections are necessary to constrain the range of the genus satisfactorily. Provisionally, it appears that the stratigraphic range of *Olenellus* in the Selwyn basin and Richardson trough does not overlap with *Elliptocephala* and *Wanneria* (Fritz 1972, 1991). Elsewhere in Laurentia, this is not the case. In Nevada, *Olenellus granulatus* co-occurs with *Wanneria* cf. *W. walcottana* (Palmer 1964). Furthermore, *Goldfieldia pacifica*, one of the oldest known spiny oryctocephalids, and ostensibly a biostratigraphically important lower

Cambrian trilobite, also occurs in this assemblage. *G. pacifica* appears to occur only in the uppermost Dyeran in the Selwyn basin (Fritz 1972, this study), although it has been sampled from relatively few locations. Palmer's (1964) assemblage indicates that (1) *Goldfieldia pacifica* and *Olenellus* occur stratigraphically lower in Esmeralda County than in the Selwyn basin, (2) *Wanneria* occurs stratigraphically higher in Esmeralda County than currently observed in the Selwyn basin, or (3) the stratigraphic ranges of all of these taxa are too poorly understood to use them to facilitate Laurentia-wide correlation. Regardless of the cause of this issue, *Wanneria* does not appear to overlap with *Olenellus* in the Selwyn basin (Figs. 2-6, 2-7), meaning that an *Olenellus* Zone *sensu novo* that overlies the *Elliptocephala* Zone could be established there, but not elsewhere in Laurentia.

In the Selwyn basin, genera and species that occur in the undivided *Bonnia-Olenellus* Zone interval above the *Elliptocephala* Zone include *Zacanthopsis*, numerous small, smooth ptychopariid genera (e.g., "*Piaziella*," "*Antagmus*," and "*Syspacephalus*"), *Bonnima*, *Ogygopsis*, and *Bonnia columbensis* (Figs. 2-6, 2-7). *Olenellus puertoblancoensis* and *Goldfieldia pacifica* appear to be confined to the top of this interval, close to the traditional lower-middle Cambrian boundary that was originally placed by Fritz (1972, 1976) in the Hess River or Rockslide formations (Figs. 2-4, 2-6, 2-7). This stratigraphic interval probably encompasses all of Webster's (2011) species based biozones, although it is difficult to diagnose them in the Sekwi Formation. There is limited generic and specific overlap between uppermost strata of the Sekwi Formation and upper Dyeran assemblages from Arizona, California, and Nevada (Fritz 1972, 1976, 1978, 1979; Webster 2011). *Olenellus puertoblancoensis* occurs in both areas, but the taxonomy of that species is murky owing to problematic type material (Webster and Landing 2016). *Bolbolenellus* has been documented in the upper Sekwi Formation (*Bo. altifrontatus*; Fritz

1972), but the presence of eponymous, zone-defining taxa or other diagnostic taxa such as representatives of *Nephrolenellus*, *Peachella*, and *Bristolia* used by Webster (2011) is largely unknown. In the Appalachians, faunas described by Webster and Landing (2016) from the Parker and Monkton formations (northwestern Vermont) probably also roughly correlate with the upper "*Bonnia-Olenellus*" Zone in this study.

2.6.2.4 Section 2

The *Elliptocephala* Zone at section 2 is ~720 m thick (Fig. 2-6), and its base is interpreted by *Fritzolenellus* cf. *F. truemani*. The *Fritzolenellus-Lochmanolenellus* Zone is is ~640 m thick and aside from *Fritzolenellus* cf. *F. truemani* is represented by a wide variety of taxa including *Lochmanolenellus* sp., indet olenellid sp. 3, *Fritzolenellus*? sp. 1, *Proliostracus* sp., *Proliostracus* cf. P. *contractus*, *Proliostracus annosus*, *Olenellus*? sp., *Elliptocephala* sp. 1, indet. olenellid sp. 4, *Elliptocephala* cf *E*. sp. 2 Fritz (1972), *Gabriellus*? sp., and *Bonnia laterispina* (Fig. 2-6). Material assigned to *Olenellus*? sp. and *Gabriellus*? sp. is very worn, and neither of these fossils is considered to be biostratigraphically meaningful. All other taxa in this interval are characteristic of the *Elliptocephala* Zone and *Fritzolenellus/Lochmanolenellus* Subzone.

The *Wanneria* Subzone at section 2 is ~60 m thick (Fig. 2-6), and its base is delineated by the appearance of *Wanneria* cf. *W. parvifrons*. *Bonnia laterispina*, *Elliptocephala*? sp., and *Wanneria parvifrons* also occur in this interval, and the disappearance of *Wanneria* cf. *W. parvifrons* marks the termination of the *Wanneria* Subzone/*Elliptocephala* Zone. The remaining ~205 m of fossiliferous strata in the upper Sekwi Formation and lower Hess River Formation at section 2 contain an assemblage of trilobites with *Olenellus* cf. *O. clarki* at its base (Fig. 2-6). A species assigned to *Elliptocephala* in open nomenclature (*Elliptocephala*? sp. 1) occurs above

Olenellus cf. *O. clarki*; if this species were to be confidently assigned to *Elliptocephala*, that would result in the stratigraphic range of *Olenellus* and *Elliptocephala* overlapping. Other taxa in this interval include *Bonnia* sp., *Olenellus puertoblancoensis*, *Goldfieldia pacifica*, and *Ogygospsis*? sp., the latter three of which are indicative of the latest Dyeran in the Selwyn basin. These latter four taxa probably occur in the uppermost Dyeran at section 2 based on the presence of *Olenellus puertoblancoensis*, which occurs in the *Bolbolenellus euryparia* Zone in the Great Basin (Webster 2011).

2.6.2.5 Section 10

The *Elliptocephala* Zone at section 10 is ~225 m thick (Fig. 2-7) and its base is placed at the first occurrence of *Elliptocephala walcotti*. *Laudonia*? sp. and *Proliostracus depressus* also occur at this stratigraphic level. The lower *Fritzolenellus-Lochmanolenellus* Subzone is ~125 m thick (Fig. 2-7) and contains typical trilobites of the *Elliptocephala* Zone such as representatives of *Proliostracus* and *Variopelta*. *Fritzolenellus* sp. 1 occurs midway through this interval, justifying the maintenance of the subzone at section 10. The base of the upper *Wanneria* Zone is delineated by the appearance of *Wanneria parvifrons* and its top by "*Olenellus*" sp. 4, which is probably assignable to either *Wanneria* or *Elliptocephala*. No material of "*Olenellus*" sp. 4, was available for this study, so no attempt to reassign it to another genus has been made. Alternatively, the top of the *Wanneria* Zone at section 10 could be based on the last occurrence of *Elliptocephala paraoculus*, which would place its upper boundary ~10 m lower (Fig. 2-7). The remaining upper ~140 m of the Sekwi Formation consists of a typical upper *Bonnia-Olenellus* Zone fauna including *Zacanthopsis*, *Olenellus*, *Bolbolenellus*, and small, smooth ptychopariids such as *Antagmus* and *Syspacephalus*. Critically, both *Olenellus puertoblancoensis* and *Bolbolenellus altifrontatus* are present in this interval. The former taxon is present in

Webster's (2011) *Bolbolenellus euryparia* Zone, and *Bolbolenellus* occurs in both the *Bo. euryparia* and *Nephrolenellus multinodus* zones. These are the uppermost two of Webster's (2011) species-based biozones, and the presence of these two taxa strongly suggests that the upper strata of the Sekwi Formation are correlatable with one or both biozones. Furthermore, Fritz (1972) assigned strata above this interval to the middle Cambrian. This suggests that *Bolbolenellus*- and *Olenellus*-bearing strata below Fritz's middle Cambrian boundary may be uppermost Dyeran, unless there is a fault, unconformity, or depositional hiatus between their stratigraphic level and where Fritz (1972) placed the lower-middle Cambrian boundary at section 10.

It should be noted that because the base of the *Elliptocephala* Zone is defined by the first appearance of *Elliptocephala*, its base at section 10 does not correspond to the base of the "*Bonnia-Olenellus*" Zone. Instead, there is a ~25 m gap between the base of the *Elliptocephala* Zone and where Fritz (1972, 1976) placed the upper boundary of the "*Nevadella*" Zone (Fig. 2-7). This boundary seems to be semi-arbitrary given the thick, non-fossiliferous interval in the lower Sekwi Formation at that locality. This results in an undefined interval between the *Elliptocephala* Zone and the "*Nevadella*" Zone.

2.7 DISCUSSION

2.7.1 Other Laurentian Sections

Faunas of the Sekwi Formation can be compared to those from other localities across North America (Fig. 2-9). Diagnostic taxa of the *Elliptocephala* Zone are present in Fritz's (1991) Illtyd Formation section (Fig. 2-10; location 2 in Fig. 2-9). Fritz (1991) considered the Illtyd Formation to have been deposited during the latter half of the "*Bonnia-Olenellus*" Zone.

Elliptocephala sp. 2 Fritz 1972 occurs close to the base of the Illtyd Formation, demonstrating that basal strata of the Illtyd Formation were deposited during the *Elliptocephala* Zone biochron. *Wanneria parvifrons* occurs 279 m above the base of the Illtyd Formation (Fig. 10), delineating the base of the *Wanneria* Subzone. The *Wanneria* Subzone, and with it the *Elliptocephala* Zone, is considered to terminate at the disappearance of "*Olenellus*" sp. 2 Fritz 1991, which appears *Wanneria*-like. The *Fritzolenellus-Lochmanolenellus* Subzone is taken to occupy strata below the first appearance of *Wanneria parvifrons*. The *Elliptocephala* Zone at Fritz's (1991) Illtyd Formation is therefore 515.4 m thick; the *Fritzolenellus-Lochmanolenellus* Subzone is assumed to be 249.3 m thick, and the *Wanneria* Subzone is 266.1 m thick (Fig. 2-10). Fritz's (1991) trilobite specimens were not analysed in this study, so it is possible that these boundaries could be subject to minor revision if those specimens were to be formally reevaluated. The remaining 430.6 m of Fritz's (1991) section corresponds to the upper part of the "*Bonnia-Olenellus*" Zone (Fig. 2-10).

Fritz's (1992) "Type Tah" section of the Mural Formation (location 3 in Fig. 2-9) records the *Nevadia addyensis* and *Nevadella eucharis* zones and *Fritzolenellus-Lochmanolenellus* Subzone (Fig. 2-11). There, the *Nevadia addyensis* Zone is ~45 m thick, and contains its eponymous species and *Nevadella mountjoyi*. The *Nevadella eucharis* Zone is ~12 m thick and consists of its eponymous taxon and *Nevadella perfecta*. The "*Nevadella*" Zone below the first occurrence of *Nevadia addyensis* is ~75 m thick (Fig. 2-11) and consists of only one occurrence of aff. *Bradyfallotaspis*. The *Elliptocephala* Zone is represented by the *Fritzolenellus-Lochmanolenellus* Subzone and is ~145 m thick (Fig. 2-11). Its base is delineated by the first occurrence of *Fritzolenellus truemani*. *Laudonia bispinata*, *Mummaspis truncatooculatus*, and *Mummaspis oblisooculatus* occur close to the base of the subzone, and two questionable occurrences of *Mummaspis oblisooculatus* co-occur with *Gabriellus lanceatus*, *Proliostracus contractus*, *Elliptocephala* cf. *E. laxocules*, and *Bonnia* sp. at the top of the Mural Formation above a barren interval of ~145 m (Fig. 2-11).

2.7.2 Utility of Genus-based Assemblage Zones

Genus-based assemblage zones exhibit substantial imprecision relative to species-based biozones because the first or last occurrence of a genus is generally affected more by diachroneity than is the first or last occurrence of a species. In contrast, although the boundaries of species-based biozones exhibit considerably less diachroneity than genus-based biozones, most lower Cambrian trilobite species have a high degree of provinciality (Palmer 1998). This makes it difficult to establish and use species-based biozones that apply to broad geographic areas. The contrasting utility of species- versus genus-based zones is evident when faunas from sections 2 and 10 are compared (Figs. 2-6, 2-7): only two of Hollingsworth's (2011) species-based biozones are diagnosable at section 2, and although uppermost strata of the undefined interval (=approximately the upper "*Bonnia-Olenellus*" Zone) were probably deposited during the *Bolbolenellus euryparia* or *Nephrolenellus multinodus* Zone biochron, this designation is not definitive.

The *Elliptocephala* Zone, although not immune to the drawbacks of large-scale, genus-based assemblage zones, offers some advantages compared to the existing lower Cambrian assemblage zones. (1) It spans less time than the "*Bonnia-Olenellus*" Zone, occupying only a fraction the Dyeran/Cambrian Stage 4 (Figs. 2-4, 2-6, 2-7) and leaving open the possibility of erecting other Cordillera-specific biozones once the ranges of some taxa are better constrained. (2) It is readily divisible into subzones that are defined by a variety of taxa, allowing it to survive possible future changes in taxonomy without seriously compromising its integrity. For example, if *Elliptocephala walcotti* were eventually to be assigned to *Fritzolenellus*, the stratigraphic range of *Elliptocephala* in the Selwyn basin would be reduced to only the upper part of the *Elliptocephala* Zone, but the taxonomic modification would not affect the integrity of the *Fritzolenellus-Lochmanolenellus* or *Wanneria* subzones, and both could be elevated to zonal status.

Webster and Bohach (2014) documented a succession of *Lochmanolenellus* species in the Cassiar Mountains and Nevada (in ascending order: *Lo. pentagonalis*, *Lo. subquadratus*, and *Lo. trapezoidalis*), indicating that various species of *Lochmanolenellus* could potentially serve as the basis for a species-based zonal scheme like the Montezuman and upper Dyeran schemes of Hollingsworth (2011) and Webster (2011). If a species-based biostratigraphic scheme for the lower Dyeran is formalised, a complementary usage of such a scheme with a smaller-magnitude genus-based biozone such as the *Elliptocephala* Zone could prove fruitful by mitigating the drawbacks of both zonal concepts.

2.7.3 Chemostratigraphy and Biostratigraphy

The AECE corresponds closely to the base of the *Elliptocephala* Zone at sections 2 and 10 (Fig. 2-12), implying that there is very little diachroneity in the first appearances of the *Elliptocephala* Zone's basal diagnostic taxa throughout the Sekwi Formation. Conversely, although the evidence is sparse, the ROECE appears to vary in stratigraphic position throughout the upper "*Bonnia-Olenellus*" Zone (Fig. 2-12). This is consistent with the diachroneity of the Sekwi-Hess River formational contact, which was previously shown (Scott et al. 2022) to vary from the middle to upper "*Bonnia-Olenellus*" Zone (the middle "*Bonnia-Olenellus*" Zone probably corresponding to some position in the *Wanneria* Subzone).

2.8 CONCLUSIONS

In some areas the Sekwi Formation contains uppermost Montezuman species-based trilobite biozones that previously had been best known from the Great Basin of southwestern USA. Marked differences between "*Nevadella*" Zone faunal assemblages in different Sekwi Formation localities are probably mainly due to a combination of depth-dependent environmental differences as well as geographic barriers produced by normal faulting (i.e., horsts and grabens cutting off some areas of the Sekwyn basin from each other). The *Elliptocephala* Zone, a new, proposed lowermost Dyeran genus-based assemblage biozone that is applicable to the Selwyn basin and surrounding areas (Cassiar Mountains and Richardson trough). The *Elliptocephala* Zone is divisible into a proposed lower *Fritzolenellus-Lochmanolenellus* Subzone and an upper *Wanneria* Subzone. The AECE appears to correspond to the lowermost part of the *Elliptocephala* Zone. New trilobite collections from the Sekwi Formation and reevaluation of existing collections are required to determine how comparable Montezuman faunas are throughout the Canadian cordillera and to calibrate the upper boundary of the *Elliptocephala* Zone.

2.9 REFERENCES

Adrain, J.R. 2011. Class trilobite Walch, 1771. In Animal biodiversity: an outline of higher-level classification and survey of taxonomic richness. Edited by: Zhang, Z.Q. Zootaxa, Vol. 3148.

Anglin, N.P. 1854. Palaeontologica Scandinavia: Academiae Regiae Scientarium Suecanae (Holmiidae). Pars II, 21-92.

Abe, F.R., Lieberman, B.S., Pope, M.C., and Dilliard, K. 2010. New information on olenelline trilobites from the Cambrian Sekwi Formation in northwestern Canada. Canadian Journal of Earth Sciences, Vol. 47, 1445-1449.

Babcock, L.E., Robison, R.A., and Peng, A. Cambrian stage and series nomenclature of Laurentia and the developing global chronostratigraphic scale. *In* Cambrian stratigraphy and paleontology of northern Arizona and southern Nevada. The 16th field conference of the Cambrian Stage subdivision working group. Edited by Hollingsworth, J.S., Sundberg, F.A., and Foster, J.R. Museum of northern Arizona, Bulletin no. 67, 12-26.

Best, R.V. 1960. *In* Kielan, Z. On two olenellid trilobites from Hokrnsund, Vestspitsbergen. Studia Polonica, Vol. 4, 83-92.

Blaker, M.R., and Peel, J.S. 1997. Lower Cambrian trilobites from North Greenland. Meddelelser om Grønland, Vol. 35, 145 pp.

Beecher, C.E. 1897. Outline of a natural classification of the trilobites. American Journal of Science, Vol. 153, 89-106, 181-207.

Bohach, L.L. Systematics and biostratigraphy of Lower Cambrian trilobites of western Laurentia. Unpublished PhD thesis. University of Victoria, Victoria, British Columbia, Canada. 410 pp.

Chatterton, B.D.E. Mid-Furongian trilobites and agnostids from the *Wujiajiania lyndasmithae* subzone of the Elvina Zone, McKay Group, southeastern British Columbia, Canada. Journal of Paleontology, **94**:653-680.

Cotton, T., and Fortey, R.A. 2005. Comparative morphology and relationships of the Agnostida. *In* Crustacea and Arthropod Relationships. *Edited by* Jenner, R., and Koenemann, S. Taylor and Francis, United Kingdom, 440 pp.

Cramer, B.D., and Jarvis, I. Carbon Isotope Stratigraphy. *In* Geological Timescale 2020. Edited by Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M. Elsevier, Amsterdam, Netherlands.

Davidson, A. 2008. Late Paleoproterozoic to mid-Neoproterozoic history of northern Laurentia: an overview of central Rodinia. Precambrian Research, **160**:5-22.

Deiss, C. 1940. Lower and Middle Cambrian stratigraphy of southwestern Alberta and south-eastern British Columbia. Bulletin of the Geological Society of America, **51**:731-794.

Dixon, J. 1997. Cambrian stratigraphy of the northern Interior Plains, Northwest Territories. Geological Survey of Canada. Open File 3510. 27 pp.

Edgecombe, G.D. 2017. Inferring arthropod phylogeny: fossils and their interaction with other data sources. Integrative and Comparative Biology, Vol. 57, p. 467-476.

Emmonds, E. 1844. The Taconic System: based on observations in New York, Massachusetts, Maine, Vermont and Rhode Island. Albany, N.Y. Privately published, 653 pp.

Fischer, B.J., and Pope, M.C. 2011. Lower Cambrian carbonate succession. *In* Geology of the central Mackenzie mountains of the northern Canadian Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories special volume 1, 142-149.

Fortey, R.A. 2001. Trilobite systematics: the last 75 years. Journal of Paleontology, Vol. 75, p. 1141-1151.

Fortey, R.A., and Theron, J.N. 1995. A new Ordovician arthropod, Soomaspis, and the Agnostid problem. Paleontology, Vol. 37, p. 841-861.

Fritz, W.H., 1972. Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada, Bulletin 212, 89 pp.

Fritz, W.H. 1973. Medial Lower Cambrian trilobites from the Mackenzie Mountains Northwestern Canada. Geological Survey of Canada, Paper 73-24, 43 pp.

Fritz, W.H. 1976. Ten stratigraphic sections from the Lower Cambrian Sekwi Formation, Mackenzie Mountains, northwestern Canada. Geological Survey of Canada, Open File 346, 96 pp.

Fritz, W.H. 1991. Lower Cambrian trilobites from the Illtyd Formation, Wernecke Mountains, Yukon Territory. Geological Survey of Canada, Bulletin 409, 77 pp. https://doi.org/10.4095/132429

Fritz, W.H. 1992. Walcott's Lower Cambrian olenellid trilobite collection 61k, Mount Robson area, Canadian Rocky Mountains. Geological Survey of Canada, Bulletin 432, 31 pp.

Fritz, W.H., and Yochelson, E.L. 1987. The status of *Salterella* as a Lower Cambrian index fossil. Canadian Journal of Earth Sciences, **25**:403-416.

Goodfellow, W.D. 2007. Base metal metallogeny of the Selwyn basin, Canada. In Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods. Edited by Goodfellow, W.D. Geological Association of Canada Special Publication 5. p. 553-579.

Hall, J. 1859. Trilobites of the shales of the Hudson River Group. Annual Report of the New York Cabinet for Natural History, 12: 59-62.

Harrington, H.J. 1956. Olenellidae with advanced genal spines. Journal of Paleontology, Vol. 30, 56-61.

Hollingsworth, J.S. 2005. A trilobite fauna in a storm bed in the Poleta Formation (Dyeran, Lower Cambrian), western Nevada, U.S.A. Geosciences Journal, **9**:129-143.

Hollingsworth, J.S. 2006. Holmiidae (Trilobita: Olenellina) of the Montezuman Stage (Early Cambrian) in Western Nevada. Journal of Paleontology, Vol. 80, 309-332.

Hollingsworth, J.S. 2011. Litostratigraphy and biostratigraphy of Cambrian Stage 3 in western Nevada and eastern California. *In* Cambrian stratigraphy and paleontology of northern Arizona and southern Nevada. The 16th field conference of the Cambrian Stage subdivision working group. Edited by Hollingsworth, J.S., Sundberg, F.A., and Foster, J.R. Museum of northern Arizona, Bulletin no. 67, 26-42.

Howell, B.F., Bridge, J., Deiss, C.F., Edwards, I., Lochman, C., Raasch, G.O., and Resser, C.E. 1944. Correlation of the Cambrian formations of North America.

Hupé, P. 1952. Contribution a l'étude du Cambrien inférieur et du Précambrien III de l'Anti-Atlas marocain. Notes et Mémoirs Service de Géologie Marocain, Vol. 103, 402 pp.

Kobayashi, T. 1935. The Cambro-Ordovician formations and faunas of South Chosen. Paleontology, Pt. III. Cambrian faunas of South Chosen with special study on the Cambrian trilobite genera and families, Vol. 4, 49-344.

Kobayashi, T. 1939. On the Agnostids (part 1). Journal of the Faculty of Science, Imperial University of Tokyo, Section 2, Geology, Mineralogy, Geography, Seismology. Vol. 5, 69-198.

Laibl, L., Maletz, J., and Olschewski, P. 2021. Post-embryonic development of *Fritzolenellus* suggests the ancestral morphology of the early developmental stages in trilobita. Papers in Palaeontology, **7**:839-859.

Lieberman, B.S. 1998. Cladistic analysis of the Early Cambrian Olenelloid trilobites. Journal of Paleontology, Vol. 72, 59-78.

Lieberman, B.S. 1999. Systematic revision of the Olenelloidea (Trilobita, Cambrian). Peabody Museum of Natural History, Bulletin 45, 145 pp.

Lieberman, B.S. 2001. Phylogenetic analysis of the Olenellina Walcott, 1890 (Trilobita, Canbrian). Journal of Paleontology, **75**:96-115.

Lochman, C. 1947. Analysis and revision of eleven Lower Cambrian trilobite genera. Journal of Paleontology, **21**:59-71.

Lochman, C. 1952. Trilobites. *In* Cambrian stratigraphy and paleontology near Caborca, northwestern Sonora, Mexico. *Authored by* Cooper, C.A., Arellano, A.R.V., Johnson, J.H., Okulitch, V.J., Stoyanov, and Lochman, C. Smithsonian Miscellaneous Collections, **119**:60-159.

MacNaughton, R.B., and Narbonne, G.M. 1999. Evolution and ecology of Neoproterozoic-lower Cambrian trace fossils, NW Canada. PALAIOS, **14**:97-115.

Matthew, G.F. 1887. Illustrations of the fauna of the St. John Group. No. IV- Part I. Description of a new species of *Paradoxides* (*Paradoxides regina*). Part II. The smaller trilobites with eyes (Ptychopariidae and Ellipsocephalidae). Proceedings and Transactions of the Royal Society of Canada, 115-166, plates 1-3.

McCausland, Phil J.A., Van der Voo, R., and Hall, C.M. 2007. Circum-Iapetus paleogeography of the Precambrian-Cambrian transition with a new paleomagnetic constraint from Laurentia. Precambrian Research, **156**:125-152.

McMenamin, M.A.S. 2001. Part VII. New trilobites from the Campito Formation of the White-Inyo Mountains. *In* Paleontology Sonora: Lipalian and Cambrian. Meanma Press, South Hadley, Massachusetts, USA, 114-116, figs. 7.1-3.

Mount, J.D. 1976. Early Cambrian faunas from eastern San Bernardino County, California. Bulletin of the Southern California Paleontological Society, **8**:173-182.

Mount, J.D. Characteristics of Early Cambrian faunas from eastern San Bernardino County, California. Bulletin of the Southern California Paleontological Society, Special Publication, **2**:19-29.

Moysiuk, J., and Caron, J. 2019. Burgess Shale fossils shed light on the agnostid problem. Proceedings of the Royal Society B, 286, 9 pp.

Okulitch, V.J. 1951. A Lower Cambrian fossil locality near Addy, Washington. Journal of Paleontology, **25**:405-407.

Palmer, A.R. 1964. An unusual Lower Cambrian fauna from Nevada. United States Geological Survey Professional Paper 483-F, 13 pp.

Palmer, A.R. 1968. Cambrian trilobites of east-central Alaska. United States Geological Survey Professional Paper 559-B, 111 pp.

Palmer, A.R., and Halley, R.B. 1979. Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin. United States Geological Survey Professional Paper 1047, 127 pp.

Palmer, A.R., and Repina, L.N. 1993. Through a glass darkly: taxonomy, phylogeny, and biostratigraphy of the Olenellina. The University of Kansas Paleontological contributions, No. 3, 35 pp.

Palmer, A.R. 1998. Why is intercontinental correlation within the lower Cambrian so difficult? Revista Espanola de Paleontologia, Special issue in memory of Professor Gonzalo Vidal:17-21.

Peach, B.N. 1894. Additions to the fauna of the *Olenellus*-zone of the Northwest highlands. Quarterly Journal of the Geological Society of London **50**:661-675.

Peach, B.N., and Horne, J. 1892. The Olenellus Zone in the north-west highlands of Scotland. Quarterly Journal of the Geological Society of London, **48**:227-242.

Peng, S.C., Babcock, L.E., and Cooper, R.A. The Cambrian Period. *In* Geological Timescale 2012. Edited by Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M. Elsevier, Amsterdam, Netherlands.

Peng, S.C., Babcock, L.E., and Ahlberg, P. 2020. The Cambrian Period. *In* Geological Timescale 2020. Edited by Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M. Elsevier, Amsterdam, Netherlands.

Poulsen, C. 1932. The Lower Cambrian faunas of East Greenland. Meddelelser om Grønland, Vol. 87, 66 pp.

Poulsen, C. 1959. In Arthropoda 1, Part O, Treatise on Invertebrate Paleontology. Edited by Moore, R.C. Geological Society of America and University of Kansas Press, Lawrence, Kansas, 560 pp.

Raymond, P.E. 1913. On the genera of the Eodiscidae. The Ottawa Naturalist, **27**:101-106.

Rasetti, F. 1945. New Upper Cambrian trilobites from the Levis Conglomerate. Journal of Paleontology, **19**:462-478.

Rasetti, F. 1951. Middle Cambrian stratigraphy and faunas of the Canadian Rocky Mountains. Smithsonian Miscellaneous Collections, **116**:277 pp.

Raw, F. 1936. Mesonacidae of Comely in Shropshire, with a discussion of classification within the family. Quarterly Journal of the Geological Society of London, **92**:236-293.

Repina, L.N. 1979. Dependence on morphologic features on habitat conditions in trilobites and evaluation of their significance for the systematics of the superfamily Olenelloidea. Akademiia Nauk USSR, Sibirski Otdelenie, Trudy Instituta Geologii i Geofizikii, **431**:11-30.

Resser, C.E. 1928. Cambrian fossils from the Mohave Desert. Smithsonian Miscellaneous Collections, Vol. 93, 46 pp.

Resser, C.E. 1936. Second contribution to nomenclature of Cambrian trilobites. Smithsonian Miscellaneous Collections, Vol. 95, 29 pp.

Resser, C.E. 1938. Cambrian System (restricted) of the southern Appalachians. Geological Society of America, Special Papers 15, 140 pp.

Resser, C.E., and Howell, B.F. 1938. Lower Cambrian *Olenellus* Zone of the Appalachians. Bulletin of the Geological Society of America, **49**:195-248.

Riccio, J.F. 1952. The Lower Cambrian Olenellidae of the southern Marble Mountains, California. Society of California Academic Science Bulletin, **51**:25-49.

Richter, R. 1932. Crustacea (Paläontologie). In Dittler, R., Joos, G., Korschelt, Linek, G., Oltmanns, F., and Schaum, K. Handwörterbuch der Naturwissenschaften, 2nd ed. Gustav Fisher, Jena, 840-864, pl. 1-64, fig. A.

Salter, J.W. 1864-1883. A monograph of the British trilobites from the Cambrian, Silurian, and Devonian formations. Palaeontographical Society, London, Monograph, 244 pp., 30 pl, compendia, 1864, errata, 1865, addenda et compendia, 1866.

Saltzman, M.R., and Thomas, E. 2012. Carbon Isotope Stratigraphy. *In* Geological Timescale 2012. *Edited by* Gradstein, F.M., Ogg, J.G., Schmitz, M., and Ogg, G. Elsevier, Amsterdam, Netherlands.

Scott, R.W., Turner, E.C., MacNaughton, R.B., and Fallas, K.M. 2022. Biostratigraphic evidence for incremental tectonic development of early Cambrian deep-water environments in the Misty Creek embayment (Selwyn basin, Northwest Territories, Canada). Canadian Journal of Earth Sciences, **59**:216-231.

Sommers, M.J., Gingras, M.K., MacNaughton, R.B., Fallas, K.M., and Morgan, C.A. 2020. Subsurface analysis and correlation of Mount Clark and Lower Mount Cap formations (Cambrian), Northern Interior Plains, Northwest Territories. Bulletin of Canadian Petroleum Geology, **68**: 1–29.

Sundberg, F.A., and McCollum, L.B. 2000. Ptrychopariid trilobites of the lower-middle Cambrian boundary interval, Piche Shale, southeastern Nevada. Journal of Paleontology, **74**:604-630.

Sundberg, F.A., Karlstrom, K.E., Geyer, G., Foster J.R., Hagadorn, J.W., Mohr, M.T., Schmitz, M.D., Dehler, C.M., and Crossey, L.J. 2020. Asynchronous trilobite extinctions at the early to middle Cambrian transition. Geology, **48**:441-445.

Sundberg, F.A., Webster, M., and Geyer, G. 2022. Biostratigraphical significance of a new trilobite fauna from the Harkless Formation (upper Stage 4, Series 2, Cambrian), Nevada, USA. 2022. Lethaia, **55**:1-12.

Sundberg, F.A., and Webster, M. 2022. “Ptychoparioid” trilobites of the Harkless Formation and Mule Spring Limestone (Cambrian Series 2, Stage 4), Clayton Ridge, Nevada. Journal of Paleontology, **96**:886-920.

Sundberg, F.A. 2014. Phylogenetic analysis of the spiny oryctocephalids (trilobita, corynexochida?, oryctocephalidae), Cambrian. Journal of Paleontology, **88**:556-587.

Swinnerton, H.H. 1915. Suggestions for a revised classification of trilobites. Geological Magazine, **2**:487-496, 538-545.

Walch, J.E.I. 1771. Die Naturgeschichte der Versteinerungen, zur Erläuterung der Knorrischen Sammlung von Merkwürdigkeiten der Natur: Dritter Theil. Nuremberg, Paul Jonathan Felstecker, 235 pp.

Walcott, C.D. 1890. The fauna of the Lower Cambrian of *Olenellus* Zone. *In* 10th Annual Report of the Director, 1888-1889, United States Geological Survey, p. 509-774.

Walcott, C.D. 1910. Cambrian geology and paleontology No. 6- *Olenellus* and other genera of the Mesonacidae. Smithsonian Miscellaneous Collections, **53**:233-423.

Walcott, C.D. 1913. Cambrian Geology and Paleontology II No. 11- new Lower Cambrian subfauna. Smithsonian Miscellaneous Collections, **57**:309-326.

Walcott, C.D. 1916. Evidences of primitive life. Smithsonian Institution Annual Report (1915), 235-255.

Walcott, C.D. 1916. Cambrian geology and paleontology III, no. 5, Cambrian trilobites. Smithsonian Miscellaneous Collections **64**:303-456.

Walcott, C.D. 1917. Fauna of the Mount Whyte Formation. Smithsonian Miscellaneous Collections, Vol. 67.

Wanner, A. 1901. A new species of Olenellus from the Lower Cambrian of York County, Pennsylvania. Proceedings of the Washington Academy of Sciences **3**:267-272.

Webster, M., and Bohach, L.L. 2014. Systematic revision of the trilobite genera *Laudonia* and *Lochmanolenellus* (Olenelloidea) from the lower Dyeran (Cambrian Series 2) of western Laurentia. Zootaxa, Vol. 3824, 63 pp.

Whittington, H.B. 1989. Olenelloid trilobites: type species, functional morphology, and higher classification. Philosophical Transactions of the Royal Society of London, **324**:111-147.

Yuan, J.Y., Zhao, Y.L., Li, Y., and Huang, Y.H. 2002. Trilobite fauna of the Kaili Formation (uppermost lower Cambrian-lower middle Cambrian) from southeastern Guizhou, South China. Shanghai Science and Technology. 422 pp.

Zhang, W., Huanling, L., Hingji, W., Jinliang, Y. 1980. Cambrian stratigraphy and trilobite fauna from the Zhongtiao Mountains, southern Shangxi. Nanjing Institute of Geology and Palaeontology, Memoir 16, 39-110, pl. 1-11.

Zhang, Q.Z., and Zhou, Z.M. 1985? Early Cambrian trilobite fauna of the Kunshan, Jiangsu. Acta Palaeontologica Sinica. New Series. 497 pp.

2.10 FIGURES

Figure 2-1. Location of sections 2 and 10 in NTS 105P (Sekwi mountain area). Section 2 is located ~193 km northwest section 10.

Figure 2-2. The configuration of major basins and syndepositional topographic features that were present on the (present-day) western margin of Laurentia during the Cambrian. The study area is southeast of the Misty Creek embayment in NTS 105P. An arch complex and "platforms" separate the Selwyn basin from the intracratonic basin. Adapted and compiled from Cecile et al. (1997), Mossop et al. (2004), Goodfellow (2007), Hannigan et al. (2011), and Bouchard and Turner (2017).

Figure 2-3. (A) Upper lower Cambrian and lower middle Cambrian Stages, biozones, and stable carbon isotope excursions. *P-P= Plagiura-Poliella* Zone, *A=Albertella* Zone, *G=Glossopleura* Zone, and *E=Ehmaniella* Zone sourced from Geyer 2019 and Peng et al. 2020 . (B) Dilliard et al. (2007) section 4 with its stable carbon isotope ($\delta^{13}C_{vpdb}$) curve, traditional, genus-based biozones, and sequence stratigraphic scheme.

Figure 2-4. Table of historical biostratigraphic schemes used in North America. Lower boundaries of Walcott's 1890 and 1910 biostratigraphic schemes are given tentatively, as they are not considered well defined. Lower boundaries of Resser and Howell (1938) and Howell et al. (1944) biostratigraphic schemes are indicated by question marks, because they are also not well defined. The *Bonnia-Olenellus* Zone of Deiss (1940)/Rassetti's (1951) and the Fritz (1972) *Fallotaspis* Zone also technically lack defined lower boundaries, because at the time of their inception, no lower trilobite assemblages were documented. Farthest right-hand column is from Hollingsworth (2011) and Webster (2011).

Figure 2-5a. (A) $\delta^{13}C_{vpdb}$ and $\delta^{18}O_{vpdb}$ raw data from section 2. (B) Unsmoothed and smoothed $\delta^{13}C$curves for section 2, based on the data in (A). (C) Chemostratigraphic curve of section 2 compared to Dilliard et al. (2007) section 4 curve and global $\delta^{13}C$ excursions. (D) $\delta^{13}C_{vpdb}$ and $\delta^{18}O_{vpdb}$ raw data from section 2.

Figure 2-5b. (A) Unsmoothed and smoothed $\delta^{13}C$ curves for section 10, based on the data in (B). (C) Chemostratigraphic curve of section 10 compared to Dilliard et al. (2007) section 4 curve and global $\delta^{13}C$ excursions.

Figure 2-6. Biostratigraphy of section 2 with, occurrences of trilobite taxa (red dots), species-based biozones (Hollingsworth 2011), the *Elliptocephala* Zone and its subzones, and indeterminate interval (this study). Traditional (Fritz 1972), genus-based "superzones" are given in the right column. Zonal boundaries are given in solid lines. Subzonal boundaries are given in dashed lines.

Figure 2-7. Biostratigraphy of section 10 with ranges of trilobite taxa (black and red bars), the *Elliptocephala* Zone and its subzones, upper "*Bonnia-Olenellus*" Zone and undefined interval (between Fritz's upper boundary of the "*Nevadella*" Zone and the lower boundary of the *Elliptocephala* Zone). Solid lines indicate zonal boundaries, and dashed lines indicate subzonal boundaries. Traditional, genus-based "superzones" are given in the right column. Red boxes and binomens indicate taxa and their stratigraphic ranges from Fritz (1972) section 10 that were not analyzed in this study because the specimens were not accessible.

Figure 2-8. Chemostratigraphic correlation of sections 2 and 10 with $\delta^{13}C_{vpdb}$ curve for Dilliard et al. (2007) section 4. A, B, and C represent isotope excursions documented in this study which are interpreted to correspond to the MICE, AECE, and ROECE, respectively. The MICE is partially expressed in section 10 and Dilliard et al. (2007) section 4. The interval in which the MICE ought to occur in section 2 was not sampled. The AECE is partially expressed in sections 2 and 10, and fully expressed in Dilliard et al. (2007) section 4. Section 10 and Dilliard et al. (2007) section 4 probably both exhibit the onset of the ROECE immediately below Sekwi-Hess River formational contact, and at section 2 negative values above and below the contact probably also represent the ROECE.

Figure 2-9. Biostratigraphically important localities in North America that are discussed in this paper. (1) The Sekwi Mountain area where the Sekwi Formation outcrops, and this study's data was collected from. (2) The Richardson trough where the Illtyd Formation outcrops. (3) The Mount Robson area, where Fritz's (1992) material was sampled. (4) Northwestern Vermont, the site of the Parker Quarry and Powerline section sampled by Webster and Landing (2016). (5) Esmeralda County, the site of numerous biostratigraphically important localities including those sampled by Palmer (1964), Hollingsworth (2011), and Webster (2011). (6) Caborca, Mexico, the site of Lochman's (1952) collection.

Figure 2-10. Simplified illustration of Fritz's (1991) Illtyd Formation (Richardson Trough, Yukon Territory) section with trilobite taxa and stratigraphic range of the *Elliptocephala* Zone. Taxa originally described by Fritz (1972) that should probably be reassigned but have not been considered in this study (e.g, most occurrences of *Olenellus*) are given informally in quotation marks. Others are given with their updated taxonomy [(e.g., *Bolbolenellus sphaeurulosus* (Fritz 1991)]. Additionally, *Bolbolenellus sphaerulosus* and *Bolbolenellus bufrontis* (Fritz 1991) are synonymized, as per Lieberman (1999).

Figure 2-11. Simplified illustration of Fritz's (1992) Mural Formation (=Tah Formation type section of earlier usage; Mount Robson area, British Columbia). Levels of occurrence of taxa are given as horizontal lines protruding from vertical bars. Two species-based biozones are diagnosable (*Nevadia addyensis* and *Nevadella eucharis* zones) as well as the lower subzone of the *Elliptocephala* Zone, the *Lochmanolenellus-Fritzolenellus* Subzone.

Figure 2-12. Carbon isotope chemostratigraphy and biostratigraphy of sections 2 and 10. The AECE consistently occurs close to the base of the *Elliptocephala* Zone.

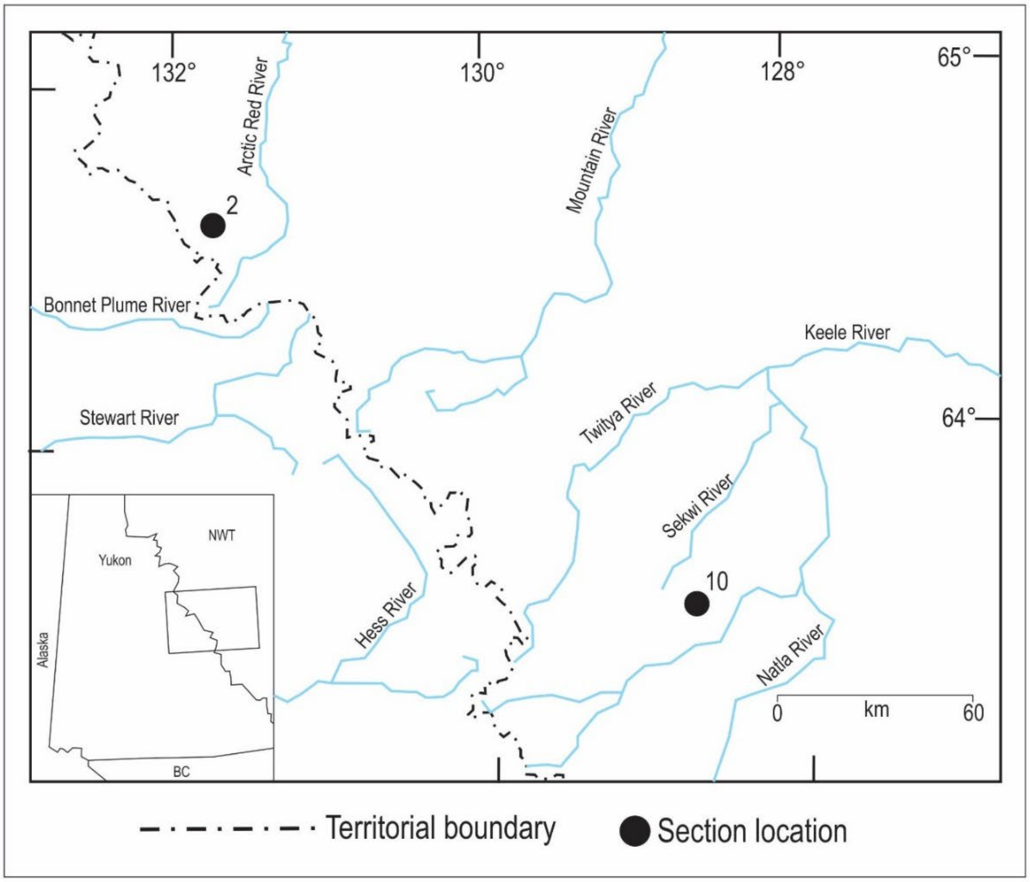

132°
130°
128°
65°
64°
Arctic Red River
Mountain River
2
Bonnet Plume River
Keele River
Stewart River
Twitya River
Sekwi River
10
Hess River
Natla River
0
km
60
NWT
Yukon
Alaska
BC
Territorial boundary
Section location

Figure 2-1

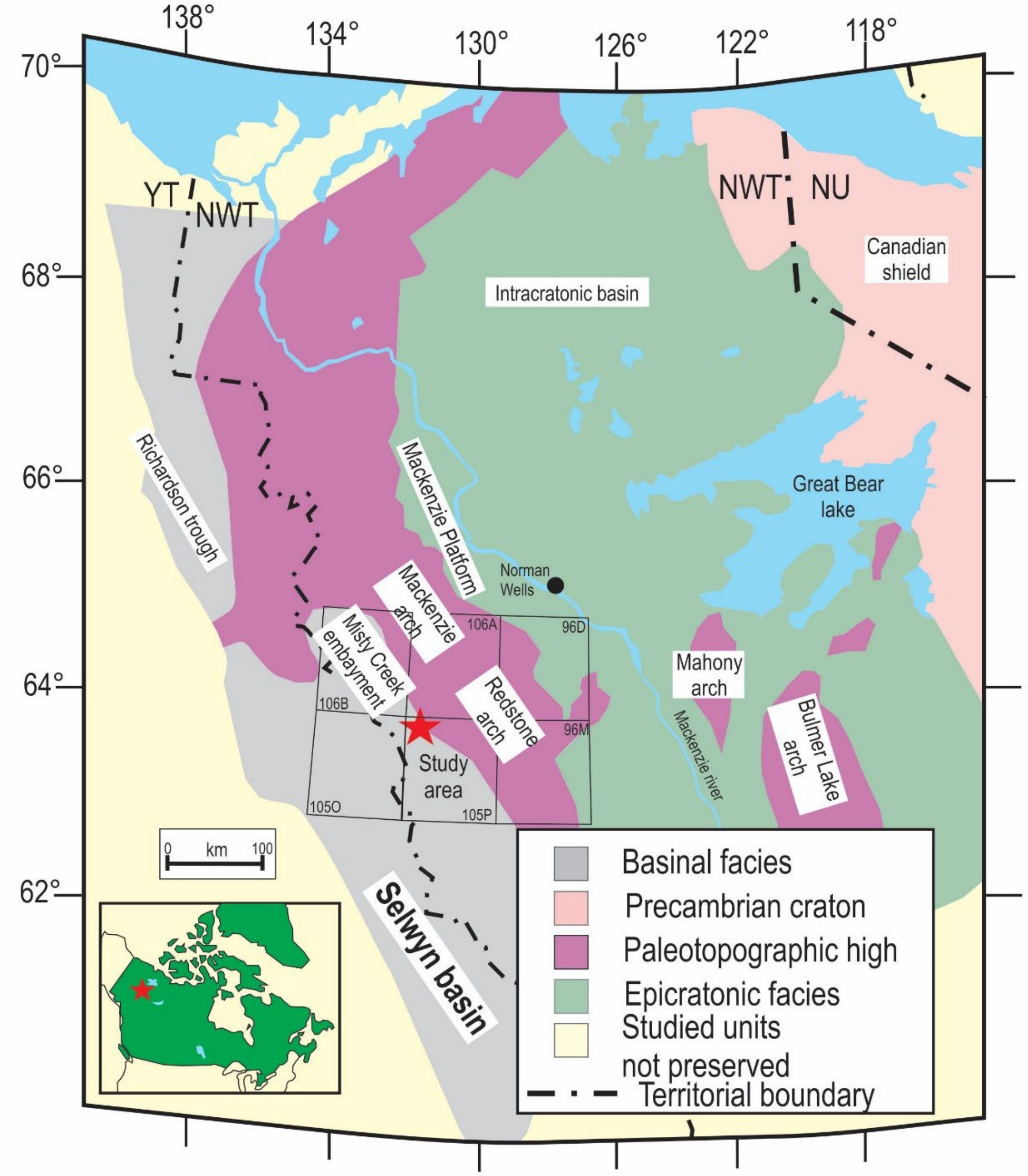
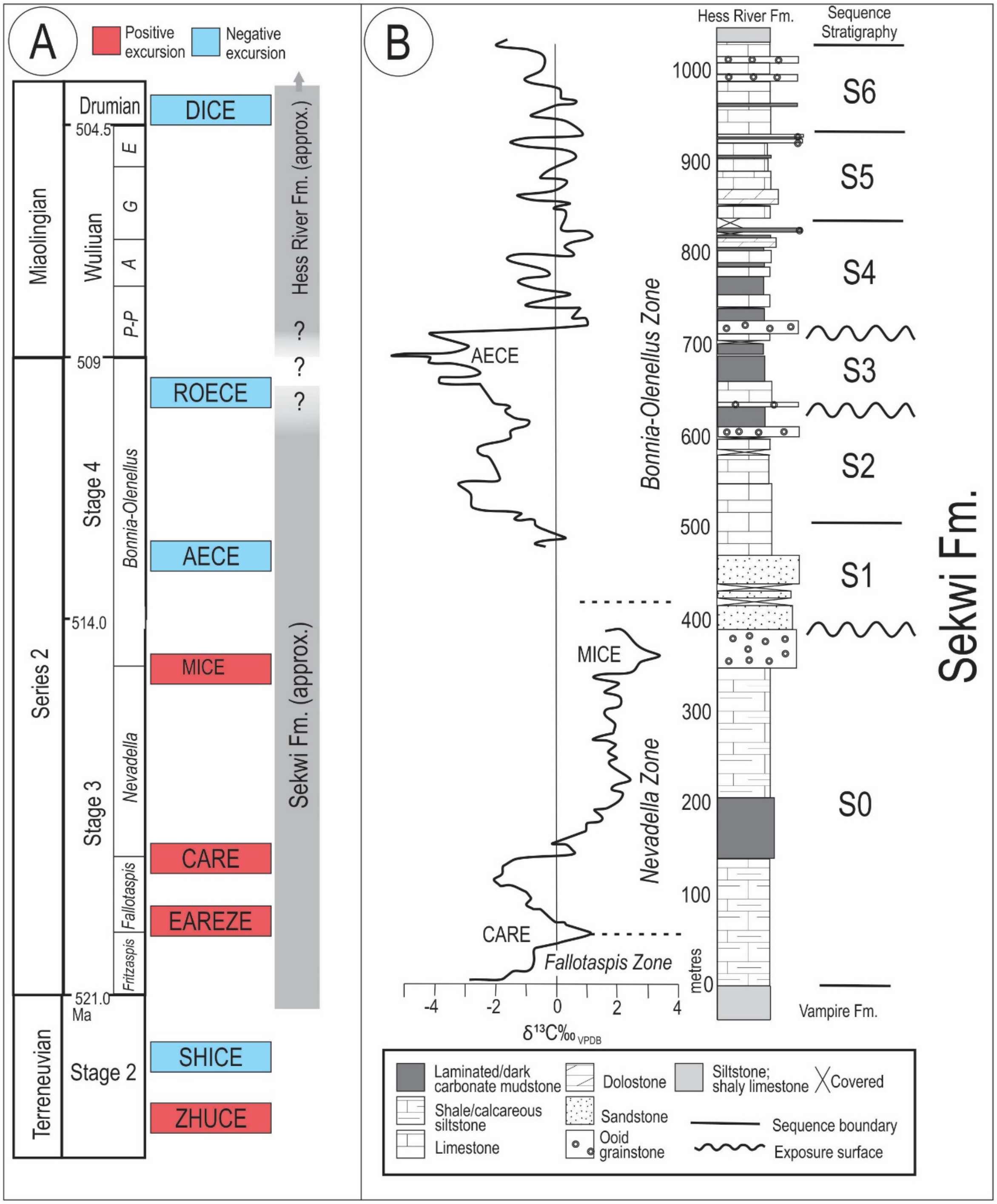

138°
134°
130°
126°
122°
118°
70°
68°
66°
64°
62°
YT
NWT
NWT
NU
Canadian shield
Intracratonic basin
Richardson trough
Mackenzie Platform
Great Bear lake
Norman Wells
Mackenzie arch
106A
96D
Misty Creek embayment
Mahony arch
Redstone arch
106B
96M
Study area
Bulmer Lake arch
Mackenzie river
105O
105P
0 km 100
Selwyn basin
Basinal facies
Precambrian craton
Paleotopographic high
Epicratonic facies
Studied units not preserved
Territorial boundary

Figure 2-2



A
Positive excursion
Negative excursion
Terreneuvian
Series 2
Miaolingian
Stage 2
Stage 3
Stage 4
Wuliuan
Drumian
521.0 Ma
514.0
509
504.5
Fritzaspis
Fallotaspis
Nevadella
Bonnia-Olenellus
P-P
A
G
E
ZHUCE
SHICE
EAREZE
CARE
MICE
AECE
ROECE
DICE
Sekwi Fm. (approx.)
Hess River Fm. (approx.)
?
?
?
B
Hess River Fm.
Sequence Stratigraphy
AECE
MICE
CARE
Bonnia-Olenellus Zone
Nevadella Zone
Fallotaspis Zone
-4
-2
0
2
4
δ13C‰ VPDB
metres
0
100
200
300
400
500
600
700
800
900
1000
S0
S1
S2
S3
S4
S5
S6
Sekwi Fm.
Vampire Fm.
Laminated/dark carbonate mudstone
Shale/calcareous siltstone
Limestone
Dolostone
Sandstone
Ooid grainstone
Siltstone; shaly limestone
Covered
Sequence boundary
Exposure surface

Figure 2-3

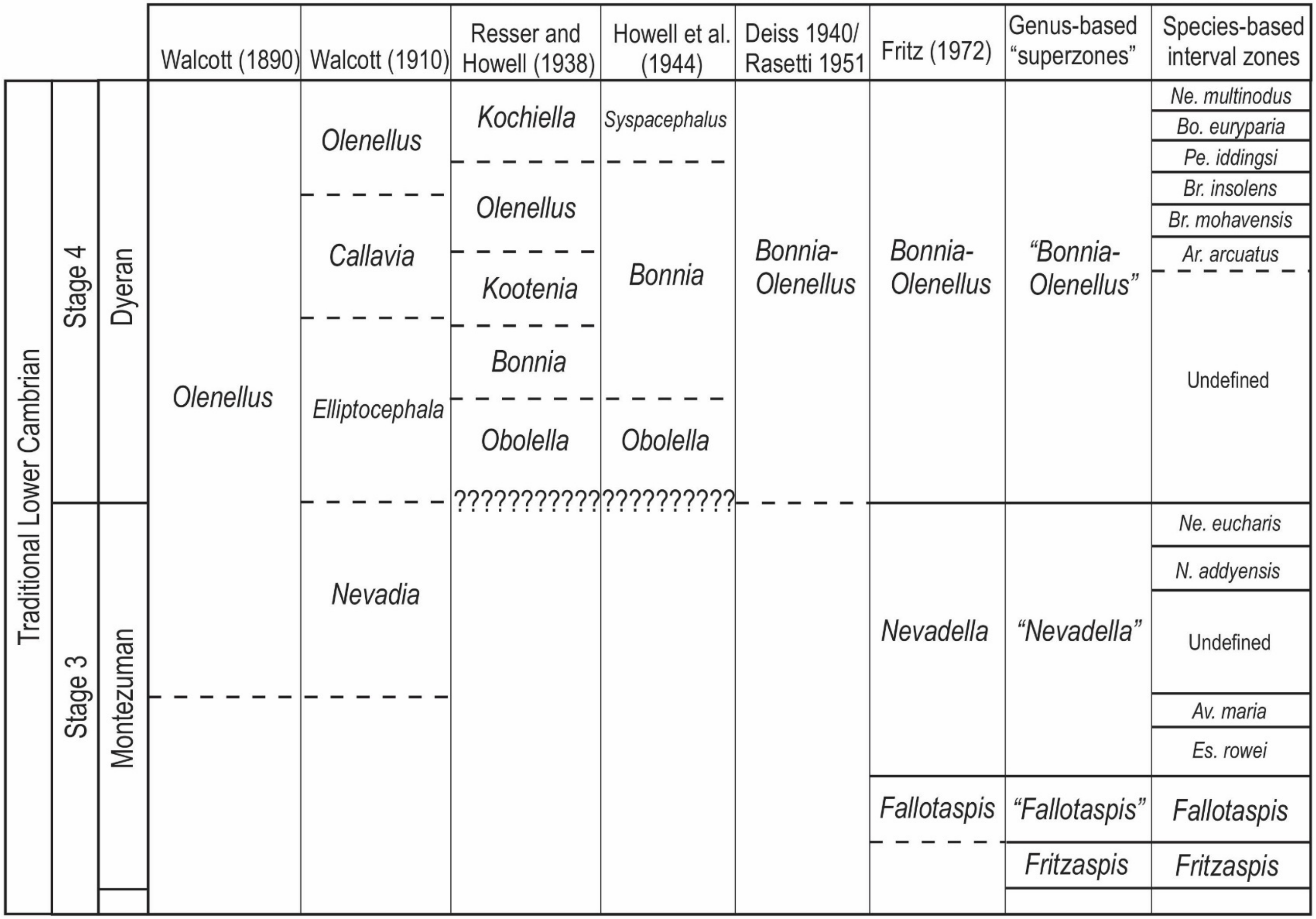

Walcott (1890)
Walcott (1910)
Resser and Howell (1938)
Howell et al. (1944)
Deiss 1940/ Rasetti 1951
Fritz (1972)
Genus-based "superzones"
Species-based interval zones
Traditional Lower Cambrian
Stage 4
Stage 3
Dyeran
Montezuman
Olenellus
Olenellus
Callavia
Elliptocephala
Nevadia
Kochiella
Olenellus
Kootenia
Bonnia
Obolella
Syspacephalus
Bonnia
Obolella
??????????????????????
Bonnia-Olenellus
Bonnia-Olenellus
Nevadella
Fallotaspis
"Bonnia-Olenellus"
"Nevadella"
"Fallotaspis"
Fritzaspis
Ne. multinodus
Bo. euryparia
Pe. iddingsi
Br. insolens
Br. mohavensis
Ar. arcuatus
Undefined
Ne. eucharis
N. addyensis
Undefined
Av. maria
Es. rowei
Fallotaspis
Fritzaspis

Figure 2-4

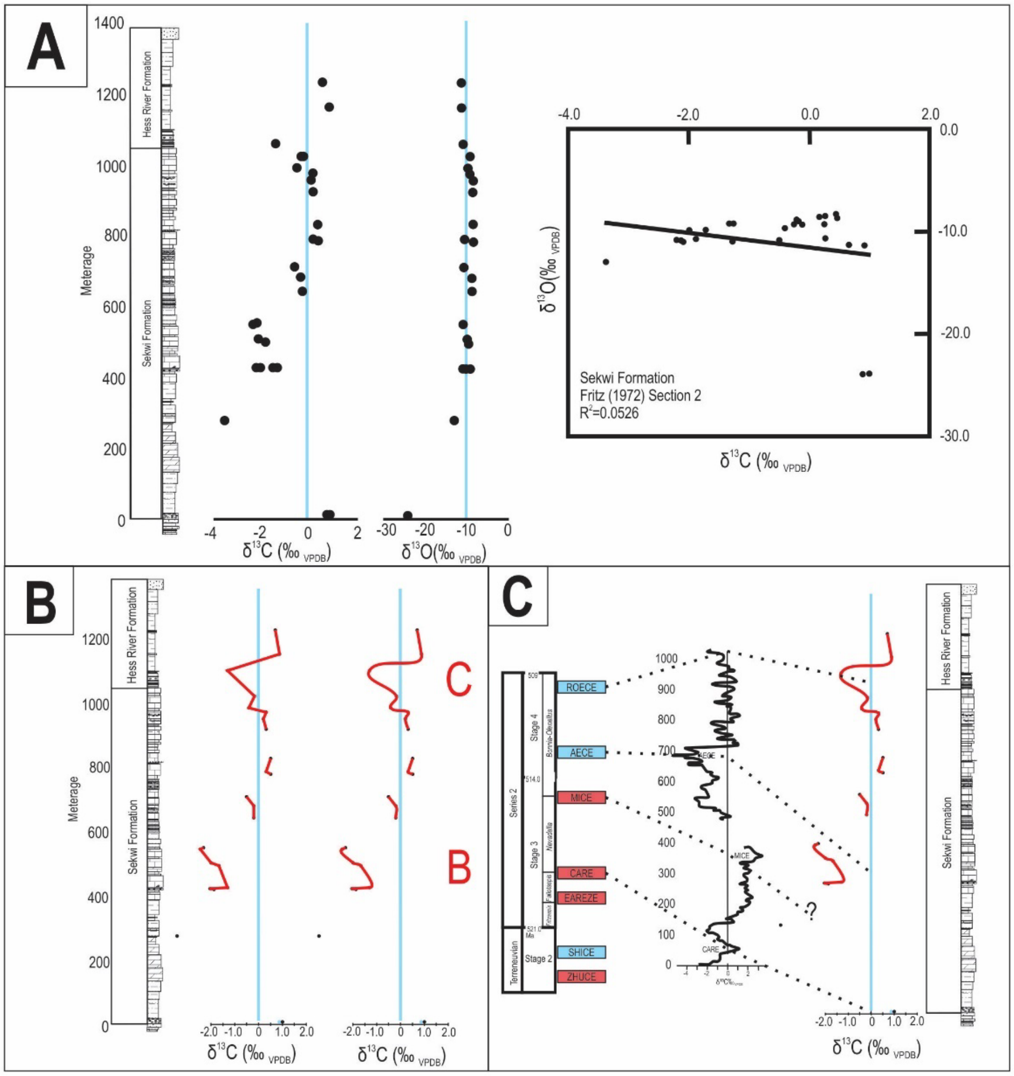

A
1400
1200
1000
800
600
400
200
0
Meterage
Hess River Formation
Sekwi Formation
-4
-2
0
2
δ13C (‰ VPDB)
-30
-20
-10
0
δ13O(‰ VPDB)
-4.0
-2.0
0.0
2.0
0.0
-10.0
-20.0
-30.0
δ13O(‰ VPDB)
δ13C (‰ VPDB)
Sekwi Formation
Fritz (1972) Section 2
R2=0.0526
B
1200
1000
800
600
400
200
0
Meterage
Hess River Formation
Sekwi Formation
C
B
-2.0 -1.0 0 1.0 2.0
δ13C (‰ VPDB)
-2.0 -1.0 0 1.0 2.0
δ13C (‰ VPDB)
C
Terreneuvian
Series 2
Stage 2
Stage 3
Stage 4
509
514.0
521.0 Ma
Bonnia-Olenellus
Nevadella
Fallotaspis
Tetraspis
ROECE
AECE
MICE
CARE
EAREZE
SHICE
ZHUCE
1000
900
800
700
600
500
400
300
200
100
0
AECE
MICE
CARE
-4
-2
0
2
δ13C‰VPDB
?
Hess River Formation
Sekwi Formation
-2.0 -1.0 0 1.0 2.0
δ13C (‰ VPDB)

Figure 2-5a

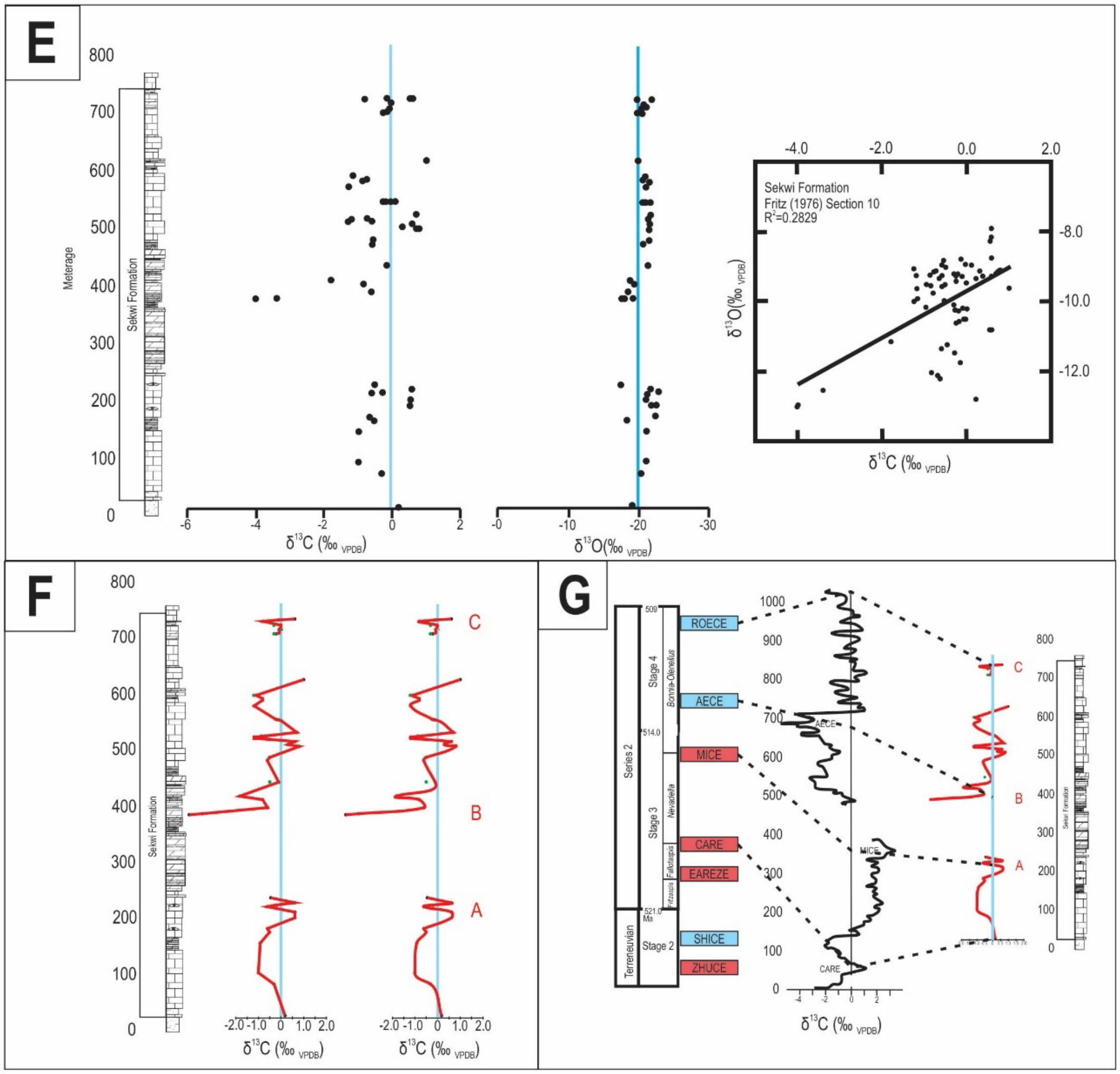

E
800
700
600
500
400
300
200
100
0
Meterage
Sekwi Formation
-6 -4 -2 0 2
δ13C (‰ VPDB)
0 -10 -20 -30
δ13O(‰ VPDB)
-4.0 -2.0 0.0 2.0
Sekwi Formation
Fritz (1976) Section 10
R2=0.2829
-8.0
-10.0
-12.0
δ13O(‰ VPDB)
δ13C (‰ VPDB)
F
Sekwi Formation
C
B
A
-2.0 -1.0 0 1.0 2.0
δ13C (‰ VPDB)
-2.0 -1.0 0 1.0 2.0
δ13C (‰ VPDB)
G
Series 2
Terreneuvian
Stage 4
Stage 3
Stage 2
509
514.0
521.0 Ma
Bonnia-Olenellus
Nevadella
Fallotaspis
Fritzaspis
ROECE
AECE
MICE
CARE
EAREZE
SHICE
ZHUCE
1000
900
800
700
600
500
400
300
200
100
0
AECE
MICE
CARE
-4 -2 0 2
δ13C (‰ VPDB)
C
B
A
Sekwi Formation

Figure 2-5b

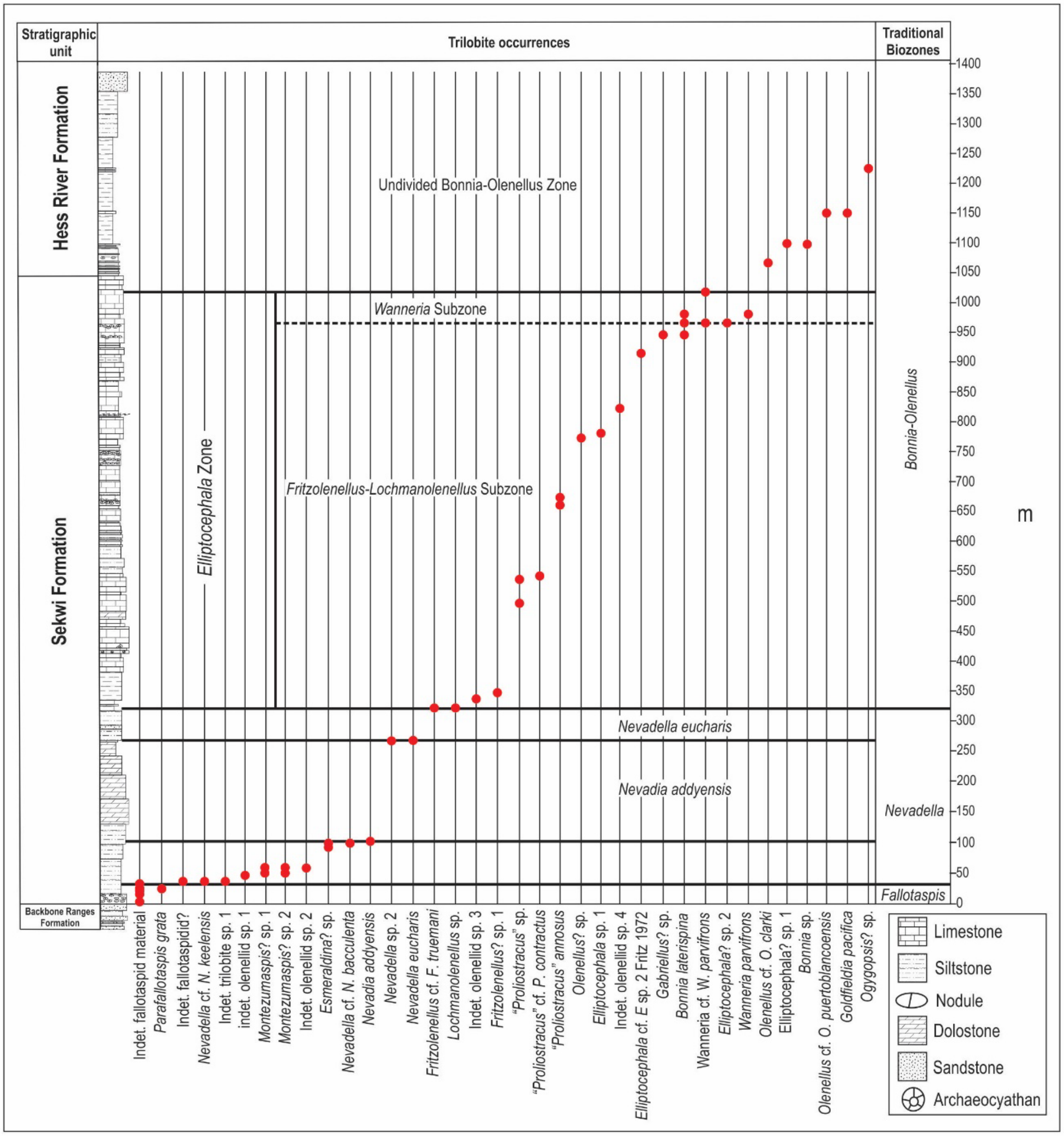

Stratigraphic unit
Trilobite occurrences
Traditional Biozones
Hess River Formation
Sekwi Formation
Backbone Ranges Formation
Undivided Bonnia-Olenellus Zone
Wanneria Subzone
Elliptocephala Zone
Fritzolenellus-Lochmanolenellus Subzone
Nevadella eucharis
Nevadia addyensis
Bonnia-Olenellus
Nevadella
Fallotaspis
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
m
Indet. fallotaspid material
Parafallotaspis grata
Indet. fallotaspidid?
Nevadella cf. N. keelensis
Indet. trilobite sp. 1
indet. olenellid sp. 1
Montezumaspis? sp. 1
Montezumaspis? sp. 2
Indet. olenellid sp. 2
Esmeraldina? sp.
Nevadella cf. N. bacculenta
Nevadia addyensis
Nevadella sp. 2
Nevadella eucharis
Fritzolenellus cf. F. truemani
Lochmanolenellus sp.
Indet. olenellid sp. 3
Fritzolenellus? sp. 1
"Proliostracus" sp.
"Proliostracus" cf. P. contractus
"Proliostracus" annosus
Olenellus? sp.
Elliptocephala sp. 1
Indet. olenellid sp. 4
Elliptocephala cf. E sp. 2 Fritz 1972
Gabriellus? sp.
Bonnia laterispina
Wanneria cf. W. parvifrons
Elliptocephala? sp. 2
Wanneria parvifrons
Olenellus cf. O. clarki
Elliptocephala? sp. 1
Bonnia sp.
Olenellus cf. O. puertoblancoensis
Goldfieldia pacifica
Ogygopsis? sp.
Limestone
Siltstone
Nodule
Dolostone
Sandstone
Archaeocyathan

Figure 2-6

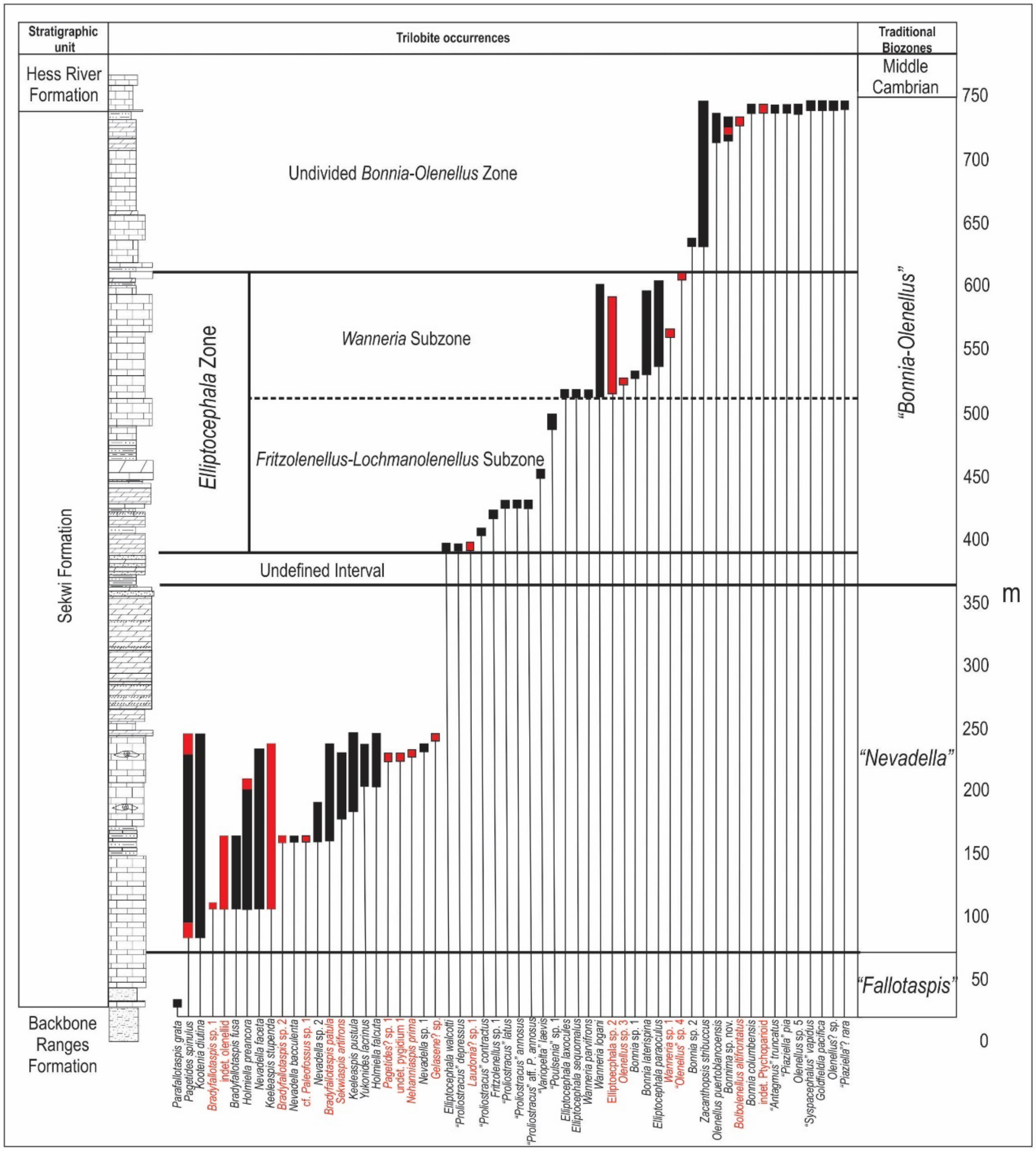
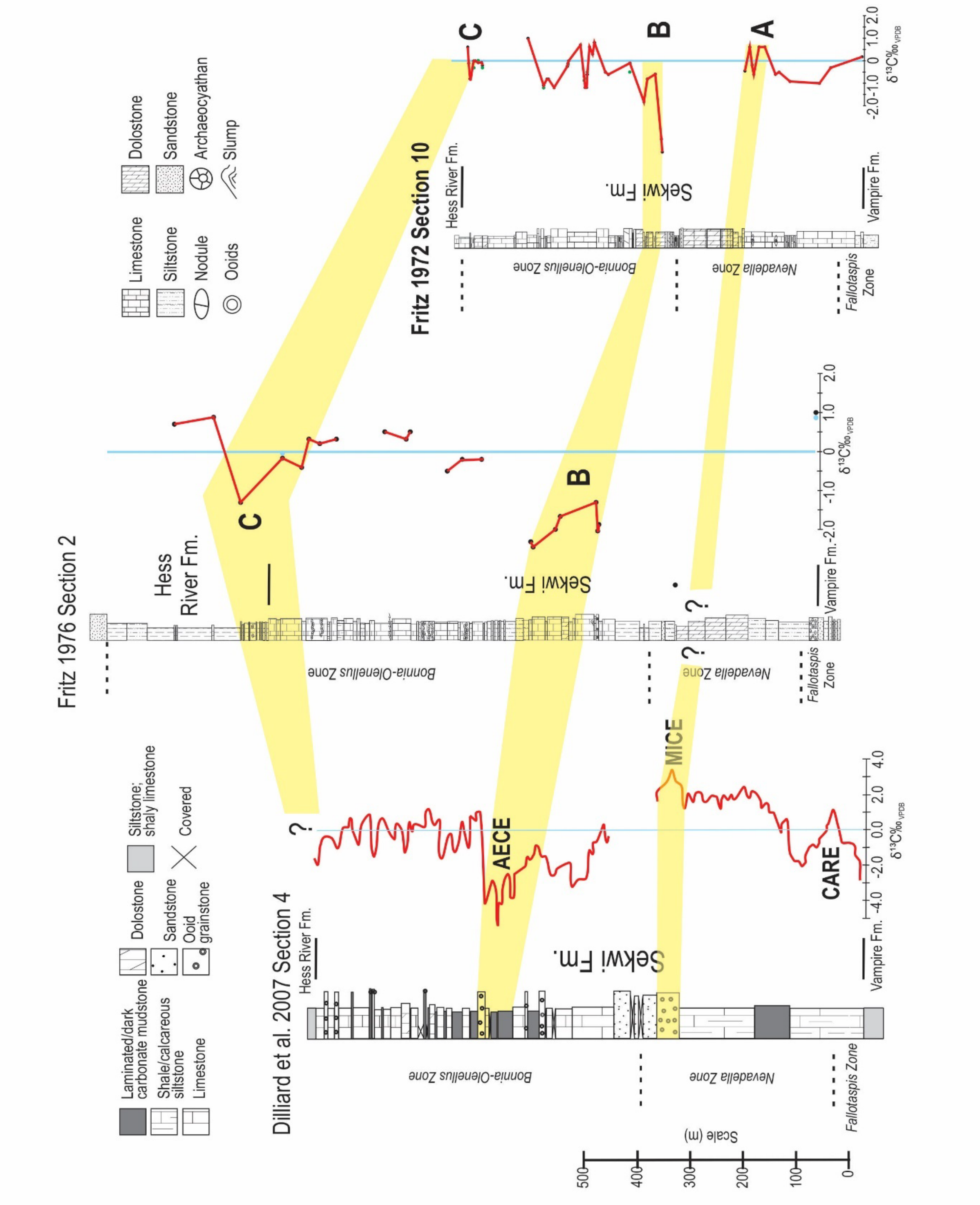

Stratigraphic unit
Trilobite occurrences
Traditional Biozones
Hess River Formation
Sekwi Formation
Backbone Ranges Formation
Middle Cambrian
Undivided Bonnia-Olenellus Zone
Elliptocephala Zone
Wanneria Subzone
Fritzolenellus-Lochmanolenellus Subzone
Undefined Interval
"Bonnia-Olenellus"
"Nevadella"
"Fallotaspis"
m
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Parafallotaspis grata
Pagetides spinulus
Kootenia diutina
Bradyfallotaspis sp. 1
indet. olenellid
Bradyfallotaspis fusa
Holmiella preancora
Nevadella faceta
Keeleaspis stupenda
Bradyfallotaspis sp. 2
Nevadella bacculenta
cf. Paleofossus sp. 1
Nevadella sp. 2
Bradyfallotaspis patula
Sekwiaspis artifrons
Keeleaspis pustula
Yukonides lacrinus
Holmiella falcuta
Pagetides? sp. 1
undet. pygidium 1
Nehanniaspis prima
Nevadella sp. 1
Gelasene? sp.
Elliptocephala walcotti
"Proliostracus" depressus
Laudonia? sp. 1
"Proliostracus" contractus
Fritzolenellus sp. 1
"Proliostracus" latus
"Proliostracus" annosus
"Proliostracus" aff. P. annosus
"Variopelta" laevis
"Poulsenia" sp. 1
Elliptocephala laxocules
Elliptocephala sequomalus
Wanneria parvifrons
Wanneria logani
Elliptoecphala sp. 2
Olenellus sp. 3
Bonnia sp. 1
Bonnia laterispina
Elliptocephala paraoculus
Wanneria sp. 1
"Olenellus" sp. 4
Bonnia sp. 2
Zacanthopsis stribuccus
Olenellus puertoblancoensis
Bonnima sp. nov.
Bolbolenellus altifrontatus
Bonnia columbensis
indet. Ptychoparioid
"Antagmus" truncatus
"Piaziella" pia
Olenellus sp. 5
"Syspacephalus" vapidus
Goldfieldia pacifica
Olenellus? sp.
"Piaziella"? rara

Figure 2-7



Dilliard et al. 2007 Section 4
Fritz 1976 Section 2
Fritz 1972 Section 10
Laminated/dark carbonate mudstone
Shale/calcareous siltstone
Limestone
Dolostone
Sandstone
Ooid grainstone
Siltstone; shaly limestone
Covered
Limestone
Siltstone
Nodule
Ooids
Dolostone
Sandstone
Archaeocyathan
Slump
Scale (m)
0
100
200
300
400
500
Fallotaspis Zone
Nevadella Zone
Bonnia-Olenellus Zone
Hess River Fm.
Sekwi Fm.
Vampire Fm.
AECE
MICE
CARE
A
B
C
?
-4.0
-2.0
0.0
2.0
4.0
-2.0
-1.0
0
1.0
2.0
$\delta^{13}C‰_{VPDB}$

Figure 2-8

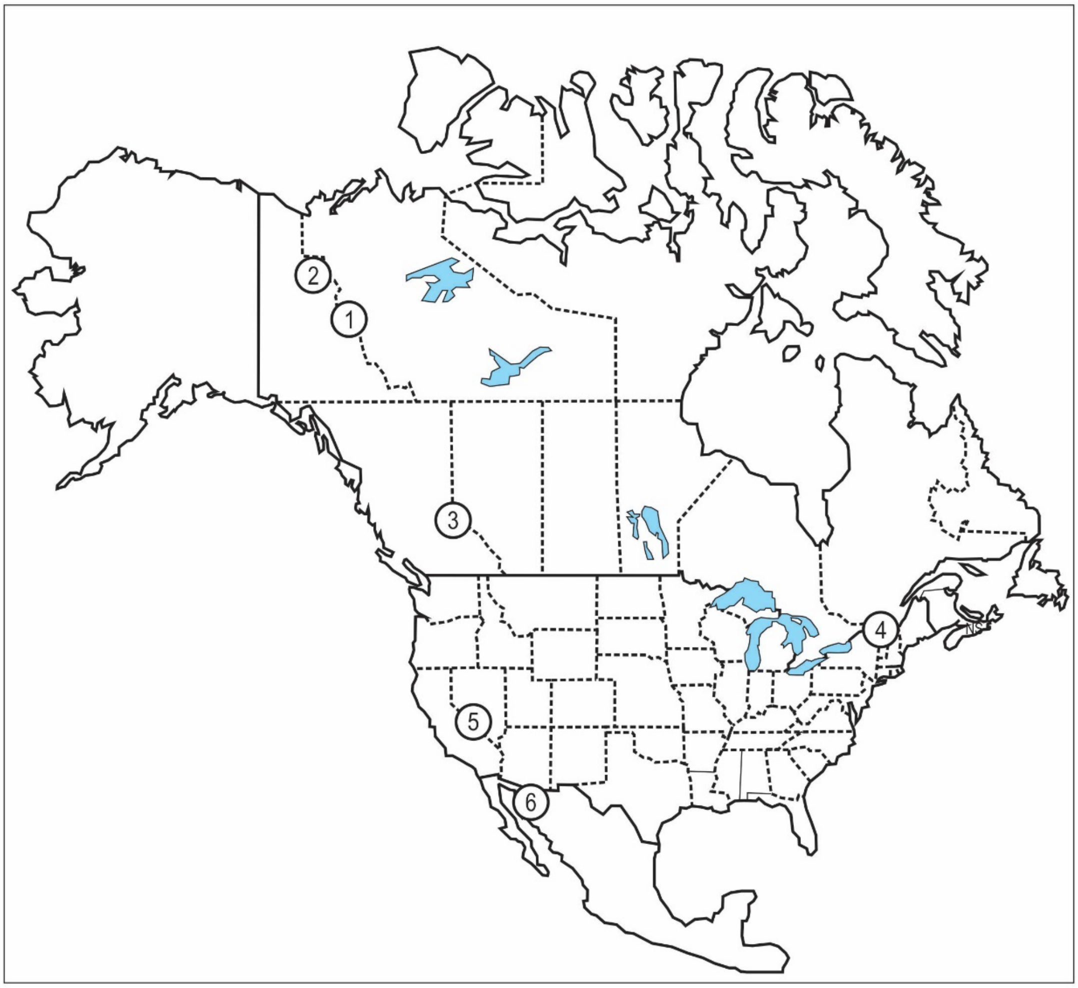


Figure 2-9

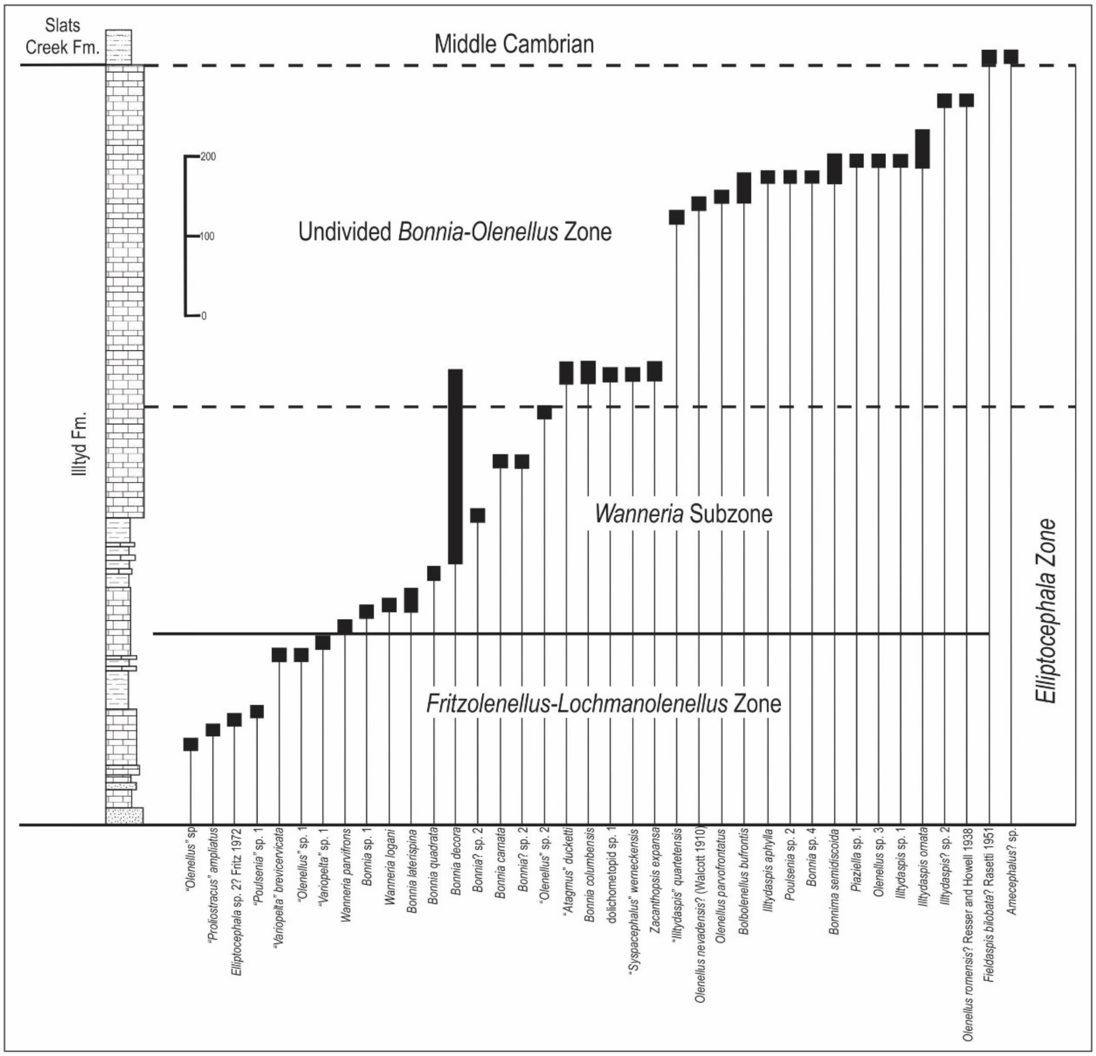

Slats Creek Fm.
Middle Cambrian
200
100
0
Undivided Bonnia-Olenellus Zone
Illtyd Fm.
Wanneria Subzone
Fritzolenellus-Lochmanolenellus Zone
Elliptocephala Zone
"Olenellus" sp
"Proliostracus" ampliatus
Elliptocephala sp. 2? Fritz 1972
"Poulsenia" sp. 1
"Variopelta" brevicervicata
"Olenellus" sp. 1
"Variopelta" sp. 1
Wanneria parvifrons
Bonnia sp. 1
Wanneria logani
Bonnia laterispina
Bonnia quadrata
Bonnia decora
Bonnia? sp. 2
Bonnia carnata
Bonnia? sp. 2
"Olenellus" sp. 2
"Atagmus" ducketti
Bonnia columbensis
dolichometopid sp. 1
"Syspacephalus" werneckensis
Zacanthopsis expansa
"Illtydaspis" quartetensis
Olenellus nevadensis? (Walcott 1910)
Olenellus parvofrontatus
Bolbolenellus bufrontis
Illtydaspis aphylla
Poulsenia sp. 2
Bonnia sp. 4
Bonnima semidiscoida
Piaziella sp. 1
Olenellus sp. 3
Illtydaspis sp. 1
Illtydaspis ornata
Illtydaspis? sp. 2
Olenellus romensis? Resser and Howell 1938
Fieldaspis bilobata? Rasetti 1951
Amecephalus? sp.

Figure 2-10

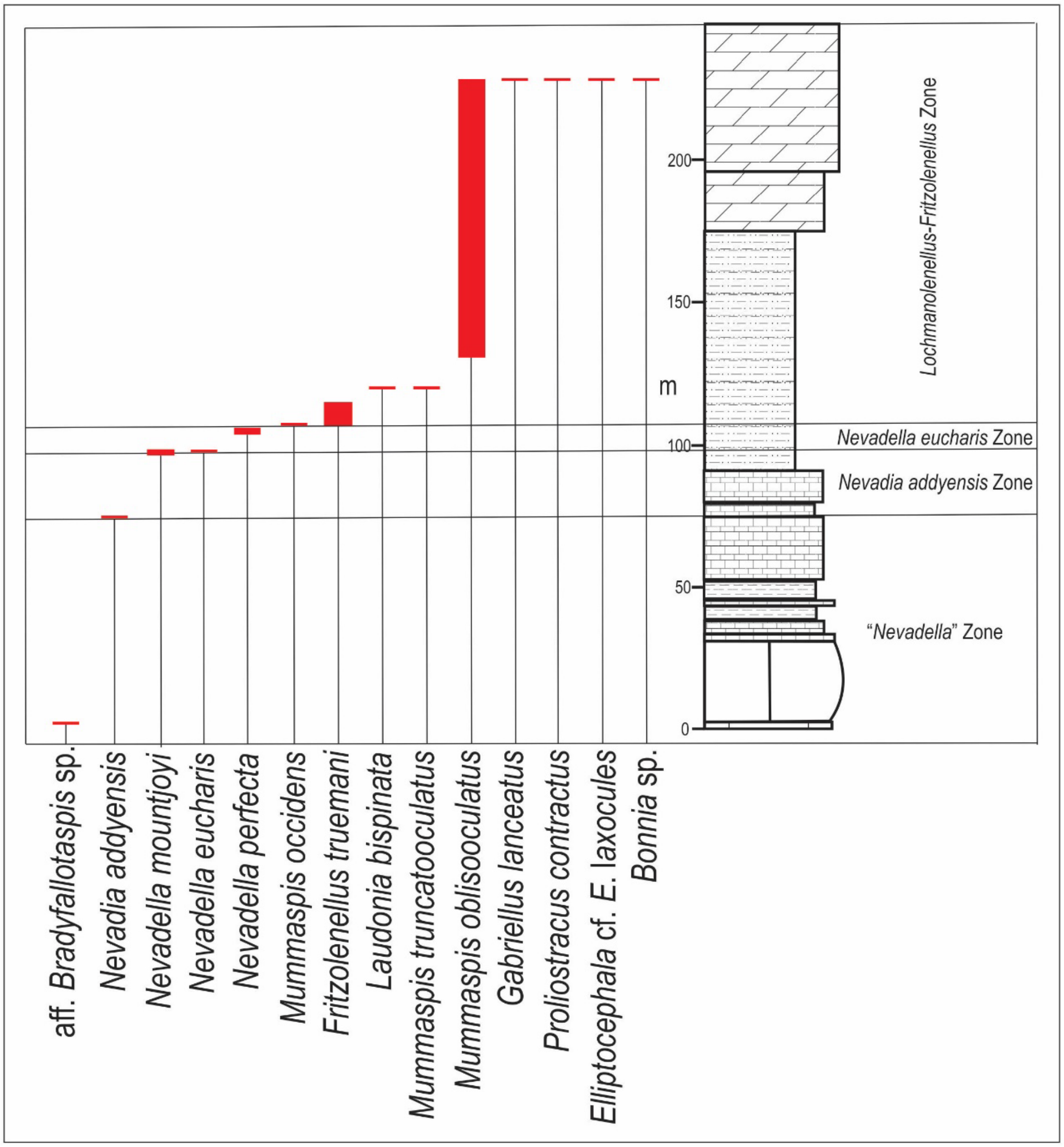

aff. Bradyfallotaspis sp.
Nevadia addyensis
Nevadella mountjoyi
Nevadella eucharis
Nevadella perfecta
Mummaspis occidens
Fritzolenellus truemani
Laudonia bispinata
Mummaspis truncatooculatus
Mummaspis oblisooculatus
Gabriellus lanceatus
Proliostracus contractus
Elliptocephala cf. E. laxocules
Bonnia sp.
0
50
100
150
200
m
Lochmanolenellus-Fritzolenellus Zone
Nevadella eucharis Zone
Nevadia addyensis Zone
"Nevadella" Zone

Figure 2-11

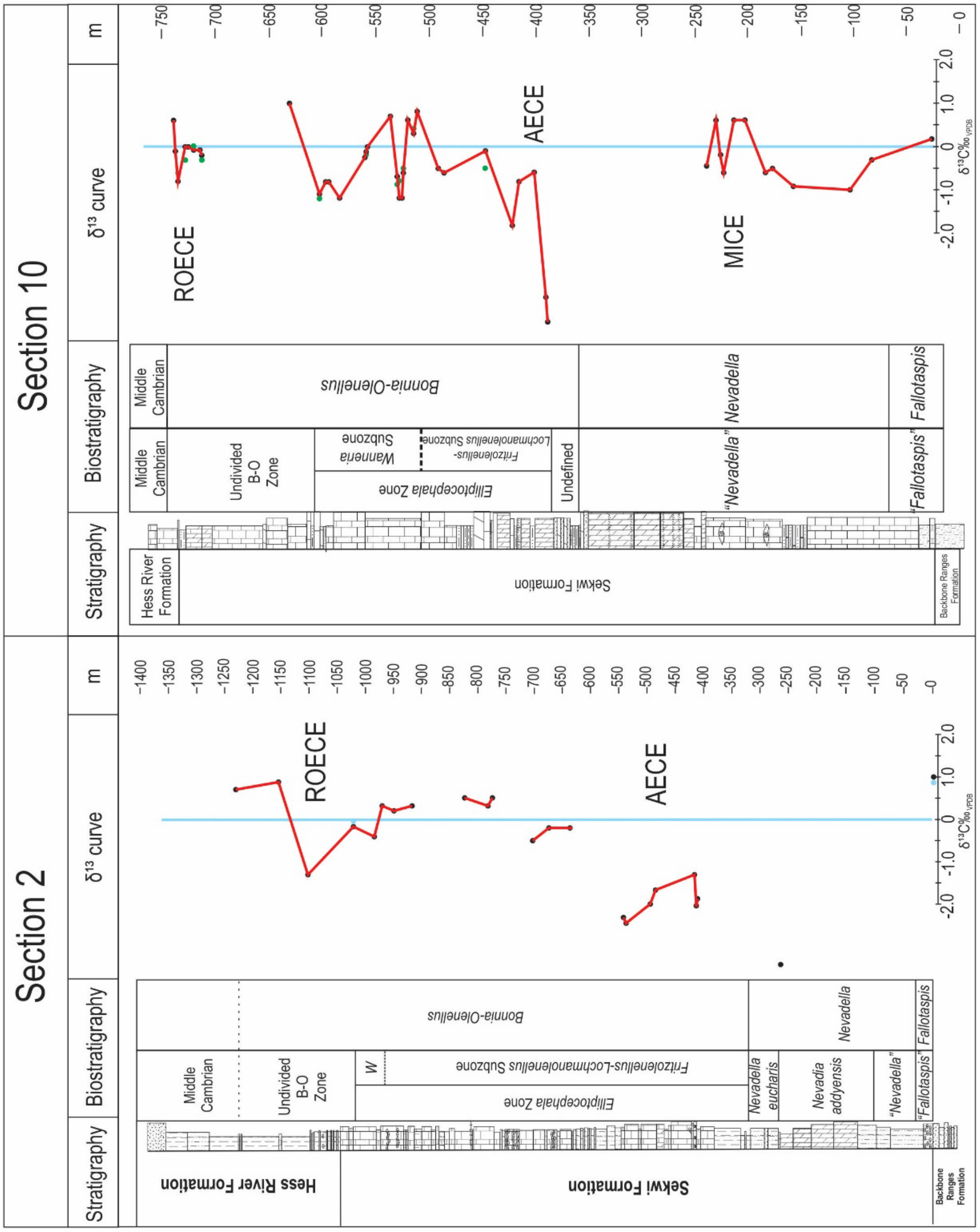

Section 2
Stratigraphy
Biostratigraphy
δ13 curve
m
Hess River Formation
Sekwi Formation
Backbone Ranges Formation
Middle Cambrian
Undivided B-O Zone
W
Fritzolenellus-Lochmanolenellus Subzone
Elliptocephala Zone
Bonnia-Olenellus
Nevadella eucharis
Nevadia addyensis
Nevadella
"Nevadella"
"Fallotaspis"
Fallotaspis
ROECE
AECE
-2.0 -1.0 0 1.0 2.0
δ13C‰VPDB
-1400 -1350 -1300 -1250 -1200 -1150 -1100 -1050 -1000 -950 -900 -850 -800 -750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 -0
Section 10
Stratigraphy
Biostratigraphy
δ13 curve
m
Hess River Formation
Sekwi Formation
Backbone Ranges Formation
Middle Cambrian
Undivided B-O Zone
Wanneria Subzone
Fritzolenellus-Lochmanolenellus Subzone
Elliptocephala Zone
Undefined
"Nevadella"
"Fallotaspis"
Middle Cambrian
Bonnia-Olenellus
Nevadella
Fallotaspis
ROECE
AECE
MICE
-2.0 -1.0 0 1.0 2.0
δ13C‰VPDB
-750 -700 -650 -600 -550 -500 -450 -400 -350 -300 -250 -200 -150 -100 -50 -0

Figure 2-12

2.11 TABLES

Table 2-1. (A) $\delta^{13}C$ and $\delta^{18}O$ data from section 2 (VPDB and VSMOW), (B) $\delta^{13}C$ and $\delta^{18}O$ data from section 10 (VPDB and VSMOW), and (C) $\delta^{13}C$ and $\delta^{18}O$ data from duplicate data from section 10 (VPDB and VSMOW).

Table 2-2. Precise meterage, nomenclature, and GSC locations of trilobites from Fritz 1972 section 2.

Table 2-3. Quantity of trilobite fossils from Fritz 1972 section 2.

Table 2-4. Precise meterage, nomenclature, and GSC locations of trilobites from Fritz (1972) section 10.

Table 2-5. Quantity of trilobite fossils from Fritz (1972) section 10.

Table 2-1

Sample ID/GSC location	Section	Formation	Meterage (above base of unit)	$\delta^{13}C$ (‰, VPDB)	$\delta^{18}O$(‰, VPDB)	$\delta^{18}O$(‰, VSMOW)	Lithology	Notes
A								
84299	Fritz (1976) section 2	Sekwi Formation	5.5	1.0	-24.0	6.2	silty lime mudstone	50-55% carbonate
84299 dup	Fritz (1976) section 2	Sekwi Formation	5.5	0.9	-24.0	6.2	silty lime mudstone	50-55% carbonate
84314	Fritz (1976) section 2	Sekwi Formation	272.2	-3.4	-13.1	17.4	lime mudstone	65-70% carbonate
84319	Fritz (1976) section 2	Sekwi Formation	418.2	-1.9	-10.8	19.8	lime mudstone/framestone	
84320	Fritz (1976) section 2	Sekwi Formation	419.4	-2.1	-11.1	19.5	lime mudstone/framestone	
84321	Fritz (1976) section 2	Sekwi Formation	419.7	-1.3	-9.3	21.3	lime mudstone/framestone	
84321 dup	Fritz (1976) section 2	Sekwi Formation	419.7	-1.3	-9.3	21.3	lime mudstone/framestone	
84322	Fritz (1976) section 2	Sekwi Formation	490.1	-1.7	-9.9	20.7	lime mudstone/framestone	
84323	Fritz (1976) section 2	Sekwi Formation	500.5	-2.0	-10.1	20.5	lime mudstone	
84324	Fritz (1976) section 2	Sekwi Formation	544.1	-2.2	-10.9	19.7	lime mudstone	
84325	Fritz (1976) section 2	Sekwi Formation	546.2	-2.1	-10.9	19.7	lime mudstone	
84326	Fritz (1976) section 2	Sekwi Formation	637.0	-0.2	-9.0	21.6	lime mudstone	
84328	Fritz (1976) section 2	Sekwi Formation	675.7	-0.2	-9.0	21.7	lime mudstone	
84329	Fritz (1976) section 2	Sekwi Formation	703.8	-0.5	-10.9	19.7	lime mudstone	45-50% carbonate
84329 dup	Fritz (1976) section 2	Sekwi Formation	703.8	-0.5	-10.9	19.7	lime mudstone	45-50% carbonate
84330	Fritz (1976) section 2	Sekwi Formation	777.8	0.5	-8.4	22.2	lime mudstone	
84331	Fritz (1976) section 2	Sekwi Formation	783.6	0.3	-10.7	19.8	lime mudstone	
84332	Fritz (1976) section 2	Sekwi Formation	824.5	0.5	-8.8	21.8	lime mudstone	
84333	Fritz (1976) section 2	Sekwi Formation	917.4	0.3	-8.6	22.0	lime mudstone	
84334	Fritz (1976) section 2	Sekwi Formation	949.5	0.2	-8.7	22.0	lime mudstone	
84335	Fritz (1976) section 2	Sekwi Formation	969.3	0.3	-9.4	21.2	lime mudstone	
84336	Fritz (1976) section 2	Sekwi Formation	984.5	-0.4	-9.8	20.8	lime mudstone	
84337	Fritz (1976) section 2	Sekwi Formation	1018.0	-0.2	-9.4	21.3	lime mudstone	
84337 dup	Fritz (1976) section 2	Sekwi Formation	1018.0	-0.1	-9.4	21.2	lime mudstone	
84338	Fritz (1976) section 2	Hess River Formation	18.6	N/A	N/A	N/A	N/A	~10% (low %carbonate)
84338 dup	Fritz (1976) section 2	Hess River Formation	18.6	N/A	N/A	N/A	N/A	~10% (low %carbonate)
84339	Fritz (1976) section 2	Hess River Formation	51.5	-1.3	-11.0	19.6	lime mudstone	
84340	Fritz (1976) section 2	Hess River Formation	103.9	0.9	-11.4	19.1	lime mudstone	
84341	Fritz (1976) section 2	Hess River Formation	179.8	0.7	-11.3	19.2	lime mudstone	

B

Sample ID/GSC location	Section	Formation	Meterage (above base of unit)	$\delta^{13}C$ (‰, VPDB)	$\delta^{18}O$(‰, VPDB)	$\delta^{18}O$(‰, VSMOW)	Lithology	Notes
73025	Fritz (1972) section 10	Sekwi Formation	1.8	0.2	-12.8	17.7	lime mudstone	
73026	Fritz (1972) section 10	Sekwi Formation	58.0	-0.3	-11.5	19.1	lime mudstone	
73027	Fritz (1972) section 10	Sekwi Formation	79.0	-1.0	-10.2	20.4	grainstone	
73030	Fritz (1972) section 10	Sekwi Formation	131.2	-0.9	-9.5	21.1	lime mudstone	
73032	Fritz (1972) section 10	Sekwi Formation	150.4	-0.5	-9.5	21.1	grainstone	
73033	Fritz (1972) section 10	Sekwi Formation	157.1	-0.6	-12.2	18.3	lime mudstone	
73034	Fritz (1972) section 10	Sekwi Formation	176.6	0.6	-8.3	22.4	lime mudstone- wackestone	
73034 dup	Fritz (1972) section 10	Sekwi Formation	176.6	0.6	-8.2	22.5	lime mudstone- wackestone	
73035	Fritz (1972) section 10	Sekwi Formation	186.7	0.6	-8.8	21.9	lime mudstone	
73036	Fritz (1972) section 10	Sekwi Formation	196.1	-0.6	-9.6	21.0	lime mudstone	
73037	Fritz (1972) section 10	Sekwi Formation	199.2	-0.2	-9.5	21.2	grainstone	
73038	Fritz (1972) section 10	Sekwi Formation	203.4	0.6	-7.9	22.7	lime mudstone	
73039	Fritz (1972) section 10	Sekwi Formation	211.7	-0.5	-9.0	21.6	lime mudstone	
73040	Fritz (1972) section 10	Sekwi Formation	360.5	-4.0	-13.0	17.5	lime mudstone	
73040 dup	Fritz (1972) section 10	Sekwi Formation	360.5	-4.0	-13.0	17.5	lime mudstone	
73041	Fritz (1972) section 10	Sekwi Formation	360.9	-3.4	-12.6	18.0	lime mudstone	
73042	Fritz (1972) section 10	Sekwi Formation	372.5	-0.6	-11.4	19.2	lime mudstone	
73043	Fritz (1972) section 10	Sekwi Formation	386.1	-0.8	-12.1	18.5	lime mudstone (recrystallized?)	
73044	Fritz (1972) section 10	Sekwi Formation	393.1	-1.8	-11.2	19.4	trilobite wackestone-rudstone	
73045	Fritz (1972) section 10	Sekwi Formation	417.9	-0.1	-11.8	18.8	lime mudstone (recrystallized?)	
73047	Fritz (1972) section 10	Sekwi Formation	455.7	-0.6	-9.3	21.3	wackestone-rudstone- recrystallized?	
73048	Fritz (1972) section 10	Sekwi Formation	461.5	-0.5	-10.0	20.6	wackestone-rudstone- recrystallized?	
73049	Fritz (1972) section 10	Sekwi Formation	481.6	0.8	-9.2	21.5	lime mudstone	
73049 dup	Fritz (1972) section 10	Sekwi Formation	481.6	0.8	-9.1	21.5	lime mudstone	
73051	Fritz (1972) section 10	Sekwi Formation	484.3	0.3	-9.2	21.5	rudstone-floatstone	
73052	Fritz (1972) section 10	Sekwi Formation	489.8	0.6	-9.3	21.3	lime mudstone	
73053	Fritz (1972) section 10	Sekwi Formation	494.4	-0.6	-9.0	21.7	lime mudstone	
73054	Fritz (1972) section 10	Sekwi Formation	495.3	-1.2	-9.1	21.5	lime mudstone	
73056	Fritz (1972) section 10	Sekwi Formation	496.8	-1.2	-9.3	21.3	lime mudstone	
73057	Fritz (1972) section 10	Sekwi Formation	498.1	-0.7	-9.2	21.5	lime mudstone	
73058	Fritz (1972) section 10	Sekwi Formation	505.4	0.7	-9.2	21.4	lime mudstone (surface very weathered)	
73059	Fritz (1972) section 10	Sekwi Formation	528.6	0.0	-9.0	21.7	lime mudstone	
73059 dup	Fritz (1972) section 10	Sekwi Formation	528.6	0.1	-9.0	21.7	lime mudstone	
73060	Fritz (1972) section 10	Sekwi Formation	528.6	-0.1	-9.3	21.3	lime mudstone	
73061	Fritz (1972) section 10	Sekwi Formation	528.8	-0.2	-9.3	21.4	lime mudstone	
73062	Fritz (1972) section 10	Sekwi Formation	553.6	-1.2	-10.0	20.6	lime mudstone	
73064	Fritz (1972) section 10	Sekwi Formation	563.6	-0.8	-9.6	21.0	lime mudstone	
73065	Fritz (1972) section 10	Sekwi Formation	566.1	-0.8	-9.2	21.5	lime mudstone	
73066	Fritz (1972) section 10	Sekwi Formation	572.7	-1.1	-9.9	20.7	lime mudstone/wackestone (recrystallized?)	
73067	Fritz (1972) section 10	Sekwi Formation	599.6	1.0	-9.6	21.0	lime mudstone	
73068	Fritz (1972) section 10	Sekwi Formation	682.9	-0.2	-10.6	20.0	lime mudstone	
73068 dup	Fritz (1972) section 10	Sekwi Formation	682.9	-0.2	-10.6	19.9	lime mudstone	
73069	Fritz (1972) section 10	Sekwi Formation	683.5	-0.1	-10.2	20.4	lime mudstone	
73070	Fritz (1972) section 10	Sekwi Formation	689.9	-0.1	-10.5	20.1	lime mudstone	
73071	Fritz (1972) section 10	Sekwi Formation	694.5	0.0	-10.2	20.4	lime mudstone	
73072	Fritz (1972) section 10	Sekwi Formation	697.5	0.0	-9.5	21.1	silty lime mudstone	
73073	Fritz (1972) section 10	Sekwi Formation	704.2	-0.8	-9.8	20.8	lime mudstone	
73074	Fritz (1972) section 10	Hess River Formatio	2.7	-0.1	-8.8	21.8	lime mudstone	
73075	Fritz (1972) section 10	Hess River Formatio	3.1	0.6	-10.8	19.7	lime mudstone	
7+A85+A34:I+A34:I83	Fritz (1972) section 10	Hess River Formatio	3.1	0.6	-10.8	19.7	lime mudstone	

C

Sample ID/GSC location	Section	Formation	Meterage (above base of unit)	$\delta^{13}C$ (‰, VPDB)	$\delta^{18}O$(‰, VPDB)	$\delta^{18}O$(‰, VSMOW)	Lithology	Notes
73043-2	Fritz (1972) section 10	Sekwi Formation	386.1	-0.7	-12.1	18.4	lime mudstone (recrystallized?)	
73045-2	Fritz (1972) section 10	Sekwi Formation	417.9	-0.5	-11.2	19.3	lime mudstone (recrystallized?)	
73051-2	Fritz (1972) section 10	Sekwi Formation	484.3	0.4	-9.3	21.3	rudstone-floatstone	
73051-2 dup	Fritz (1972) section 10	Sekwi Formation	484.3	0.2	-9.4	21.3	rudstone-floatstone	
73053-2	Fritz (1972) section 10	Sekwi Formation	494.4	-0.5	-8.9	21.8	lime mudstone	
73056-2	Fritz (1972) section 10	Sekwi Formation	496.8	-0.8	-9.3	21.3	lime mudstone	
73057-2	Fritz (1972) section 10	Sekwi Formation	498.1	-0.9	-9.3	21.4	lime mudstone	
73060-2	Fritz (1972) section 10	Sekwi Formation	528.6	-0.2	-9.2	21.4	lime mudstone	
73060-2 dup	Fritz (1972) section 10	Sekwi Formation	528.6	-0.3	-9.2	21.4	lime mudstone	
73066-2	Fritz (1972) section 10	Sekwi Formation	572.7	-1.2	-9.6	21.0	lime mudstone/wackestone (recrystallized?)	
73068-2	Fritz (1972) section 10	Sekwi Formation	682.9	-0.3	-10.1	20.5	lime mudstone	
73070-2	Fritz (1972) section 10	Sekwi Formation	689.9	0.0	-10.5	20.1	lime mudstone	
73072-2	Fritz (1972) section 10	Sekwi Formation	697.5	-0.3	-10.3	20.3	silty lime mudstone	
73072-2 dup	Fritz (1972) section 10	Sekwi Formation	697.5	-0.2	-10.3	20.3	silty lime mudstone	
73073-2	Fritz (1972) section 10	Sekwi Formation	704.2	-0.6	-9.4	21.3	lime mudstone	

Table 2-2

Table 1 (Section 2)				
Distance from base of unit				
Metres	**Feet**	**Unit**	**GSC location**	**Taxa**
0.0	0	Sekwi Formation	84298	N/A
5.5	18	Sekwi Formation	84299	Indet. fallotaspid material
17.1	56	Sekwi Formation	84300	*Parafallotaspis grata*
17.7	58	Sekwi Formation	84301	*Parafallotaspis grata* , indet. fallotaspid material
23.5	77	Sekwi Formation	84302	Indet. fallotaspid material
25.0	82	Sekwi Formation	84303	*Parafallotaspis grata* , indet. fallotaspid material
34.4	113	Sekwi Formation	84304	Indet. fallotaspid material
35.4	116	Sekwi Formation	84305	Indet. fallotaspidid?, *Nevadella* cf. *N. keelensis* , indet. trilobite sp. 1
47.5	156	Sekwi Formation	84306	indet. olenellid sp. 1
50.0	164	Sekwi Formation	84307	*Montezumaspis* ? sp. 1, *Montezumaspis* ? sp. 2
55.2	181	Sekwi Formation	84308	Indet. olenellid sp. 2
57.3	188	Sekwi Formation	84309	*Montezumaspis* ? sp. 1, *Montezumaspis* ? sp. 2
93.9	308	Sekwi Formation	84311	*Esmeraldina* ? sp.
100.3	329	Sekwi Formation	84312	*Esmeraldina* ? sp., *Nevadella* cf. *N* . *bacculenta* Fritz
101.8	334	Sekwi Formation	84313	*Nevadia addyensis*
272.8	895	Sekwi Formation	84314	*Nevadella* sp. 2
272.8	895	Sekwi Formation	84315	*Nevadella eucharis*
327.7	1075	Sekwi Formation	84316	*Fritzolenellus* cf. *F* . *truemani* , *Lochmanolenellus* sp.
343.2	1126	Sekwi Formation	84317	Indet. olenellid sp. 3
397.8	1305	Sekwi Formation	84318	*Fritzolenellus* ? sp. 1
500.5	1642	Sekwi Formation	84323	*"Proliostracus"* sp.
544.1	1785	Sekwi Formation	84324	*"Proliostracus"* sp. (tentatively assigned)
546.2	1792	Sekwi Formation	84325	*:Proliostracus"* cf. *P. contractus*
668.4	2193	Sekwi Formation	84327	*"Proliostracus" annosus*
675.7	2217	Sekwi Formation	84328	*"Proliostracus" annosus*
777.8	2552	Sekwi Formation	84330	*Olenellus* ? sp.
783.6	2571	Sekwi Formation	84331	*Wanneria?* sp.
824.5	2705	Sekwi Formation	84332	Indet. olenellid sp. 4
917.4	3010	Sekwi Formation	84333	*Elliptocephala* cf. *E* . sp. 2 Fritz 1972
949.5	3115	Sekwi Formation	84334	*Gabriellus* ? sp., *Bonnia laterispina*
969.3	3180	Sekwi Formation	84335	*Wanneria* cf. *W* . *parvifrons* , *Elliptocephala* ? sp. 2, *Bonnia laterispina*
984.5	3230	Sekwi Formation	84336	*Wanneria parvifrons* , *Bonnia laterispina*
1018.0	3340	Sekwi Formation	84337	*Wanneria* cf. *W. parvifrons*
18.6	61	Hess River Formation	84338	*Olenellus* cf. *O. clarki* Ressser 1928
51.5	169	Hess River Formation	84339	*Elliptocephala* ? sp. 1, *Bonnia* sp.
103.9	341	Hess River Formation	84340	*Olenellus* cf. *O* . *puertoblancoensis* , *Goldfieldia pacifica*
179.8	590	Hess River Formation	84341	*Ogygopsis* ? sp.

Table 2-3

Taxon	**Material**
Indet. Fallotaspid material	46 partial cephala and one associated opisthothorax
Parafallotaspis grata	11 partial cephala
Nevadella cf. *N. keelensis*	1 complete cephalon and 13 partial cephala
indet. trilobite sp. 1	4 partial cephala
indet. olenellid sp. 1	1 partial cephalon
Montezumaspis ? sp. 1	13 partial cephala and one associated hypostome
Montezumaspis ? sp. 2	2 partial cephala
Indet. olenellid sp. 2	3 partial cephala
Esmeraldina ? sp.	3 partial cephala
Nevadella cf. *N . bacculenta* Fritz 1972	1 cephalon and 3 genae
Nevadia addyensis	6 cephala
Nevadella sp. 2	13 cephala
Nevadella eucharis	1 complete cephalon and 3 partial cephala
Fritzolenellus cf. *F . truemani*	4 complete cephala, 1 complete early stage meraspid, and 9 incomplete cephala
Lochmanolenellus sp.	11 incomplete cephala and 4 meraspid cephala
Indet. olenellid sp. 3	one tentatively assigned
Fritzolenellus ? sp. 1	1 complete cephalon and 1 partial cephalon
"Proliostracus" sp.	4 partial cranidia and 1 compacted, tentatively assigned cranidium
"Proliostracus" cf. *P. contractus*	34 cranidia
"Proliostracus" annosus	numerous small, silicified skeletal elements in silt
Olenellus ? sp.	1 damaged cephalon
Wanneria ? sp.	2 cephala
Indet. olenellid sp. 4	1 effaced cephalon
Elliptocephala cf. *E* . sp. 2 Fritz 1972	1 partial cephalon
Gabriellus ? sp.	1 partial cephalon
Bonnia laterispina	4 cranidia, 5 partial cranidia, 1 pygidium, 3 partial pygidia, and 1 worn, questionably assigned pygidium
Elliptocephala ? sp. 2	3 partial adult cephala and 3 meraspid cephala
Wanneria parvifrons	1 partial cephalon
Wanneria cf. *W . parvifrons*	3 partial cephala
Olenellus cf. *O. clarki* Ressser 1928	4 partial cephala
Elliptocephala ? sp. 1	2 partial cephala
Bonnia sp.	3 cranidia, 1 partial cranidium, 3 pygidia, and 2 partial pygidia
Olenellus cf. *O . puertoblancoensis*	1 partial cephalon
Goldfieldia pacifica	9 cranidia, 2 partial cranidia, 3 partial thoraxes, and one partial thorax with pygidium
Ogygopsis ? sp.	1 partial cranidium

Table 2-4

Table 1 (Section 10)

Distance from base of unit				
Metres	**Feet**	**Unit**	**GSC location**	**Taxa**
3.1	10	Hess River Formation	73075	*"Syspacephalus" vapidus*
2.7	9	Hess River Formation	73074	*Olenellus* sp. 5 Fritz 1972
704.2	2309	Sekwi Formation	73073	*Bonnia columbensis* , *Olenellus* sp. 5 Fritz 1972, *Zacanthopsis stribuccus* , *"Antagmus" truncatus* , and *"Piaziella" pia*
697.5	2287	Sekwi Formation	73072	*Olenellus puertoblancoensis*
694.5	2277	Sekwi Formation	73071	*Olenellus puertoblancoensis* and *Bonnima* sp, nov.
689.9	2262	Sekwi Formation	73070	*Olenellus puertoblancoensis*
683.5	2241	Sekwi Formation	73069	*Olenellus puertoblancoensis*
682.9	2239	Sekwi Formation	73068	*Bonnima* sp. nov., *Olenellus puertoblancoensis* and *Zacanthopsis stribuccus*
599.6	1966	Sekwi Formation	73067	*Bonnia* sp. 2 Fritz 1972
566.1	1856	Sekwi Formation	73065	*Elliptocephala paraoculus* and *Elliptocephala* sp. 2 Fritz 1972
563.6	1848	Sekwi Formation	73064	*Elliptocephala paraoculus* and *Wanneria logani*
553.6	1815	Sekwi Formation	73062	*Wanneria logani* and *Elliptocephala* sp. 2 Fritz 1972
528.6	1733	Sekwi Formation	73060	*Elliptocephala paraoculus*
528.6	1733	Sekwi Formation	73059	*Elliptocephala paraoculus*
505.4	1657	Sekwi Formation	73058	*Elliptocephala paraoculus*
498.1	1633	Sekwi Formation	73057	*Elliptocephala* sp. 2 Fritz 1972
496.5	1628	Sekwi Formation	73055	*Wanneria logani*
495.3	1624	Sekwi Formation	73054	*Wanneria logani*
494.4	1621	Sekwi Formation	73053	*Wanneria logani*
484.3	1588	Sekwi Formation	73051	*Wanneria logani*
483.7	1586	Sekwi Formation	73050	*Wanneria logani*
481.6	1579	Sekwi Formation	73049	*Wanneria logani* and *Elliptocephala sequomalus*
461.5	1513	Sekwi Formation	73048	*"Poulsenia"* sp. 1 Fritz 1972
N/A	N/A	Sekwi Formation	73046	Indet. olenellid sp. 5 and *Elliptocephala laxocules*
417.9	1370	Sekwi Formation	73045	*"Variopelta" laevis*
393.1	1289	Sekwi Formation	73044	*"Proliostracus" annosus*
386.1	1266	Sekwi Formation	73043	*Fritzolenellus* sp. 1 Fritz 1972
360.5	1182	Sekwi Formation	73040	*Elliptocephala walcotti* and *"Proliostracus" depressus*
211.7	694	Sekwi Formation	73039	*Holmiella falcuta* , *Kootenia diutina* , and *Keeleaspis pustula*
203.4	667	Sekwi Formation	73038	*Yukonides lacrinus* , *Holmiella falcuta* , *Holmiella preancora* , *Kootenia diutina* , *Keeleaspis gratia* , and *Keeleaspis pustula*
199.2	653	Sekwi Formation	73037	*Yukonides lacrinus* , *Holmiella falcuta* , *Nevadella faceta* , *Kootenia diutina* , *Nevadella* sp. 2 Fritz 1972, *Keeleaspis pustula* , *Keeleaspis gratia*
196.1	643	Sekwi Formation	73036	*Pagetides spinulus* , *Nevadella faceta* , *Kootenia diutina* , *Keeleaspis gratia*
186.7	612	Sekwi Formation	73035	*Yukonides lacrinus* , *Holmiella falcuta* , *Nevadella faceta* , *Kootenia diutina*
176.6	579	Sekwi Formation	73034	*Pagetides spinulus* , *Holmiella falcuta* , *Nevadella faceta* , *Kootenia diutina* , *Keeleaspis gratia*
157.1	515	Sekwi Formation	73033	*Pagetides spinulus* , *Holmiella preancora* , *Nevadella* sp. 2 Fritz 1972, *Kootenia diutina* , and *Keeleaspis pustula*

Table 2-4 (continued)

150.4	493	Sekwi Formation	73032	*Pagetides spinulus* , *Nevadella faceta* , *Kootenia diutina* , *Keeleaspis gratia*
0.0		Sekwi Formation	73031	
131.2	430	Sekwi Formation	73030	*Pagetides spinulus* , *Bradyfallotaspis fusa* , *Holmiella preancora* , *Nevadella bacculenta* , *Nevadella* sp. 2 Fritz 1972, *Kootenia diutina* ,
79.0	259	Sekwi Formation	73027	*Pagetides spinulus* , *Bradyfallotaspis fusa* , *Holmiella preancora* , *Nevadella faceta* , *Kootenia diutina* , *Keeleaspis gratia*
58.0	190	Sekwi Formation	73026	*Kootenia diutina*
1.8	6	Sekwi Formation	73025	*Parafallotaspis grata*

Table 2-5

Taxon	**Material**
"Syspacephalus" vapidus	23 cranidia
Olenellus sp. 5 Fritz 1972	5 cephala and 2 genae
Bonnia columbensis	13 cranidia and 21 pygidia
Zacanthopsis stribuccus	1 cranidia and 3 questionably assigned cranidia
"Antagmus" truncatus	4 cranidia
"Piaziella" pia	1 cranidium
Olenellus puertoblancoensis	20 cephala, 1 partial thorax, and 1 genae
Bonnima sp. nov.	8 cranidia and 1 tentatively assigned pygidium
Bonnia sp. 2 Fritz 1972	2 cranidia
Elliptocephala paraoculus	41 cephala, 1 genae, and 2 hypostomata
Elliptocephala sp. 2 Fritz 1972	11 cephala and 8 genae
Wanneria logani	23 cephala, 9 genae, and 1 pleura
Fritzolenellus sp. 1 Fritz 1972	12 cephala, 7 genae, and 3 hypostomata.
Elliptocephala sequomalus	5 cephala
"Poulsenia" sp. 1 Fritz 1972	1 cranidium
Elliptocephala laxocules	19 cephala and 1 hypostome
"Variopelta" laevis	19 cranidia
"Proliostracus" annosus	8 cranidia
"Proliostracus" depressus	8 cranidia
Elliptocephala walcotti	19 cephala, 1 pleura, and 1 hypostome
Holmiella falcuta	32 cephala and 12 pygidia
Kootenia diutina	79 cranidia, 50 pygidia, 3 librigenae, and 8 hypostomata
Keeleaspis pustula	4 cranidia and 1 librigena
Yukonides lacrinus	11 cranidia and 2 pygidia
Holmiella preancora	7 cephala and 2 pygidia
Keeleaspis gratia	8 cranidia, 5 pygidia, and 3 librigenae
Nevadella sp. 2 Fritz 1972	1 cephalon and 3 associated hypostomata
Pagetides spinulus	37 cranidia and 29 pygidia
Nevadella faceta	11 cephala and 3 genae
Bradyfallotaspis fusa	3 cephala
Parafallotaspis grata	8 partial cephala

Chapter 3 - Lower and middle Cambrian biostratigraphy of the Wrigley Lake area (Sekwi and Rockslide formations; Northwest Territories, Canada) and its implications for tectonic activity of the Redstone arch

3.1 ABSTRACT

The tectonic evolution of the Redstone arch, a northwest-trending, linear paleotopographic high that bordered the southern part of the deep-water Selwyn basin in the early Paleozoic, and episodically influenced sediment deposition in adjacent areas of the Selwyn basin, is not well understood. Historical trilobite collections spanning the lower-middle Cambrian *Bonnia-Olenellus* to *Bolaspidella* zones from the Wrigley Lake map area (NTS 95M; Northwest Territories) are examined and used in conjunction with lithostratigraphic data to constrain the timing and nature of Redstone arch tectonic events. Two major tectonic events occurred in this area early in the Selwyn basin depositional history: (1) Cambrian Stage 3 to early Cambrian Stage 4 regional uplift affecting Sekwi Formation deposition, and (2) regional subsidence between late Cambrian Stage 4 and the early Wuliuan, which resulted in the onset of Rockslide Formation deposition. Other areas along the ancestral western margin of Laurentia may have experienced coeval episodes of tectonism, many of which were expressed in arch behaviour. These episodes differed in nature and timing, indicating that the ancestral western margin of Laurentia in the early to middle Cambrian was a time of widespread but subtle tectonic activity that strongly influenced deposition in newly developed "passive-margin" environments.

3.2 INTRODUCTION

The Selwyn basin was a latest Neoproterozoic to lower Paleozoic deep-water basin along the (present-day) northwestern margin of ancestral North America (Gordey and Anderson, 1993) and is currently exposed in the northwesternCanadian cordillera (British Columbia to Alaska; Fig. 3-1). Strata in and adjacent to the Selwyn basin host past-producing and prospective sedimentary exhalative/clastic-dominant (SEDEX/CD) carbonate-hosted base- and precious-metal deposits (Dewing et al. 2006; Goodfellow 2007; Ootes et al. 2013; Thiessen et al. 2016). The Selwyn basin was flanked on its (present-day) northeastern margins by two “arches,” (from north to south: the Mackenzie and Redstone arches; Cecile et al. 1997; Fig. 3-1). These arches were high standing, paleotopographic structures that were episodically tectonically active and influenced deposition in the basin intermittently throughout the early Paleozoic (Gabrielse 1967; Aitken et al. 1973; Cecile et al.1997; MacNaughton and Fallas 2014).

The southeasternmost of these arches, the Redstone arch, trends (present-day) southeast and separates deep-water environments of the Selwyn basin from the shallow, intracratonic basin to the northeast (Fig. 3-1). The lowermost strata of the Selwyn basin near the Redstone arch (Fig. 3-2) consist of (in ascending order) (1) the Backbone Ranges Formation (Neoproterozoic to lower early Cambrian), (2) the Sekwi Formation (Cambrian Stage 4), and (3) the Rockslide Formation (Wuliuan to Drumian stages) [Fritz 1972, 1976, 1978, 1979; Gabrielse et al. 1973; MacNaughton 2011]. The Redstone arch episodically affected the deposition and preservation of these units, but the timing and nature of these events is poorly understood.

This study evaluates biostratigraphic (trilobite) material that was collected by the Geological Survey of Canada (GSC) in the 1960s from the Wrigley Lake area (Operation Nahanni; Gabrielse et al. 1973, Fig. 3-3), and uses these data to clarify the nature and chronology of the Redstone arch early in the depositional history of the Selwyn in the present-day Wrigley

Lake area (Fig. 3-3, NTS 95M). These data are used to determine the nature and chronology of the Redstone arch, and how it affected deposition in the Selwyn basin during the early to middle Cambrian. Determining the chronology of events in the Selwyn basin is important both for developing a regional tectonostratigraphic synthesis in this economically important basin, and for understanding the important paleobiological information it contains.

3.3 REGIONAL GEOLOGY

3.3.1 Backbone Ranges Formation

The Backbone Ranges Formation (Gabrielse et al. 1973) is a predominantly siliciclastic unit that was deposited during the Ediacaran to early Cambrian (Fig.3- 2). Proximal (nearshore; eastern) sections of the Backbone Ranges Formation express three members at many localities (Fritz 1982, Aitken 1989, MacNaughton et al. 1999, 2008, 2018; MacNaughton 2020a, 2020b).

1) A lower member (~500 m thick) consists largely of quartz sandstone, siltstone, and lesser dolostone (Gabrielse et al. 1973, MacNaughton 2011, MacNaughton and Fallas 2021). Rocks of the lower member are typically orange-brown to brown-weathering (Gabrielse et al. 1973). Common sedimentary structures include cross-stratification, parallel bedding/lamination, desiccation cracks, and synaeresis cracks (MacNaughton 2011).
2) The middle member (~150 m thick) is dominated by brightly coloured dolostone and minor limestone (MacNaughton 2011). At the Backbone Ranges Formation type section, the upper part of the middle member is karsted and brecciated. (MacNaughton et al. 1999; MacNaughton 2011). Intraclast rudstone and microbial lamination are common throughout this unit (MacNaughton 2011). Carbonate beds

are typically thin- or medium-bedded and parallel lamination is common. Some locations preserve mudstone partings between carbonate beds (MacNaughton 2011).

3) The highly resistant upper member (~760 m thick) consists mostly of sandstone with minor siltstone and quartz-pebble conglomerate (Gabrielse et al. 1973, MacNaughton and Fallas 2021). Thick-bedded quartz sandstone dominates this unit, with cross-beds, overturned foresets, channels, and parallel lamination/bedding. Hummocky or swaley cross-stratified quartz arenite to wacke is common in the upper member. Current ripples are also common in this lithofacies, and bed bases commonly exhibit tool marks (MacNaughton 2011). Subordinate brown to maroon siltstone/shale lithofacies commonly exhibit synaeresis and desiccation cracks (MacNaughton and Narbonne 1999; MacNaughton 2011).

At distal (basinward; westward) locations the tripartite organization of the Backbone Ranges Formation cannot be recognized (MacNaughton 2011; MacNaughton et al. 2016, Fig. 2) and correlation from proximal to distal exposures of the Backbone Ranges Formation is problematic (MacNaughton 2011). Although some workers have considered distal Backbone Ranges Formation sections to be readily correlatable with proximal sections that exhibit the characteristic tripartite organization (Aitken 1989), others have considered the distal Backbone Ranges Formation to correlate only with the upper member of the proximal Backbone Ranges Formation (MacNaughton 2011; Fig. 3-2), or with the upper part of the upper member (MacNaughton and Fallas 2019). For this reason, distal exposures of the Backbone Ranges Formation are referred to herein informally as “Backbone Ranges Formation” (following MacNaughton 2011).

In NTS 95M, the Backbone Ranges Formation unconformably overlies dark-weathering shale of the Sheepbed Formation (Gabrielse et al. 1973) or the pale-weathering, informal "Sheepbed carbonate" unit (e.g., MacNaughton and Fallas 2021). The Backbone Ranges Formation is commonly overlain by the lower Cambrian Sekwi Formation in NTS 95M (Fig. 3-2; Fritz 1984; MacNaughton and Fallas 2021), although at its type section in NTS 95L it is overlain by the middle Cambrian Avalanche Formation (Gabrielse et al. 1973; Fritz, 1982) . In more distal sections (e.g., NTS 105P), strata assigned to the "Backbone Ranges Formation" are overlain by shelf-environment fine-grained siliciclastic strata of the Vampire Formation (MacNaughton et al. 1997; MacNaughton 2011; Fig. 3-2), which are in turn overlain by the Sekwi Formation.

Regional stratigraphic relationships strongly suggest that the lower and middle members of the Backbone Ranges Formation are Ediacaran (MacNaughton and Fallas 2019, 2021).. If stratigraphic correlations proposed by MacNaughton and Fallas (2019) are correct, then the Ediacaran-Cambrian boundary is in the upper member.

In NTS 105P, strata assigned to the the upper member of the "Backbone Ranges Formation" probably correlate with the upper part of the upper member (MacNaughton and Fallas 2019) and contain trace fossils suggesting a pre-trilobitic early Cambrian age (Fortunian, *Rusophycus avalonensis* Zone; MacNaughton and Narbonne 1999). The same is true of the overlying Vampire Formation (MacNaughton and Narbonne 1999). Neither unit has yielded body fossils (MacNaughton 2011).The lowermost ~10 m of the overlying Sekwi Formation contain trilobites of the *Fallotaspis* Zone at shore-distal locations (Fritz 1972, 1976, 1978, 1979). Given that strata of the *Fallotaspis* Zone elsewhere in Laurentia are significantly thicker (>100 m in the Campito Formation, Nevada; Hollingsworth 2011) and exhibit far greater taxonomic diversity (Hollingsworth 2011), it seems implausible that the *Fallotaspis* Zone as expressed in the Sekwi Formation records the entirety of the biozone. Furthermore, the oldest trilobite biozone in Laurentia, the *Fritzaspis* Zone, has not been documented in the northern Canadian cordillera. Where the Backbone Ranges or Vampire formations are conformably overlain by the Sekwi Formation, it may be that at least the upper part of the upper member of the Backbone Ranges Formation was deposited during *Fritzaspis* and *Fallotaspis* Zone time, but it is not evident because the Backbone Ranges Formation does not contain body fossils (MacNaughton 2011).

3.3.2 Sekwi Formation

The Sekwi Formation (Handfield 1968) is a heterogeneous, carbonate-dominated unit that outcrops widely throughout the Mackenzie Mountains (Chan et al. 2019, Fig. 2). The Sekwi Formation in the Wrigley Lake map area (NTS 95M) is thin relative to elsewhere in the Selwyn basin, averaging ~100 m (MacNaughton and Fallas 2021). The Sekwi Formation represents a west-facing carbonate ramp (Dilliard et al. 2007, 2010), and is much thicker in distal locations (500 to 1300 m; Fischer and Pope 2011) than in proximal locations such as those near the Redstone arch in the Wrigley Lake area (~150 m or less; Chan et al. 2019). Thicker, arch-distal exposures of the Sekwi Formation such as those in NTS 105P (Figs. 3-2, 3-3) commonly have a conspicuous sandstone marker in the middle of the unit (Fischer and Pope 2011). Gabrielse et al. (1973) originally assigned some of the strata of the Sekwi Formation in sections 19 and 14/18 to the Backbone Ranges Formation. Fritz (1981) reassigned these strata to the Sekwi Formation based on a predominance of maroon-weathering calcareous siltstone and the presence of trilobite fossils, which resemble upper Sekwi Formation strata in the Nahanni area and differ from typical lithologies of the Backbone Ranges Formation. MacNaughton and Fallas (2021) followed Fritz's (1981) revision.

In NTS 95M (Fig. 3-3), the Sekwi Formation is composed mostly of maroon-weathering, locally calcareous or dolomitic siltstone that is locally interbedded with fine-grained, silty sandstone. Subordinate orange-weathering dolomitic sandstone, dolostone, and dolorudstone are also locally present (Fritz 1981, MacNaughton and Fallas 2021). Common sedimentary structures include parallel-lamination, cross-lamination, mud cracks, and possible hummocky or swaley cross-lamination (MacNaughton and Fallas, 2021).

Strata of the Sekwi Formation in the vicinity of Wrigley Lake were deposited during the *Bonnia-Olenellus* Zone biochron (Gabrielse et al. 1973, MacNaughton and Fallas 2021, Figs. 3-2, 3-4). Older trilobite biozones (*Fallotaspis* and *Nevadella* zones) are not expressed in the Sekwi Formation in the Wrigley Lake area, which is typical of eastern, arch-proximal locations (Figs. 3-2, 3-3; Fritz 1972, 1976, 1978, 1979; Gabrielse et al. 1973; Dilliard et al. 2010; Chan et al. 2019). These older biozones are typically preserved in distal, westward sections (Fritz 1972, 1976, 1978, 1979). Olenelloid trilobites collected by R.B. MacNaughton as float from the base of the Sekwi Formation at an arch-proximal locality were identified as *Nephrolenellus* cf. *mutinodus* (Morgan, pers. comm. 2022). *Nephrolenellus* occurs in the uppermost *Bonnia-Olenellus* Zone (Webster 2011), and *N. multinodus* is the eponymous taxon for the uppermost olenellid-dominant trilobite biozone (Fig. 3-4) that Webster (2011) erected based on data from the Great Basin of Nevada, California, and Arizona. Near Wrigley Lake, the Sekwi Formation may have been deposited only during upper *Bonnia-Olenellus* Zone time, and the lower and middle parts of the biozone may be absent.

Dilliard et al. (2007, 2010) divided the Sekwi Formation into seven unconformity-bounded transgressive-regressive (T-R) sequences (S0-S6). Sequence S0 is composed of subtidal carbonate and siliciclastic rocks and includes the uppermost part of the underlying Vampire Formation. Sequence S1 records inner ramp and basinal deposits. Both sequences are thick (100s of m). Collectively, S0 and S1 span the lower part of the Sekwi Formation and were deposited during the *Fallotaspis* to *Nevadella* Zone biochrons. The upper sequences (S2-S6) are thinner (10s to ~100 m thick) and record shallower-water settings. Each consists of basal shallow-water carbonates that shallow upward to peritidal carbonate caps. Sequences S2-S6 were deposited during the *Bonnia-Olenellus* Zone biochron and represent the upper half of the Sekwi Formation (Dilliard et al. 2010).

Dilliard et al. (2007) established a $\delta^{13}C$ isotope curve for the Sekwi Formation. At least three globally recognised isotope excursions were retroactively interpreted to be present in this dataset (Fig. 3-4): the Cambrian arthropod radiation isotope excursion (CARE; a positive excursion), the Mingxinsi carbon isotope excursion (MICE; a positive excursion), and the archaeocyathan extinction isotope excursion (AECE; a negative excursion) (Scott et al. 2022). In the Sekwi Formation, the CARE is coincident with the boundary between the *Fallotaspis* and *Nevadella* Zones. The MICE is near the top of the *Nevadella* Zone and seems to be only partially expressed. The MICE commonly exhibits a “two-pronged” shape in which the excursion is initially quite positive (~2.0-4.0‰), retracts to lower positive values that may be as low as ~0‰, and then returns to positive values that are similar to the initial prong (Cramer and Jarvis 2020; Brasier and Sukhov 1998, fig. 8; Betts et al. 2018, fig. 23). The MICE recorded by the Sekwi Formation in the Dilliard et al (2007) dataset contains only one prong (Dilliard et al. 2007 Fig. 3-6), and is truncated by the regionally correlatable sandstone marker unit. The AECE is present in the middle part of the *Bonnia-Olenellus* Zone and reaches ~5.0‰ at its minimum (Dilliard et al. 2007; Scott et al. 2022). The Redlichiid-Olenellid extinction carbon isotope excursion (ROECE) may be expressed in the top of the Sekwi Formation and the overlying Hess River Formation in the vicinity of the Misty Creek embayment (Scott et al. 2021) given that Dilliard et al.'s (2007) curve reaches values of ~-2.0‰ close to the Sekwi-Hess River formational contact (Dilliard et al. 2007, Fig. 3-6). The upper contact of the Sekwi Formation varies in age (middle to upper *Bonnia-Olenellus* Zone; Fritz 1972, 1976, 1978, 1979; Scott et al. 2022) where it is conformable, and it is probable that the placement of the ROECE in the Sekwi Formation and overlying units varies geographically.

The Sekwi Formation unconformably overlies quartz arenite and siltstone of the Backbone Ranges Formation in the Wrigley Lake map area (Gabrielse et al. 1973, MacNaughton and Fallas 2021; Fig. 3-2) and its base is marked by the first occurrence of orange-weathering dolostone (MacNaughton and Fallas 2021). Locally, the lithological transition between the Backbone Ranges and Sekwi formations superficially appears gradational because of the presence of quartz sandstone interbedded with carbonates and siltstone that are characteristic of the Sekwi Formation. However, this contact is regarded as being unconformable in the Wrigley Lake area because of (1) a comparatively thinner upper member of the Backbone Ranges Formation (~100 m as opposed to ~500 m elsewhere; MacNaughton and Fallas 2021); (2) the local absence of a widespread carbonate marker unit in the upper Backbone Ranges Formation; and (3) the presence of *Bonnia-Olenellus* Zone trilobites in the Sekwi Formation without any trilobites from the underlying *Nevadella* and *Fallotaspis* zones. These features suggest that erosion truncated the upper Backbone Ranges Formation (MacNaughton and Fallas 2021).

Basinward, the Sekwi Formation gradationally and conformably overlies the Vampire Formation (Fischer and Pope 2011).

3.3.3 Rockslide Formation

The Rockslide Formation (Gabrielse et al. 1973) is a recessive, highly fossiliferous unit dominated by limestone- and calcareous siltstone (Gabrielse et al. 1973; Gordey and Anderson 1993, Fig. 3-2). The Rockslide Formation type section (Section 16; Gabrielse et al. 1973) is in the west-central Wrigley Lake map area (Fig. 3-3) and consists of three subunits: (1) a lower unit dominated by dolomitic siltstone and calcareous siltstone that locally contains pyrite and locally evaporite mineral casts; (2) a highly recessive middle unit dominated by calcareous siltstone, shale, and argillaceous limestone, with only the latter lithology intermittently forming resistant beds, and a resistant layer of grey-to-brown-weathering sandstone close to its top; and (3) an upper unit dominated by platy limestone that is locally silty with minor amounts of sandstone and sandy limestone. The upper unit locally contains abundant limestone concretions (Gabrielse et al. 1973).

Other Rockslide Formation sections in the Wrigley Lake area differ from the type section. Poorly fossiliferous easternmost outcrops consist of recessive siltstone and nodular limestone close to the base, which transition upward to locally oolitic limestone (Gabrielse et al. 1973); the upper part of the formation is dominated by oolitic dolostone (Gabrielse et al. 1973). Southwestern sections also differ from the type section in consisting of black, calcareous shale at the base which is overlain by thinly bedded limestone and dolostone with minor chert nodules (Gabrielse et al. 1973). The uppermost Rockslide Formation in southwestern localities consists of grey-weathering, medium-bedded dolostone (Gabrielse et al. 1973).

The Rockslide Formation is known to contain trilobites that are diagnostic of all traditional, genus-based, Laurentian middle Cambrian trilobite zones (*Plagiura-Poliella*, *Albertella*, *Glossopleura*, *Ehmaniella*, *Bolaspidella*, *Cedaria,* and *Crepicephalus* zones, in ascending order; Gabrielse et al. 1973, Gordey and Anderson 1993; Fig. 3-4).

Pratt (1988) documented a lenticular deep-water bioherm composed mostly of *Girvanella* and *Epiphyton* in the Rockslide Formation. Kimmig and Pratt (2015) documented a Burgess Shale-type Lagerstätte containing a low-diversity, deep-water assemblage of arthropods, hyoliths, priapulids, and algae. The Rockslide Formation reef and Lagerstätte were both deposited during the *Bolaspidella* Zone biochron, constraining them to the Drumian Age.

At its type section, the Rockslide Formation is considered to overlie quartz-sandy strata of the Backbone Ranges Formation unconformably. The interval directly below the Rockslide Formation type section is covered (Section 16, Gabrielse et al. 1973), and it is possible that it is underlain by recessive Sekwi Formation strata. The Rockslide Formation type section is overlain by limestone and dolostone of the Broken Skull Formation (Gabrielse et al. 1973). Elsewhere, the Rockslide Formation sharply but conformably overlies the Sekwi Formation and is consistently overlain by limestone and shale of the Rabbitkettle Formation (Gordey and Anderson 1993, Roots et al. 2011). Carbonates of the Haywire Formation (upper Cambrian to lower Silurian) overlie the Rockslide Formation in the Nahanni area (Gordey and Anderson, 1993). The Avalanche Formation is considered to be the lateral, shallow-water equivalent of the Rockslide Formation, replacing the Rockslide Formation eastward in the Glacier Lake and Nahanni areas (NTS 95L; Gordey and Anderson 1993; Roots et al. 2011). Gordey and Anderson (1993) considered the Rockslide Formation to have been deposited on a deep-water slope because of the presence of local slump structures. The Avalanche Formation was interpreted by

Gordey and Anderson (1993) to represent a shallow, subtidal to peritidal environment based on its dolomitic composition, floating quartz sand, and the presence of oncoids. The upper contact of the Rockslide Formation with the Avalanche Formation is diachronous; Avalanche Formation deposition may be laterally equivalent to all of Rockslide Formation or only a part of it (Gordey and Anderson 1993).

3.3.4 “Arches” and the Redstone Arch

The term “arch” is widespread in Phanerozoic stratigraphic literature but is rarely defined. Cecile et al. (1997) roughly defined an arch as an elongate, positive feature that had been subjected to numerous episodes of erosion on which anomalously thin and/or shallow-water strata had accumulated. “Arches” are thought to be episodically tectonically active, and their activity is commonly contemporaneous with distal basin evolution events such as abrupt deepening or shallowing episodes that cannot be satisfactorily explained by eustasy. An arch may, therefore, be defined as a long-lived paleotopographic high that was episodically tectonically active. Such features were probably occasionally subaerially exposed, resulting in erosional episodes. Williams (1987) speculated that tectonic arches and ridges may have formed islands during the Paleozoic. The existence of arches has been attributed to lithospheric bending or buckling, and the underlying crust is generally regarded as being cratonic (Balley 1989). Given how poorly defined and understood arches are, it is possible that multiple causes and underlying cratonic structures are responsible for them, including inverted extensional systems and lithospheric thermal events (Balley 1989).

The Redstone arch was an elongate, (present-day) northwest-trending feature that was present during the early Paleozoic along Laurentia’s (present-day) western margin (Gabrielse 1967; Cecile et al., 1997). Like the Mackenzie arch to its north, (Fig. 1), it is flanked to the southwest by the Selwyn basin and to the northeast by a shallow-water epicratonic basin (Aitken et al. 1973; Cecile et al. 1997; Dixon, 1997; Dixon and Stasiuk, 1998; Maclean 2011; Sommers et al. 2020), and was a fundamental feature in the tectonic evolution of Laurentia's paleo-margin, exerting a strong influence over depositional conditions in adjacent basins (Cecile et al., 1997).

3.4 MATERIALS AND METHODS

3.4.1 Fossil Material

Trilobite specimens (n=388) were identified to the lowest possible taxonomic level in order to provide as refined a temporal record of sedimentation as possible. Trilobite specimens were whitened with ammonium chloride sublimate and photographed with a Canon EOS T7i with a Tamron 90 mm lens under either a ring light or high-angle incident LED lighting. Photographs of each specimen were stacked and brightness and contrast were adjusted to enhance clarity using Adobe Photoshop 2022.

3.4.2 Stratigraphic Sections

Fossil material from two published stratigraphic sections was reassessed for this study: Gabrielse et al. (1973) sections 14/18 and 19. Gabrielse et al. (1973) measured these sections during Operation Nahanni in 1963 and 1965 and collected biostratigraphic samples from both. Fritz *in* Gabrielse et al. (1973) originally identified the fossils, compiled faunal lists, and gave age determinations, but no systematic taxonomy has previously been published for this material.

3.4.2.1 Gabrielse et al. 1973 Section 14/18

Section 14 is located slightly north of Redstone River (Figs. 3-3, 3-5, 3-6) and spans the informal "Sheepbed carbonate," Backbone Ranges, and Sekwi formations (Gabrielse et al. 1073;

MacNaughton and Fallas 2021). Gabrielse et al. (1973) originally identified the entirety of Section 14 as Backbone Ranges Formation. All three members of the Backbone Ranges Formation are present at section 14. The lower member is 259 m thick [not represented in Gabrielse et al.'s (1973) illustrations] and consists of interbedded sandstone and siltstone. The middle member is 52 m thick and consists of orange-weathering dolostone. Gabrielse et al. (1973) originally assigned the entirety of the rest of section 14 to the upper member of the Backbone Ranges Formation. Fritz (1981) and MacNaughton and Fallas (2021) reassigned the uppermost strata of section 14 to the Sekwi Formation, leaving 100 m of sandstone-dominated strata in the upper member of the Backbone Ranges Formation at that locality. The uppermost strata of section 14 (Sekwi Formation; 122 m thick) consist of dolostone, quartz sandstone, siltstone, and shale (MacNaughton and Fallas, 2021).

Section 18 is adjacent to Section 14 (~1.5 kilometres west of section 14 and is considered to be continuous with it (Figs. 3-3, 3-5, 3-6). The base of this section contains the upper Sekwi Formation (~40 m), which is dominated by siltstone. The rest of the section spans the Rockslide and Broken Skull formations. The Rockslide Formation is ~250 m thick and is dominated by thin-to-medium-bedded limestone and minor dolostone. Siltstone is a subordinate component of the Rockslide Formation. The overlying Broken Skull Formation is ~150 m thick and consists of thick- to -medium-bedded dolostone.

3.4.2.2 Gabrielse et al. 1973 Section 19

Section 19 is located ~35 kilometres west of Section 14/18 in the Wrigley Lake map area (Figs. 3-3, 3-5, 3-7) and spans the Sekwi, Rockslide, and Broken Skull Formations. The thickness of the upper member of the Backbone Ranges Formation was not recorded by Gabrielse et al. (1973). The Sekwi Formation consists almost entirely of dolostone except for an uppermost limestone unit and is ~30 m thick. The overlying Rockslide Formation (~275 m thick) consists mostly of medium-bedded limestone with minor dolostone and siltstone. The Broken Skull Formation is ~300 m thick and consists of thick-bedded dolostone in the lower half and thin-bedded limestone in the upper half.

3.5 RESULTS

3.5.1. Fossils and lithostratigraphy

3.5.1.1. Gabrielse et al. 1973 Section 14/18

GSC location 68967 (15 m above the base of the Sekwi Formation) contains an olenellid assemblage (*Olenellus*? sp. 2; Fig. 3-6, Table 1, Plate 5) from a siltstone interval (Gabrielse et al. 1973).

GSC location 68964 (88 m above the base of the Sekwi Formation) contains a siltstone-hosted olenellid assemblage (*Bolbolenellus* sp. 1, *Bolbolenellus* sp. 2, and *Olenellus* cf. *O. transitans*; Fig. 3-6, Table 1, Plates 1-4). (Gabrielse et al. 1973).

3.5.1.2 Gabrielse et al. 1973 Section 19

GSC location 68983 (~29 m above the base of the Sekwi Formation) contains a dolostone-hosted olenellid-ptychopariioid-dominated assemblage (*Olenellus*? sp. 1, "*Onchocephalus*" sp., and an indeterminate biceratopsid trilobite (Fig. 3-7, Table 2, Plate 5).

GSC location 68992 (~1 m above the base of the Rockslide Formation) contains *Ogygopsis spinulosa* Rasetti 1951, *Olenoides* sp., *Zacanthoides* cf. *Z. sexdentatus* Rasetti 1951, *Oryctocephalus indicus* Reed 1910, *Nyella*? sp., *Chancia* sp., *Yohoaspis*? sp. "*Syspacephalus*" *tardus*? Rasetti 1951, *Kochiella* sp., *Pachyaspis* sp., and *Pagetia bootes* Walcott 1916a (Fig. 3-7,

Table 2, Plates 5-8). These fossils were collected from an interval of fissile mudstone, and most are highly compressed.

GSC location 69004 (~72 m above the base of the Rockslide Formation, Fig. 3-7) contains *Hypagnostus* sp., *Elrathia* sp., and *Utaspis*? sp (Plate 9). GSC location 69005 (~81 m above the base of the Rockslide Formation, Fig. 3-7) contains *Hypagnostus* sp., *Utaspis*? sp., *Ptychagnostus*? sp., and *Eldoradia*? sp (Plate 9). GSC location 69007 (~87 m above the base of the Rockslide Formation) contains *Hypagnostus* sp., *Utaspis*? sp., *Ptychagnostus*? sp., and *Baltagnostus*? sp (Plate 9). GSC location 69008 (125 m above the base of the Rockslide Formation) contains a very weathered ptychopariid trilobite that is tentatively attributed to *Utaspis*? sp. (Plate 9; Fig. 3-). The uppermost GSC location, 68999 (~178 m above the base of the Rockslide Formation; Fig. 3-7), contains *Hypagnostus* sp., *Homagnostus*? sp., *Utaspis*? sp., and *Hemhirodon*? sp. (Plate 9). These fossils were collected from an interval of thin-bedded limestone to dolostone.

3.6 SYSTEMATIC PALEONTOLOGY

Class Trilobita Walch, 1771
Order Agnostida Salter, 1864
Suborder Eodiscinidae Kobayashi, 1939
Family EODISCIDAE Raymond, 1913
Genus *Pagetia* Walcott 1916a
Pagetia bootes Walcott 1916a
Appendix 3A, Plate 8, No. 10-22.

Pagetia bootes Walcott, 1916, p. 408, pl. 67, figs. 1, 1-a-f.
Pagetia bootes Rasetti 1951, p. 137, pl. 25, figs. 6-10.
Pagetia cf. *bootes* Rasetti 1951, pl. 33, fig. 11.
Pagetia bootes Rasetti 1966, pg. 504-505, pl. 59, figs. 11-13.

Pagetia bootes Fletcher and Collins 2003, fig. 5, pl. 18.

Material. 45 cranidia and 69 pygidia.

Discussion. Fritz designated two species of *Pagetia* in Gabrielse et al. (1973) at GSC location 68992: *P. clytia* and *P. resseri*. *P. resseri* has a cranidium with marginal furrows that are pitted and a pygidium with a wide axis and well-defined pleural ribs. None of the material from the 68992 collection appears to exhibit these features. *P. clytia* is very close to the pagetiid material from GSC location 68992, but has a short preglabellar field, four well-defined pygidial axial rings and a fifth poorly differentiated axial ring that merges with the posterior tip, and moderately well-defined pleural ribs. Cranidia in this collection exhibit a long preglabellar field, pygidia have 5 strongly to moderately well-defined axial rings and a posterior tip, and pleural regions of the pygidium that are highly effaced and bear no sign of well-defined ribs. *P. bootes* is consistent with these observations.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 section 19. *Albertella* Zone.

Suborder Agnostina Salter 1864

Genus *Hypagnostus* Jaekel 1909

Hypagnostus sp. cf. *H. parvifrons* Linnarson 1869

Appendix 3A, Plate 9, No. 8-13

cf. *Agnostus parvifrons* Linnarson 1869, p. 82, figs. 56 and 57.

cf. *Hypagnostus parvifrons* Cobbold and Pocock 1934, p. 343, pl. 44, figs. 13-19.

cf. *Hypagnostus parvifrons* Westergard 1946, p. 45, pl. 4, figs. 27-31.

cf. *Hypagnostus métisensis* Rasetti 1948, p. 320-321, pl. 45, figs. 21-27.

cf. *Hypagnostus parvifrons* Robison 1964, p. 529, pl. 81, figs. 4-23.

cf. *Hypagnostus parvifrons* Tortorello and Bordonaro 1997, p. 78-79, figs. 3.20-3.22.

Material. Ten cranidia, seven pygidia (1 worn and tentatively assigned), and one worn but complete individual.

Description. Cranidia overall circular, posterior margin subtransverse at axis and curved laterally. Border narrow, convex, and of consistent width throughout. Border furrow narrow and shallow. Posterior does not appear to bear any spines. Cranidum overall convex (dorsally). Axial and preglabellar furrows narrow and shallow. Glabella overall rectangular, sides parallel and straight, front gently rounded. Basal lobes triangular, separated from glabella by axial furrow and from genae by furrow that is sub-equivalent in depth and width to axial furrow and oriented at ~45° relative to axis.

Pygidium slightly longer than wide and of similar convexity to cranidium. No marginal spines are evident. Border thin at sides, thickening slightly posteriorly and reaching maximum width at posterior. Pleural fields smooth. Axis overall tapered, margins at midpoint slightly concave, end pointed. Length of axis is equivalent to ~4/5 of total length of pygidium. Axial furrows very thin and narrow.

Discussion. This species of *Hypagnostus* differs from the type, *H. parvifrons*, in that the posterior of the cranidium does not bear spines. The pygidia that have been assigned to this species are similar to *H. parvifrons* in gross aspect but are generally quite worn and appear to have an axis that terminates farther away from the posterior border. The poor state of the pygidia and the apparent morphological difference do not allow for confident assignment to *H. parvifrons*.

Occurrence. GSC location 69004, 69005, 69007, and tentatively 68999. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Genus *Itagnostus* Öpik 1979

Itagnostus? sp.

Appendix 3A, Plate 9, No. 14-16

Material. Ten cranidia.

Description. Cranidia slightly longer than wide. Anterior margin broadly curved. Anterior border thin, slightly convex; anterior border furrow shallow and wide. Border furrow narrows laterally and is slightly deeper along lateral margin. Pre-glabellar and pleural areas smooth and moderately convex. Glabella occupies ~1/3 of total length of cranidium. Anterior glabellar lobe equal to slightly more than 1/5 length of cranidium, front broadly curved, sides straight and parallel. Sides of posterior glabella lobe slightly tapered. Axial furrows narrow and shallow. Basal lobes small (~1/8 cranidial length) and triangular.

Discussion. Fritz originally designated this material as *Ptychagnostus*? sp. These cranidia lack a strongly tapered glabella and rugose genae, and the overall proportions are closer to other agnostines such as *Itagnostus*; glabellae are slightly tapered, and bear small basal lobes coupled with a transverse medial glabellar furrow and a thin cephalic border. This material is generally poorly preserved and is not confidently assigned to *Itagnostus*.

Occurrence. GSC location 69005 and 69007. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Genus *Baltagnostus* Lochman and Duncan 1944

Baltagnostus? sp.

Appendix 3A, Plate 9, No. 17 and 18

Material. Three cranidia and four pygidia.

Description. Cranidia slightly wider than long. Glabella occupies ~1/4 of cranidial length and ~1/3 of width, sides parallel, front of anterior lobe broadly curved. Axial furrows narrow and shallow. Median glabellar furrow transverse, of moderate depth, and narrow. Basal lobes triangular, separated from glabella by furrows that are equivalent in depth and width to axial furrows and oriented at 30°to axis. Orientation of posterior unclear.

Width of pygidium slightly greater than length. Anterior margin parallel along axis and directed backwards (~20° relative to transverse line), anterior border thin and convex, merges gradually with lateral border. Lateral border flat, widens posteriorly towards small, broad-based postero-lateral pygidial spine. Posterior border slightly convex and wider than lateral border. Posterior border furrow wide and shallow. Axis consists of three lobes. Anterior lobe wide (~1/3 width of pygidium; ~1/5 length), margins strongly curved. Middle lobe constricted, margins parallel and slightly convex. Margins of posterior tip initially directed outwards along anterior 1/3 of lobe, and then tapered backwards, terminating as moderately blunt tip. Pleural area smooth.

Discussion. *Baltagnostus* possesses a pygidium that is slightly wider than long and an axis that is slightly constricted at the middle. The posterior of the axis is bluntly rounded. Pygidia assigned to these species bear these features and have short, marginal spines that are Baltagnostus-like. The cranidia that are assigned to this species differ from cranidia assigned to *Itagnostus*? sp. mainly in that the glabella is wider. This material is sparse and generally poorly preserved, making the comparison to *Baltagnostus* tentative.

Occurrence. GSC location 69007. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Genus *Homagnostus* Howell 1935

Homagnostus? sp.

Appendix 3A, Plate 9, No. 19

Material. One pygidium.

Description. Length of pygidium ~4/5 that of width. Axis occupies most of length of pygidium excepting presumably the posterior border (which is chipped off). Axis consists of three lobes: 1) an anterior-most lobe equal to slightly less than 1/5 total length of pygidium, anterior concave, sides gently rounded, 2) a medial lobe slightly longer than anterior lobe and bearing a node on its posterior half, and 3) the posterior tip, which occupies ~1/2 of the length of the pygidium, tapers posteriorly, and terminates as a dull, rounded point. Pleural area smooth and evenly convex. Lateral border thin initially (~1/12) of pygidial width) and widening posteriorly, merging with slight postero-lateral pygidial spines that are directed straight backwards. Posterior border appears wider than average width of lateral border.

Discussion. This partial pygidium resembles other pygidia that have been assigned to *Homagnostus* in that it bears a medial node on the posterior part of the middle pydigial lobe. The overall parallel-sided nature of the axis and a posterior tip that (probably) nearly reaches or touches the posterior border. This pygidium differs in that the anterior axial lobe is not divided into three parts, and the medial node on the middle axial lobe is smaller compared to other representatives of *Hypagnostus*. These differences do not allow for confident assignment to *Hypagnostus*.

Occurrence. GSC location 68999. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Order Redlichiida Richter, 1932

Suborder Olenellina Walcott, 1890

Family BICERATOPSIDAE Pack and Gayle 1971

Genus *Bolbolenellus* Palmer and Repina 1993

Bolbolenellus sp. 1

Appendix 3A, Plate 1, No. 1-13; Plate 2, No. 1-9

Material. 51 cephala, twocephala with partial thoraxes, one near-complete individual, two juvenile cephala, three genae, four glabellae, and three worn, tentatively assigned cephala.

Description. Outline of cephalon overall pentagon-like; anterior 2/3 length (sag.) of cephalon approximates a half-circle. Proximal portion of posterior margin swept slightly back (~10°-20° relative to transverse line), distal portion advanced (~40° relative to sagittal line). Metagenal spines absent; proximal portion of posterior margin meets distal portion at blunt corner. Base of genal spines parallel to midpoint of L1. Genal spines slightly curved, directed outwards, average ~1/3 cephalic length. Anterolateral border present as rounded (dorsally) ridge, equal to 1/6 length of LA and of consistent width throughout. Posterior border slightly thinner than anterolateral border. Border furrow shallow and of consistent depth throughout, excepting the anterior portion of the cephalon where the junction between LA and the anterior border results in a narrower, slightly deeper furrow. LA globular, slightly wider than rest of glabella, equal to ~1/2 length of glabella (L0 exclusive), equivalent to slightly less than 1/3 maximum width of cephalon. L3 and L2 merged at distal margins. L1 of slightly less length than combined length of L3 and L2; both L1 and fused L3 and L2 overall chevron shaped. L0 equal in length to L1, anterior margin parallel to chevron outline of L1, posterior margin sub-transverse. L0 bears slight node at posterior. S3 V-shaped, merges across the sagittal axis. S2 slit-like, slightly convex anteriorly. S1 straight. S0 similar to S1 except deeper distally and terminating farther away from the sagittal axis. S2-S0 parallel and inclined forwards at ~20°relative to sagittal line. S3 inclined forwards slightly more (~30°). Ocular lobes originate at posterolateral corner of LA, reach maximum distal extent from glabella parallel to anterior of L2, and terminate parallel to the posterior of L1 or S0. Ocular lobes slightly rounded dorsally, of very low divergence from axis (~10°). Interocular area slightly arched, slopes sightly towards axis, equal to ~1/5 width of L0 at point of maximum width. Axial furrow shallow and absent opposite to L2. Extraocular area slightly convex and equal to slightly less than 1/3 total width of cephalon. Some cephala bear faint, concave anteriorly intergenal ridges (e.g., Appendix 3A, Plate 1, No. 8 and 10) which originate from slightly below the posterior tip of the ocular lobe and contact the posterior border at the midpoint of the proximal, swept back portion of the posterior margin.

Thorax is incompletely known. Prothorax consists of at least 3 segments. T1-T2 have tapering inner pleural regions that deflect posteriorly distal to the axis. T1-T2 pleural spines unknown. T3 is macropleural; inner pleural region flexed posteriorly and tapering such that it occupies only ½ of the total length of the pleurae at the 2/3 width point. T3 macrospine short and broad. T4-T13 progressively slope back more towards the posterior and bear tapering inner pleural regions that are overall convex anteriorly and posteriorly. T4-T13 spines slender and directed posteriorly.

Discussion. This species is best assigned to *Bolbolenellus* based on 1) ocular lobes that exhibit low divergence from the glabella and 2) a prominent, sub-spherical LA that is separated from the anterior border by only a furrow. Webster (2007) placed a high precedence on the former feature, which seems to be present in all species assigned to *Bolbolenellus*. *Nephrolenellus* and *Paranephrolenellus* are similar to *Bolbolenellus* but have ocular lobes with a higher angle of divergence relative to the axis (~30° to ~60° as opposed to ~10° to ~20°; Webster 2007, fig. 4C) and highly constricted L3-L0. *Arcuolenellus* is also similar to *Bolbolenellus* but has a swept back posterior margin and genal spines with bases that originate posterior to the point of maximum cephalic transverse width. *Bristolia* has a similar configuration of its ocular lobes, and the outline of the glabella is similar to *Bolbolenellus*. The configuration of its cephalon is different, however, in that the genal spines are highly advanced and have bases parallel to the anterior of L2 (Palmer and Repina, 1993).

This species has a few features that differ from some of the defining characteristics of *Bolbolenellus* as per Lieberman 1999. Namely, S1 and S2 do not conjoin across the axis as strongly as they do in other species of *Bolbolenellus*. Some cephala bear S1 and S2 that appear to be joined across the axis by a very faint furrow (e.g., Appendix B, Plate 1, No. 8, 11, and 13)- this characteristic appears variable in this material because of differential compaction. The weight of evidence best supports assignment of this material to *Bolbolenellus*, indicating that some aspects of the definition of the genus may have to be broadened.

Seven species aside from *Bolbolenellus* sp. nov. are treated herein as belonging to *Bolbolenellu*s: *Bo. euryparia* Palmer and Halley 1979, *Bo. altifrontatus* Fritz 1972, *Bo. spaerulosus* Fritz 1991, *Bo. bufrontis* Fritz 1991, *Bo. cylindricus* Palmer and Halley 1979, *Bo. brevispinus* Palmer 1998, and *Bo. dodoensis* Handkamer and Pratt 2022. It should be noted that the material figured in Palmer and Halley 1979 as *Bo. cylindricus* are probably not all conspecific- fig. 2-14 has a posterior margin that is subtransverse rather than transverse and then advanced, and that cephalon was questionably assigned to that species by Palmer and Halley 1979. The outline of *Bo. groenlandicus* Poulsen 1927 is quite disparate from other representatives of the genus in that its genal spines are highly advanced, and *Bristolia* may also be a more valid comparison for that species. *Bo. hermani* Kindle and Tasch 1948 is not considered herein owing to taxonomic uncertainty; it may or may not be synonymous with *Bo. brevispinus* (Lieberman 1998, 1999; Webster and Landing, 2016). *Bo. euryparia* differs from this species in that it has an LA that is slightly wider transversely that deflects the anterior border, a more constricted L3 to L0, and an L3 and L2 are separated rather than fused. *Bo. altifrontatus*, *Bo. sphaerulosus*, and *Bo. bufrontis* can be distinguished from this species by their swept back posterior margins. *Bo. cylindricus* differs from this species in that its LA expands more prominently along its posterior half and its posterior margin is initially subtransverse rather than swept slightly back, and genal spines with bases parallel to L3 rather than L2. *Bo. brevispinus* differs from this species in that it has a crestlike spine on the posterior of LA. *Bo. dodoensis* differs from this species mainly in that it possesses far less advanced genal spines and has an LA that slightly deflects the anterior border.

Occurrence. GSC location 68964. Sekwi Formation, Gabrielse et al. 1973 Section 14. Upper *Bonnia-Olenellus* Zone.

Bolbolenellus sp. 2

Appendix 3A, Plate 2, No. 10 and 11

Material. 2 cephala and 1 cephalon with a partial thorax.

Description. Similar in most aspects to *Bolbolenellus* sp. 1 except for the following features: 1) genal spines that are moderately less advanced (bases parallel to anterior of L1 rather than posterior), and 2) a posterior margin in which the transition from the transverse, proximal portion to the advanced, distal portion is rounded rather than sharp and angular.

Discussion. These differences probably cannot be accounted for by compaction, making the assignment of a separate species of *Bolbolenellus* more plausible.

Occurrence. GSC location 68964. Sekwi Formation, Gabrielse et al. 1973 Section 14. Upper *Bonnia-Olenellus* Zone.

Indet. biceratopsid

Appendix 3A, Plate 5, No. 5-7

Material. 1 partial cephalon and 3 genae.

Description. Partial cephala with advanced genal spines.

Discussion. Specimen 83-3A (Appendix B, Plate 5, No. 5) exhibits an ocular lobe that is strongly directed outwards. Highly advanced genal spines are common in olenellids, but the combination of advanced genal spines and ocular lobes that are directed strongly outwards is similar to several biceratopsid genera including *Nephrolenellus* and *Paranephrolenellus*. Biceratopsidae is therefore the most plausible family for this material to be assigned to.

Occurrence. GSC location 68983. Sekwi Formation, Gabrielse et al. Section 19. Upper *Bonnia-Olenellus* Zone.

Family OLENELLIDAE Walcott 1890

Olenellus sp. cf. *O. transitans* Walcott 1910

Appendix 3A, Plate 3, No. 1-11, Plate 4, No. 1-9

See Webster and Landing (2016) for a synonymy list of *Olenellus transitans*.

Material. Seven cephala, six cephala with associated thoraxes, one juvenile cephalon, one thorax, two genae, and 2 glabellae.

Description. Outline of cephalon overall semicircular. Posterior cephalic margin angled backwards on intermediate-sized cephala (~5-10°) and subtransverse on larger cephala. Metagenal spines or swellings absent. Genal spines slender, directed slightly outwards, and equal to ~1/2 length (sag.) of cephalon. Base of genal spines parallel to posterior of occipital ring.

Anterolateral cephalic border well-defined and slightly convex; width equal to ~1/5 length of LA. Anterolateral border furrow of consistent, moderate depth throughout. Posterior border thinner and slightly more convex than anterolateral border. Length of preglabellar field generally slightly less than width of anterior border. Plectrum absent. Glabella slightly constricted from occipital ring to L1. L2 and L3 expand slightly outwards and are of subequivalent width as LA. Anterior of LA gently rounded, tangent of margin is parallel to axis at ½ length of LA and then slopes outwards to merge with ocular lobes. L3 and L2 merged at distal margins. L3 chevron-shaped, margins angled inwards 40° relative to axis. L2 margins obscured by fused L3. Margins of L1 slightly convex, angled inwards at ~15° relative to axis. Margins of occipital ring straight to gently curved, parallel to axis. S3 deepest and slit-like distally and shallows towards the axis in non-compacted specimens. Compacted specimens exhibit an S3 that apparently merges across the axis and is of more consistent depth. S2 slit-like. S1 convex anteriorly, of moderate depth; tangent to apex of curve angled 20° from transverse line. Occipital furrow sub-parallel to S1 but terminates closer to margins of glabella. Ocular lobes crescentic, originate at posterolateral corner of LA, reach maximum distal extent from axis parallel to S2, and terminate parallel to posterior of L1 or S1. Interocular area equal to 1/3 width of L1. Posterior 2/3 length of interocular area slightly swelled dorsally and convex (Appendix 3A, Plate 3, No. 7). Extraocular area gently convex and equal to slightly less than 1/3 maximum width of cephalon. Extraocular area marked by faint genal caeca in well-preserved specimens. Faint genal ridges extend from the ½ length point of the ocular lobes and terminate distally in the genal field, often bifurcating and merging with genal caeca. Intergenal ridge extends from posterior tip of ocular lobes, slopes gently posteriorly, and merges with posterior border at 2/3 half width from axis.

Thoracic remains are incomplete. Prothorax appears to have 14 segments. Width of axis approximately 2/3 that of T1. Some axial rings bear faint, medial nodes (Appendix 3A, Plate 3, No. 6). Inner pleural region of T1 and T2 subtransverse and taper distally. Pleural spines slender, directed slightly outwards. T3 macropleural; inner pleural region convex anteriorly and straight posteriorly. T3 macrospine broad and directed more strongly backwards. Posterior segments (T4-T14) bear inner pleural regions that are convex anteriorly and directed slightly backwards. T4-T14 bear spines that are essentially similar to those of T1 and T2. T14 may bear an elongate spine. Opisthothorax is unknown.

Discussion. This species is similar to *O. transitans* in gross effect but differs in that 1) it lacks well-defined metagenal swellings or spines, 2) its preglabellar field is less long, 3) it lacks a plectrum, and 4) *O. transitans* lacks nodes on its glabellar furrows. *O. puertoblancoensis* is also similar to this species and has a preglabellar field of similar proportions but has a more transverse posterior margin.

Occurrence. GSC location 68964. Sekwi Formation, Gabrielse et al. 1973 Section 14. *Bonnia-Olenellus* Zone.

Olenellus? sp. 1

Appendix 3A, Plate 5, No. 3 and 4

Material. Three genae and one partial juvenile cephalon.

Description. Partial cephala with subtransverse posterior borders that bear a pronounced intergenal swelling and ocular lobes that terminate parallel to the occipital ring or the posterior of L1.

Discussion. The general proportions of one juvenile cephalon collected from GSC location 68983 seem to match *Olenellus* more closely than most other known olenellid genera. Genae that exhibit subtransverse posterior borders are also assigned to this species. The sparseness and incompleteness of this material does not allow for confident generic assignment.

Occurrence. GSC location 68983. Sekwi Formation, Gabrielse et al. 1973 Section 19. *Bonnia-Olenellus* Zone.

Olenellus? sp. 2

Appendix 3A, Plate 5, No. 1 and 2

Material. Two partial cephala.

Description. Cephalic outline unknown. Anterolateral border convex and defined by a shallow border furrow. Preglabellar field equal to ~1/4 length of LA; plectrum absent. Anterior of LA rounded, margins of LA swept back. L3 and L2 merged. Margins of L3 inclined inwards at 30° relative to axis. Margins of L2 appear rounded. Margins of L1 parallel to that of L3. S3 shallow, convex anteriorly at distal margins of glabella and joined across axis. S2 pit-like. S1 deeper and broad, oriented at ~40° relative to transverse line. Ocular lobes initially directed strongly outwards, reach maximum distance from axis parallel to S1, and terminate parallel to L1. Genae bear a short genal spine.

Discussion. These cephala are too fragmentary to be assigned with confidence to a genus. A merged L3 and L2 is characteristic of *Olenellus*, making that genus the closest comparison.

Occurrence. GSC location 68967, Sekwi Formation, Gabrielse et al. Section 14. *Bonnia-Olenellus* Zone.

Order Ptychopariida Swinnerton 1915

Family PTYCHOPARIIDAE Matthew, 1887

Genus *Chancia* Walcott 1924

Chancia sp.

Appendix 3A, Plate 7, No. 13-15

Material. One cranidium with a partial thorax and exuviated librigenal, one partial cranidium with a partial thorax, and two associated pygidia.

Description. Cranidium overall trapezoidal. Anterior margin gently rounded, convex, of equal height (dorsally) as glabella, and equal to ~1/7 of cranidial length. Pre-glabellar area very slightly convex and slightly less than twice the length of the anterior margin. Anterior limb of facial sutures convex and directed inwards. Glabella moderately tapered, sides slightly concave, front gently rounded. Axial furrows of moderate depth and narrow, preglabellar furrow narrow and shallower. S3 and S2 shallow, lateral, and subtle; S2 extents slightly farther towards the axis than S3. S1 convex anteriorly and deeper. Occipital furrow sub-transverse, deep, and narrow, slightly convex anteriorly at axis and directed outwards laterally. Palpebral area slightly convex, equivalent to width of glabella at base. Palpebral lobes narrow, crescentic, and centered opposite S2 (~midpoint of glabella). Ocular line convex anteriorly, well-defined, and originates from immediately posterior the anterior of glabella. Posterior limb of facial sutures initially concave along anterior ½ and then convex. Posterior limb of cranidium wide, equivalent to ~2/5 of maximum width of cranidium. Posterior border furrow wide, deep, and sub-transverse. Posterior border thin and convex; posterior margin directed slightly backwards.

Librigena ~1/5 of total cephalic width. Distal, lateral margin broadly curved. Genal field very slightly convex. Inner margin initially concave, convex along medial 1/3, and then directed strongly outwards. Genal spine appears slight, length unknown.

Number of thoracic segments unknown. Pleurae oriented slightly backwards, inner pleural area parallel to orientation of pleurae and tapering laterally. Tips of pleurae pointed.

Associated pygidia are overall triangular in outline. Axis strongly tapered, consists of articulating half-ring, 5 well-defined axial rings, and a terminal piece that terminates at the border. Pleural area bears 4 ribs, each bearing a narrow adaxial furrow. Anterior of pygidium convex and swept slightly backwards. Lateral and posterior border narrow and flat.

Discussion. Walcott (1924) defined *Chancia* as having a wide cephalon with fixigena that are sub-equivalent in width to the glabella at their narrowest point, small palpebral lobes, and a wide anterior border that is separated from the rim by a pronounced, transverse furrow. Trilobites that were assigned to *Chancia* subsequently (e.g., *Chancia maladensis*; Sundberg 2018) lack as wide a border as the type, *C. ebdome* Walcott 1924. The two specimens assigned to *Chancia* herein more closely resemble *C. maladensis* in that they have a narrower anterior border and a longer preglabellar field.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Genus *Kochiella* Poulsen 1927

Kochiella sp.

Appendix 3A, Plate 8, 1-4

Material. Five cranidia.

Description. Cranidium sub-trapezoidal, anterior margin strongly curved. Anterior border concave, equal to ~1/5 cranidial length at maximum (middle). Preglabellar field slightly convex, roughly half length of anterior margin. Anterior border furrow narrow and shallow. Anterior limb of facial suture straight and divergent between palpebral lobes and anterior border, and then slightly convex and convergent along anterior border. Glabella narrow, front broadly curved, glabellar furrows faint. Ocular line faint, convex anteriorly, originates from anterior 1/5 of glabella and terminates at anterior 2/5 point of glabella. Palpebral lobe crescentic, equal to ~1/3 length of glabella and centered opposite glabellar midpoint. Palpebral area slightly convex, equal to width of glabella at maximum (~1/3 total width of cranidium). Posterior margin slightly concave. Posterior border furrow wide, deep, and follows trace of posterior margin. Occipital ring thin, posterior convex. Occipital furrow transverse and of moderate depth and width. One well-preserved cranidium (Appendix 3A, Specimen 92-13B, Plate 8, No. 2) bears faint granulation.

Discussion. The combination of a concave anterior border, granulation, low cranidial relief, and relatively long, curved palpebral lobes are consistent with the definition of *Kochiella*. The associated pygidia are triangular and micropygous, which is typical of many ptychopariids. Kochiella, however, has a pygidium that bears broad, flat lobes on either side. These pygidia probably belong to another genus but are tentatively kept with the five cranidia that are more confidently assigned to *Kochiella*.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1972 Section 19. *Albertella* Zone.

Genus *Nyella* Palmer and Halley 1979

Nyella? sp.

Appendix 3A, Plate 7, No. 5 and 6

Material. Two partial cranidia.

Description. Cranidium of overall moderate convexity (dorsally). Anterior border broadly curved, anterior margin raised, convex and slightly raised upwards anteriorly, tapering slightly laterally. Anterior border furrow shallow and subtle. Anterior branches of facial sutures slightly convergent (~10°), straight sided. Preglabellar field convex, slightly swollen along central ½ of cranidium length slightly greater than that of anterior border. Glabella moderately tapered, sides straight or slightly concave, front blunt and slightly curved. Width of glabella equal to slightly less than 1/3 total width of cranidium. Axial furrows deep, narrow; slightly shallower at anterior of glabella. Three shallow glabellar furrows present: S3 slightly convex anteriorly and directed very slightly anteriorly, S2 straight and directed posteriorly (~40° relative to transverse line), S1 straight or slightly curved, directed posteriorly (~40°-50° relative to transverse line), and slightly deeper than S3 and S2. Fixigena slightly convex, equal to ~1/3 width of cranidium at widest point. Ocular ridges moderately defined, curved anteriorly; originate from anterior of glabella slightly above S3 and terminate parallel to S2.

Discussion. These partial cranidia are best assigned to *Nyella* based on their relatively strongly tapering, straight to concave-sided glabellae that are well-defined by deep axial furrows, anterior facial sutures that are fairly straight and convergent, and a convex, relatively well-defined anterior border. *Kochaspis* is a similar genus to *Nyella* but has a “bowed-out” anterior branch of its facial sutures and a slightly more tapered glabella. *Kochiellina* has a flat or concave border that contains a medial swelling. *Kochiella* is also morphologically disparate from this material in that most of its representatives appear to have a concave anterior border as well as wider fixigena. Fritz (in Gabrielse et al. 1973) designated this material as cf. *Kochiella* in his faunal list. It is difficult to assign this material definitively to most known kochaspid genera because of its incompleteness, hence it is only questionably assigned to *Nyella*.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Genus *Onchocephalus* Resser 1937

"*Onchocephalus*" sp.

Appendix 3A, Plate 5, No. 8-12

Material. Five cranidia.

Description. Cranidium roughly trapezoidal in outline and of high dorsal convexity. Anterior margin of moderate curvature; anterior border highly convex, curved, and tapers laterally. Anterior border furrow of moderate depth and broad towards margins, slightly shallower medially. Anterior branch of facial sutures initially convergent from palpebral lobes to anterior border, parallel to axis to slightly divergent initially along the border, and then strongly convergent anteriorly. Preglabellar field slightly convex, equal to slightly more than 1/5 length of cranidium and slightly less long than anterior border. Anterior margin of glabella slightly curved to nearly straight, glabellar margins straight or slightly convex. Length of glabella equal to ¾ length of cranidium. Preglabellar furrow shallow; axial furrows moderately deep and wider. S3 convex anteriorly, shallow and narrow, tangent to apex of curve directed inwards at 30° relative to transverse line; S2 shallow, narrow, convex anteriorly, and roughly transverse; S1 slightly deeper, convex anteriorly and directed inwards. Palpebral lobes equal to ~1/4 length of glabella and centered opposite glabellar midpoint. Ocular line indistinct, originates from immediately posterior to anterior of glabella and terminates parallel to S2. Palpebral area gently convex dorsally and subequivalent to width of glabella. Occipital furrow deep, broad, and transverse; occipital ring equal to 1/3 length of rest of glabella. No occipital node is evident. Posterior margin directed slightly backwards and straight. Posterior border furrow slightly convex at anterior portion, broad, deep, and straight along posterior portion.

Discussion. Sundberg and McCollum (2000) suggested that *Onchocephalus* ought to be restricted to its type material owing to its poor preservation. Numerous Cambrian "ptychoparioid" genera are poorly defined, based on problematic type material, morphologically similar, known from partial sclerites, or some combination of these listed issues (Sundberg and Webster 2022). *Onchocephalus* is a problematic genus because of many of these factors and is referred to in open nomenclature herein.

Occurrence. GSC location 68983. Sekwi Formation, Gabrielse et al. 1973 Section 19. *Bonnia-Olenellus* Zone.

Genus *Pachyaspis*

Pachyaspis sp.

Appendix 3A, Plate 7, No. 1-4.

Material. Seven cranidia and one isolated glabella.

Description. Cranidium approximates trapezoid; length ~4/5 width. Anterior margin broadly curved; convex; equal to ~1/5 length of glabella at midpoint but tapers distally from axis. Preglabellar field equal in length to anterior margin. Glabella ~4/5 length of cranidium. Anterior of glabella very broadly curved; almost quadrate; lateral margins very slightly concave and slightly expanding outwards posteriorly. S3 faint; convex anteriorly; S2 sub-parallel, convex anteriorly, and deeper; S1 deeper still and forked at 2/3 length, closest to axis. Occipital furrow slightly convex anteriorly across middle ~1/2 and then angled anteriorly at margins. L0 equal to ~1/4 length of glabella; posterior convex. Ocular line faint; convex anteriorly; originates slightly above S3 and terminates slightly above S2. Palpebral lobes straight, equal to >1/4 length of glabella, centered slightly anteriorly to glabellar midpoint, and directed outwards at ~10° relative to axis. Anterior margin of facial suture straight to slightly convex; directed outwards at ~5° relative to axis. Posterior limb of facial suture more strongly convex, directed outwards at ~10°. Posterior margin directed very slightly backwards; thinner than occipital ring and tapering inwards. Posterior border furrow deep and wide; tapers slightly inwards.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. Section 19. *Albertella* Zone.

Genus *Syspacephalus* Resser 1936

Discussion. *Syspacephalus* is referred to in open nomenclature in this paper for similar reasons as *Onchocephalus*.

"*Syspacephalus*" *tardus*? Rasetti 1951

Appendix 3A, Plate 6, No. 14-20

Syspacephalus tardus Rasetti 1951, p. 247, pl. 22, figs. 7-10.

Material. 24 cranidia.

Discussion. This material has the same general proportions as *Syspacephalus tardus* Rasetti 1951. Rasetti's 1951 material displays slightly longer posterior limbs- this apparent difference is attributed to compaction. The compacted state of this material does not allow for these cranidia to be confidently attributed to the species.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Genus *Yohoaspis* Rasetti 1951

Yohoaspis? Sp.

Appendix 3A, Plate 7, No. 7-12

Material. Eight cranidia.

Description. Cranidium overall trapezoidal in shape and apparently of low (dorsal) convexity. Anterior broadly curved. Anterior border long (slightly less than ¼ total length of cranidium) and strongly concave. Anterior border tapers slightly laterally; posterior margin of anterior border curved towards margins and straight medially. Anterior border furrow consistently of moderate depth and width throughout, excepting the area that is directly anterior to the glabella where it is deeper and constricted. Anterior branch of facial suture straight or slightly convex and directed outwards (~15° relative to axis) initially until mid-length and then convergent. Glabella occupies ~3/4 of total length of cranidium (including occipital ring). Margins of glabella straight to slightly concave, gently tapering; front of glabella gently and evenly curved. Width of glabella at base equal to slightly more than ¼ width of glabella at widest point; width of glabella at anterior ~3/4 width of base. Axial furrows deep, narrow; preglabellar of similar width but shallower. Preglabellar field virtually absent. S3 straight to slightly convex anteriorly and oriented transversely. S2 convex anteriorly, shallow, narrow, and oriented at ~45° relative to axis. S1 parallel to S2 but deeper. Medial portion of occipital furrow deep, broad, and transverse; margins shallower and directed slightly anteriorly (~10°. Occipital ring of equal height as rest of glabella, equal to 1/5 length of glabella, and follows trace of occipital furrow. Occipital node absent. Palpebral area slightly convex, equal to 1/5 width of cranidium. Palpebral lobes small and crescentic, equal to 1/5 length of glabella, and centered opposite midpoint of glabella. Ocular line poorly defined and convex anteriorly, originating slightly anterior to S3 and terminating at junction with palpebral lobe parallel to S2. Posterior margin slightly concave, overall transverse. Posterior border tapers inwards. Posterior border furrow deep, wide, and slightly convex anteriorly. Posterior portion of fixigena convex, terminates as sharp triangle, and equal to ~1/6 length of cranidium close to the axis.

Discussion. Rasetti (1951) erected *Yohoaspis*, which is currently conspecific and contains only the type, *Y. pachycephalus*. Rasetti 1951 listed several criteria for *Yohoaspis*, including: 1) a cranidium of high relief, 2) indistinct glabellar furrows, 3) an anterior margin that is wide and occludes the preglabellar field, resulting in the glabella being separated from the anterior margin by only a furrow, 4) narrow palpebral lobes couple with indistinct ocular lines, and 5) facial sutures in which the anterior is fairly divergent. The first of these criteria cannot be evaluated with the material in this study that has been assigned to *Yohoaspis* owing to its compacted nature. The latter features correspond strongly to this material: ptychoparioid trilobites with long, concave anterior borders, virtually no preglabellar field, small palpebral lobes parallel to the glabellar midpoint, anterior branches of facial sutures that are divergent, a wide posterior portion of the cranidium, and faint ocular lines seem to correspond strongly to Rasetti's (1951) definition of *Yohoaspis*. This species differs from *Y. pachycephala* in that it bears a more gently curved anterior, has slightly more distinct glabellar furrows, an overall wider cranidium, and an anterior border furrow that is transverse medially and then convex anteriorly laterally as opposed to entirely transverse.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Family ALOKISTOCARIDAE Resser 1939

Genus *Elrathia* Walcott 1924

Elrathia sp.

Appendix 3A, Plate 9, No. 1

Material. One small cranidium.

Description. Outline of cranidium trapezoidal. Anterior border convex, equal to 1/12 length of cranidium. Anterior border furrow narrow and shallow. Anterior margin broadly and evenly curved. Posterior limb of facial sutures directed slightly inwards and convex from palpebral lobes to anterior border and then directed straight forwards along border region. Preglabellar field slightly convex and twice the length of the anterior border. Lateral glabellar margins slightly tapered and slightly convex overall, anterior margin broadly curved. Glabella occupies slightly more than ¾ length of cranidium. Glabellar furrows shallow and poorly visible- S1 appears convex anteriorly and directed backwards. Palpebral lobes crescentic, equal to slightly more than 1/3 length of glabella and centered slightly anterior of the glabellar midpoint. Ocular lines slightly convex anteriorly and poorly visible. Palpebral area slightly convex and equal to ¼ width of glabella. Posterior margin transverse; posterior border furrow slightly convex anteriorly, deep, and moderately wide.

Discussion. A lightly tapered, poorly furrowed glabella, evenly rounded anterior margin, an anterior border that is ~1/2 the length of the preglabellar field, and fixigenae that are ~1/2 the width of the glabella at its base are all consistent with *Elrathia*. Anterior facial suture branches that are initially divergent and then converge are also consistent with *Elrathia*.

Occurrence. GSC location 69004. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Genus *Utaspis* Robison 1964

Utaspis? sp.

Appendix 3A, Plate 9, No. 2-5 and 7

Material. Eight cranidia, four juvenile cranidia, three pygidia, two glabellae, three near-complete individuals, and one badly weathered, tentatively assigned individual (from GSC location 69008).

Description. Cranidia of small to moderate size and moderately convex dorsally. Anterior margin broadly and evenly curved. Anterior border convex, equal to ~1/6 length of cranidium medially and tapers laterally. Pre-glabellar field sub-equal or less in length than anterior border, slightly convex. Anterior branch of facial suture initially divergent (~15° outwards from axis) from palpebral lobes to posterior of anterior border and then strongly convergent across anterior border. Glabella of moderate taper, sides straight, front strongly rounded. Glabellar furrows mostly effaced; S1 and S2 (both straight and oriented at ~30° relative to transverse line) visible on some exfoliated specimens. Occipital furrow transverse and shallow medially, deepening laterally. Anterior of occipital ring transverse and straight; posterior convex and longest medially, tapering towards margins. Axial and preglabellar furrows narrow and shallow. Ocular line absent. Palpebral lobes crescentic, centered opposite glabellar midpoint, and equal to slightly less than 1/3 length of glabella. Palpebral area broadly convex and narrow (equal to 1/3 width of glabella at midpoint). Posterior branch of facial suture convex, directed strongly outwards. Posterior area of cranidium convex and overall triangular due to orientation of posterior facial suture. Posterior border furrow broad, deep; posterior border tapers inwards and is of moderate convexity. Posterior overall directed slightly backwards; margin straight to slightly convex. Specimens preserving the exterior of the cranidium in detail bear numerous, small granules (Plate xxx-x).

Thorax equal to ~3/5 of total length of exoskeleton, consists of 13 segments, and tapers towards pygidium. Axis equal to ~1/4 width of thorax. Pleurae oriented slightly postero-laterally; inner portion of pleurae tapers laterally and overall parallel to orientation of pleurae. Tips of pleurae bluntly rounded.

Pygidium small, equal to ~1/10 length of exoskeleton. Anterior margin slightly rounded and directed backwards. Posterior margin broadly curved. Antero-lateral corner opposite posterior of second axial ring. Axis consists of two distinct rings and posterior piece. Axis overall gently tapering, rear of posterior tip only slightly curved. Border wide, border furrow absent. Pleural area slightly convex, consists of three poorly defined ribs. Anterior two ribs bear faint interpleural furrows.

Discussion. *Utaspis* is similar in cranidial proportions to *Elrathia* but has a more elongate pygidium with more axial rings and a prominent anterolateral spine. *Modocia* is also a similar genus but differs from *Elrathia* in that the anterior portion of its facial sutures are convergent. *Marjumia* has a narrower palpebral area, longer palpebral lobes, and a thinner posterior area of the cranidium. Most species of *Elrathia* differ from this species slightly in that they possess slightly wider palpebral areas and a glabella that is slightly less tapered with a more broadly curved front. These features are similar to the configuration of *Utaspis marjumensis* Resser 1935. Robison (1964) hypothesized that *Utaspis* and *Elrathia* are very closely related genera, and some gradation between them may be expected if this hypothesis is true. In addition, pygidia assigned to this species differ from other species of *Elrathia* and the other genera mentioned in this discussion in that they possess only 2 axial rings rather than 3-5.

Occurrence. GSC locations 68999, 69004, 69005, 69007, and tentatively 69008. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Family BOLASPIDIDAE Howell *in* Harrington et al. 1959

Genus *Eldoradia* Resser 1935

Eldoradia? sp.

Appendix 3A, Plate 9, No. 20

Material. Two partial cranidia.

Description. Anterior border equal to slightly more than 1/6 length of glabella. Anterior border long, equal to ~1/4 cranidial length, appears to bear medial swelling. Glabella quadrate; sides straight and tapering, anterior margin straight. Axial furrows deep and of moderate depth, anterior glabellar furrow shallower and narrower. Glabellar furrows shallow and present only on glabellar margins: S3 transverse; S2 slightly deeper and directed very slightly backwards; S1 deepest, orientation unclear. Palpebral lobes centered opposite glabellar midpoint. Ocular lines effaced. Occipital furrow wide and deep; occipital ring swept back posteriorly, posterior convex.

Discussion. The slight medial swelling that is visible on specimen 05-1G (Appendix 3A, Plate 9, No. 20) is chipped but is somewhat *Eldoradia*-like. *Acrocephalops* is similar but has significantly longer palpebral lobes. The two cranidia assigned to this species are incomplete and damaged, making confident assignment to the genus impossible.

Occurrence. GSC location 68905. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Order Corynexochida Kobayashi 1935

Family DOLICHOMETOPIDAE Walcott 1916b

Genus *Hemhirodon* Raymond 1937

Hemhirodon? sp.

Appendix 3A, Plate 9, No. 6

Material. Two partial pygidia.

Description. Large pygidia with slightly convex pleural areas that bear moderately well-defined interpleural furrows.

Discussion. These partial pygidia are *Hemirhodon*-like, but the incompleteness and sparseness of the material does not allow for confident assignment.

Occurrence. GSC location 68999. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Family DORYPYGIDAE Kobayashi 1935

Genus *Ogygopsis* Walcott 1889

Ogygopsis spinulosa Rasetti 1951

Appendix 3A, Plate 5, No. 13-17; Plate 6, No. 1-8

Ogygopsis spinulosa Rasetti 1951, p. 192, pl. 21, fig. 4.

Material. One near-complete individual, eight cranidia, one glabella, and 22 pygidia.

Description. Anterior margin broadly rounded. Anterior border convex, equal to ~1/14 total length of cranidium medially and tapering slightly laterally. Pre-glabellar field virtually absent. Preglabellar furrow wide and deep, separating the anterior border from the glabella. Glabella occupies ~9/10 of length of cranidium, sides straight to slightly concave, anterior margin gently curved. Glabellar furrows absent. Occipital furrow perpendicular to axis, broad, deep, and straight. Anterior margin of occipital ring straight, posterior convex. Anterior branch of facial sutures convex from palpebral lobes to anterior border and directed slightly outwards. Ocular lines originate from anterior ¼ of glabella and terminate parallel to slightly anterior of middle of glabella. Palpebral lobes crescentic, slightly curved, and directed nearly straight backwards at termination. Palpebral lobes centered slightly behind midpoint of glabella. Palpebral area appears slightly convex, equal to ~1/4 of width of cranidium at palpebral lobes. Margins of posterior portion of facial sutures slightly convex and directed strongly outwards. Posterior border furrow wide, deep, and transverse. Posterior border thin and convex.

Thorax consists of 8 segments. Margins of thorax parallel. Axial furrows narrow. Width of axial rings ~1/4 width of thorax. Pleurae subtransverse along proximal two thirds and then turned back along distal 1/3, terminating with narrow spine. Interpleural furrows narrow, straight, and directed slightly adaxially (anteriorly).

Rasetti (1951) described the pygidium of this species.

Discussion. Rasetti (1951) erected *Ogygopsis spinulosa* based only on pygidial material. Although specimens assigned to this taxon in this paper include other segments, all the cranidia are rather compacted, and data on the anterior of this species is still limited. The pygidia herein are very close to Rasetti's (1951; Pl. 22-4) figured material in that they are similar to *Ogygopsis klotzi* Rominger 1887 but lack interpleural furrows, have a shorter axis, and bear minute spines along the pygidial margin.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Bolaspidella* Zone.

Genus *Olenoides* Meek 1877

Olenoides sp.

Appendix 3A, Plate 6, No. 9-13

Material. Ten pygidia and two tentatively assigned cranidia.

Description. Tentatively assigned cranidia bear smooth, parallel-sided, glabellae (~9/10 cranidial length) with slightly convex margins. Occipital furrow curved posteriorly, deep, and moderately wide. Ocular line directed strongly backwards and convex anteriorly, originates slightly posterior from anterior ¼ point of glabella and terminates parallel to glabellar midpoint. Palpebral lobes crescentic, centered posterior from glabellar midpoint; tips directed slightly inwards.

Pygidia are overall semi-circular. Margins are flanked by 10 small spines, each originating from the posterior of its adjacent pleural band. Axis consists of articulating half-ring, 9 axial rings and a terminal piece and occupies 7/8 of total pygidial length. Posterior 2 axial rings (excluding terminal piece) thinner and separated by fainter lateral furrows. Anterior margins convex anteriorly and swept slightly back. Pleural bands swept back, each bearing a faint pleural furrow. Interpleural furrows moderately wide and deep, becoming slightly shallower posteriorly. Postero-lateral border thin and ill defined.

Discussion. The tentatively assigned cranidia appear superficially similar to cranidia assigned to *Ogygopsis spinulosa* but have palpebral lobes with tips that are directed slightly inwards rather than straight back.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Family ORYCTOCEPHALIDAE Beecher 1897

Genus *Oryctocephalus* Walcott 1886

Oryctocephalus indicus Reed 1910

Appendix 3A, Plate 8, No. 23-26

See Sundberg et al. (2011) for a synonymy list. See Esteve et al. (2017) for discussion on the taphonomy of *O. indicus* and synonymy.

Material. Three cranidia, one partial thorax and pygidium, and one partial pygidium.

Discussion. This material satiates the criteria for the species in that it has a slightly conical glabella, transglabellar glabellar furrows, crescentic, posterolaterally directed palpebral lobes, a very gently curved, nearly straight anterior margin, and a pygidium that consists of 3 segments.

Esteve et al. (2017) quantified morphological variation in specimens of *Oryctocephalus indicus* in several sections from China. This material generally appears to fall within the bounds of variation that is expected in *O. indicus*. The apparent differences between these specimens and the types are accounted for by compaction. The occipital furrow in these specimens appears as a straight line with only slight lateral pits. The glabellar margins also appear “bowed-out” parallel to S2 and S1. The former morphological difference can be seen in specimens that Esteve et al. 2017 assigned to *O. indicus* (e.g., Esteve et al. fig. 15D), and the latter is also apparent in some of the figured specimens in that publication (e.g., Esteve et al. Fig. 15B). If it is accepted that this material can be assigned to *O. indicus*, this represents the first recorded occurrence of this species in the Canadian cordillera. This is significant because the first occurrence of *O. indicus* defines the base of the Miaolinginan Series and the Wuliuan Stage.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

Family ZACANTHOIDIDAE Swinnerton 1915

Genus *Zacanthoides* Walcott 1888

Zacanthoides cf. *Z. sexdentatus* Rasetti 1951

Appendix 3A, Plate 8, No. 5-9

cf. *Zacanthoides sexdentatus* Rasetti 1951, p. 142-143, pl. 22, figs. 22-27.

Material. Nine cranidia and two associated pygidia.

Discussion. Although compacted, this material appears to resemble material figured and described by Rasetti (1951) that was assigned to *Zacanthoides sexdentatus*. In particular, 1) the glabellar lobes are long and of similar curvature, terminating parallel to the anterior of the occipital ring or the occipital furrow, 2) the anterior branch of the facial sutures is highly divergent, and 3) the glabella has a similar profile and expands slightly anteriorly. The pygidium associated with this material differs from Rasetti's 1951 material, however, in that it has three axial rings and a terminal piece rather than four axial rings. The pygidial axis also terminates farther from the posterior of the pygidium.

Occurrence. GSC location 68992. Rockslide Formation, Gabrielse et al. 1973 Section 19. *Albertella* Zone.

3.7 INTERPRETATION

3.7.1 Biostratigraphic assignments

3.7.1.1 Gabrielse et al. 1973 Section 14/18

The cephala from GSC location 68967 (Fig. 3-6) are unlike fallotaspidid and nevadiid trilobites, precluding assignment to the *Fritzaspis*, *Nevadella*, or *Fallotaspi*s assemblage zones. The *Bonnia-Olenellus* Assemblage Zone is the only trilobite biozone that is consistent with these cephala. No attempt can be made to assign strata of GSC location 68967 to the upper, middle, or lower *Bonnia-Olenellus* zones or to one of Webster's (2011) species-based biozones because of the low quantity and incompleteness of the cephala (Appendix 3A, plate 3-5, figs. 1-2). It is possible that these cephala are from the upper *Bonnia-Olenellus* Zone because all of the laterally related assemblages (e.g., Gabrielse et al. 1973 Section 19, GSC location 68983) have been assigned to the upper *Bonnia-Olenellus* Zone. These fossils place GSC location 68967 in the Dyeran Stage/Global Stage 4 (Fig. 3-4).

The fauna at GSC location 68964 is probably assignable to either the *Bolbolenellus euryparia* or *Nephrolenellus multinodus* zone (Fig. 3-6). Both species-based biozones contain (1) occurrences of *Bolbolenellus* and (2) *Olenellus transitans*-like forms (e.g., *Bolbolenellus euryparia*, *Bolbolenellus brevispinus*, *Olenellus puertoblancoensis*, *Olenellus* aff.

puertoblancoensis; Webster 2011, Fig. 12) and are comparable to the GSC location 68964 fauna, making temporal equivalency probable. This assignment would also place GSC location 68964 in the upper *Bonnia-Olenellus* Zone and indicate that strata of the upper Sekwi Formation around GSC location 68964 were deposited during the latest part of the Laurentian Dyeran Stage (Global Stage 4; Fig. 3-4).

Webster's (2011) species-based biozones (Fig. 3-4) for the upper Dyeran in Nevada, California and Arizona are defined by the First appearance datum (FAD) of their eponymous taxa (*Arcuolenellus arcuatus*, *Bristolia mohavensis*, *Bristolia insolens*, *Peachella idingsi*, *Bolbolenellus euryparia*, and *Nephrolenellus multinodus*, in ascending order). Because none of these taxa are present in these collections, the boundary between the undifferentiated *Bonnia-Olenellus* Zone and the *Bo. euryparia* or *N. multinodus* zones is arbitrarily placed between GSC locations 68967 and 68964.

3.7.1.2. Gabrielse et al. 1973 Section 19

The olenellid trilobites at GSC location 68983 (Fig. 3-7) consist of numerous small, smooth ptychopariids, which is typical of the upper *Bonnia-Olenellus* Zone (Fritz 1991), placing GSC location 68983 in the uppermost Laurentian Dyeran/Global Stage 4. GSC location 68983 may be approximately equivalent to GSC location 68964 (uppermost strata of section 14).

The fauna at GSC location 68992 belongs to the *Albertella* Zone and resembles Rasetti's (1951) *Yohoaspis pachycephala* faunule, indicating an upper *Albertella* Zone age. The uppermost two faunules that Rasetti (1951) assigned to the *Albertella* Zone, the *Yohoaspis pachycephala* and *Chancia bigranulosa* faunules, have a high degree of generic and specific overlap. *Y. pachycephala* also occurs in the *C. bigranulosa* faunule (Rasetti 1951, p. 96). Given the range of taxonomic overlap between these two faunules, it may be possible that they are not distinct entities. Nevertheless, the GSC location 68992 fauna resembles the *Y. pachycephala* faunule in that it contains (1) forms assignable to *Chancia*, *Yohoaspis*, and *Zacanthoides*, (2) *Ogygopsis spinulosa*, and (3) compacted trilobites that are similar to *Syspacephalus tardus*. The presence of *Oryctocephalus indicus* at GSC location 68992 also allows for assignment to the *Oryctocephalus indicus* Range Zone. This stratigraphic interval was deposited during the middle of the Laurentian Delamaran Stage (global Wuliuan Stage). Strata that were deposited during the *Glossopleura* and *Ehmaniella* Zone biochrons are probably present between GSC locations 68992 and 69004 because of the substantial stratigraphic thickness (~70 m) between those two fossiliferous sample locations. The apparent absence of trilobite fossils from these biozones could be because of a variety of reasons, including (1) a lack of sampling, (2) the presence of a condensed interval that does not contain fossils, (3) an undetected unconformity, or (4) paleoenvironmental factors.

The faunas collected from GSC locations 69004, 69005, 69007, 69008, and 68999 belong to the *Bolaspidella* Assemblage Zone based on their general similarity to the defining *Bolasipidella* Zone assemblages as defined by Lochman and Wilson (1958) and further expounded on by Robison (1964). These faunas indicate that the stratigraphic intervals between GSC locations 69004 and 68999 (inclusive) were deposited during the Laurentian Marjumian Stage (Drumian Stage).

3.7.2 Depositional Ages of the Sekwi and Rockslide formations in the vicinity of Wrigley Lake

Although the Sekwi Formation in NTS 95M and NTS 95L has not been as extensively sampled for trilobite faunas as other locations in the Selwyn basin (e.g., Fritz 1972, 1976, 1978, 1979), it appears as though its depositional age in the study area is limited compared to most Sekwi sections (Figs. 3-5, 3-6, and 3-7). Lowest strata of the Sekwi Formation in this area probably belong to the middle *Bonnia-Olenellus* Zone. Some sections may have been deposited only during the late *Bonnia-Olenellus* Zone biochron. Gabrielse et al. 1973 section 15 (south of the study area; NTS 95L) contains an occurrence of *Wanneria*? sp. and *Olenellus* sp. associated with archaeocyathans ~208 m and 0-30 m above the base of the Sekwi Formation, respectively. Age determinations based on these historical data are ambiguous because of open nomenclature, sparseness of data, and subsequent taxonomic revision (e.g., Lieberman 1998, 1999, 2001) but may indicate a middle *Bonnia-Olenellus* Zone age for the base of the Sekwi Formation at that location. The *Bonnia-Olenellus* Zone faunas described in this study are either unambiguously upper *Bonnia-Olenellus* (GSC locations 68964 and 68983; Figs. 3-5 and 3-7) or indeterminate (GSC location 68967; Fig. 3-6). Elsewhere in NTS 95M, cf. *Nephrolenellus multinodus* has been identified from float at the base of the Sekwi Formation, which indicates the upper *Bonnia-Olenellus* Zone (Section 08MWB-S3; MacNaughton and Fallas 2021, Fig. 9). Although biostratigraphic data in the Wrigley Lake map area are sparse, the depositional age of the Sekwi Formation in that area is probably the middle *Bonnia-Olenellus* Zone biochron, and possibly as young as the late *Bonnia-Olenellus* Zone biochron at some locations. This differs from most biostratigraphically well-constrained Sekwi Formation sections elsewhere in the Selwyn basin. Typically, even proximal locations contain the entire *Bonnia-Olenellus* Zone and the *Nevadella* Zone (Fritz 1976, 1978, 1979). The *Fallotaspis* Zone is present and typically only tens of m thick in distal locations (Fritz 1972, 1976, 1978, 1979). In addition to these trilobite data, the Sekwi Formation in the vicinity of Wrigley Lake lacks the well-documented quartz arenite marker unit that marks the boundary between the *Nevadella* and *Bonnia-Olenellus* Zones (Figs. 3-2, 3-5), indicating that the Sekwi Formation in the NTS 95M area was almost certainly deposited after the *Nevadella* Zone biochron.

Based on the re-evaluated data in this study and historical data (Gabrielse et al. 1973, Fritz 1979), deposition of the Rockslide Formation in the study area began during latest Cambrian Stage 4 or the Wuliuan Stage. The Rockslide Formation at Section 19 is unusual compared to most other sections because the *Plagiura-Poliella* Zone is apparently absent (Fig. 3-7). Fritz *in* Gabrielse et al. (1973) speculated that the base of the Rockslide Formation may be faulted at that locality. In contrast, biostratigraphically well-sampled Rockslide Formation sections that are close to Section 19 contain all of the earliest middle Cambrian genus-based assemblage zones (e.g., Section 16, Gabrielse et al. 1973), suggesting a conformable contact with the underlying Sekwi Formation, or a depositional hiatus that was too brief to be captured by the resolution of trilobite biostratigraphy. Although faulting could explain the absence of the *Plagiura-Poliella* Zone at Gabrielse et al. (1973) section 19, the base of the Rockslide Formation could instead (1) contain a highly condensed interval in which a few m of strata record several million years of depositional history, or (2) represent original deposition during the *Plagiura-Poliella* biochron, followed by a mass wastage event that removed those strata. The former hypothesis is geographically consistent with the location of section 19, which is quite distal (westward). That location would have been in deep water and probably had a very low sedimentation rate. The latter hypothesis is consistent with the presence of slump structures and penecontemporaneous breccias in the Rockslide Formation (Gordey and Anderson 1993), which indicate an unstable slope.

The *Glossopleura* and *Ehmaniella* assemblage zones are not recorded by any of the faunas in Section 19 (Fig. 3-7). It is probable that strata deposited during the *Glossopleura* to

Ehmaniella Zone biochron are present in section 19 given that there are ~70 m of strata between GSC locations 69992 and 69004, but no diagnostic fossil material was located during Operation Nahanni. The boundaries between the *Albertella*, *Glossopleura*, *Ehmaniella*, and *Bolaspidella* Zones are therefore arbitrarily placed. Excepting the possible absence of the *Plagiura-Poliella* Zone, the trilobite data from section 19 are broadly consistent with data from other sections that typically record most or all the middle Cambrian trilobite biozones (Gabrielse et al. 1973, Fritz 1976, 1978, 1979). At proximal sections (Figs. 3-3, 3-8), uppermost strata of the Rockslide Formation may have been erosionally removed. Section 19 contains the *Bolaspidella* Zone, whereas Fritz (in Gabrielse et al. 1973) assigned uppermost strata of section 16 to the underlying *Ehmaniella* Zone. Locally, uppermost middle Cambrian strata may have been eroded, resulting in the absence of the *Bolaspidella* Zone at some sections.

3.7.3 Activity of the Redstone arch

Isopach thickness patterns of the Sekwi Formation (Chan et al. 2019, MacNaughton and Fallas 2021), trilobite biostratigraphic data, and limited lithostratigraphic data indicate two discrete episodes of Redstone arch activity during the deposition of the Backbone Ranges, Sekwi, and Rockslide formations. The first episode occurred during the late *Nevadella* Zone biochron and the earliest *Bonnia-Olenellus* Zone biochron (late Stage 3 to early Stage 4). The second episode probably occurred during the late *Bonnia-Olenellus* Zone biochron (late Stage 4) but possibly persisted into the Wuliuan.

3.7.3.1. Event I (late Stage 3 to early Stage 4)

The expression of event I differs in proximal versus distal locations. Proximal sections exhibit (1) the truncation of the upper member of the Backbone Ranges Formation (Fig. 3-8; MacNaughton and Fallas 2021), which at easternmost sections eroded parts of the upper member that had been deposited during the early, non-trilobitic Cambrian, leaving only Ediacaran strata based on the absence of the carbonate marker unit (MacNaughton and Fallas 2021); and (2) the limited depositional age of the overlying Sekwi Formation, which is probably limited to a maximum depositional age of the middle *Bonnia-Olenellus* Zone biochron and generally appears to have been deposited during the latest *Bonnia-Olenellus* Zone biochron. In contrast, distal sections (Figs. 3-10 and 3-11) contain (1) the *Fallotaspis* and *Nevadella* zones, and probably the entire *Bonnia-Olenellus* Zone, (2) the Vampire Formation overlying the Backbone Ranges Formation and underlying the Sekwi Formation, and (3) definitively Fortunian strata of the Backbone Ranges Formation. In addition, the well-documented sandstone marker unit in the middle of the Sekwi Formation (Dilliard et al. 2010; Fischer and Pope 2011) is present in distal sections but not proximal ones, and is bracketed by strata containing *Nevadella* Zone (below) and lower *Bonnia-Olenellus* Zone trilobites (above).

The temporal constraints on the first Redstone arch event at proximal sections are loose. The maximum age estimate for the timing of the event is Fortunian (or possibly latest Ediacaran), given that Fortunian strata of the upper Backbone Ranges Formation are absent. The overlying Sekwi Formation provides a minimum age estimate - the upper *Bonnia-Olenellus* Zone faunas indicate that the event ended at the latest Dyeran, imparting the accommodation space that allowed for the deposition of the silty, proximal Sekwi Formation. In contrast, if it is accepted that the sandstone marker unit in the Sekwi Formation is the result of Backbone Ranges

Formation sand eroded from the Redstone arch being deposited, that narrows the timing of the event to the late *Nevadella* Zone biochron to the early *Bonnia-Olenellus* Zone biochron.

Additional lithostratigraphic evidence for a regional uplift event during deposition of the Sekwi Formation includes the presence large olistoliths that are associated with polymictic breccias and conglomerates (Dilliard et al. 2010 sections 1 and 2) in distal sections and contemporaneous local karsting (Dilliard et al. 2010 sections 10 and 14) in proximal sections (Fig. 12, increment 3). The olistoliths in Dilliard et al. 2010 sections 1 and 2 are composed mostly of archaeocyathan/microbialite material and are 5 to 25 m in diameter. These olistoliths syndepositionally (compactionally) folded the associated conglomerates/breccias, which are composed of a variety of clast types (ooid grainstone, subtidal sandstone, arcaeocyathan/microbialite material, mudstone, and calcareous siltstone) that must have been sourced from a variety of proximal and distal locations. Clast sizes in the polymictic breccias are highly variable, and some reach large sizes (~tens of m; Dilliard et al. 2010). Dilliard et al. 2010 interpreted polymictic breccia/conglomerate beds as having been deposited by sediment gravity flows. At Dilliard et al. (2010) section 2, archaeocyathan/calcimicrobe olistoliths are associated with polymictic conglomerate/breccia, skeletal wackestone-packstone, and carbonate mudstone in the *Bonnia-Olenellus* Zone, ~20 m above the top of the *Nevadella* Zone. In contrast, Dilliard et al. (2010) section 1 contains a similar collection of lithofacies immediately below the top of the *Nevadella* Zone (Dilliard et al. 2010, fig. 3; Dilliard 2006, appendix A).

Dilliard et al. (2010) sections 10 and 14 are shore-distal locations but are somewhat more proximal (eastward) than many other distal sections, and are located slightly north (~5 km from Fritz section 33; along strike) from the outboard sections discussed in this paper. Karsted areas at these sections correspond closely to the top of the *Nevadella* Zone [Dilliard et al. 2010, Fig. 3;

Dilliard 2006, appendix A]. Fritz (1979) section 36 is located ~45 kilometres south of Dilliard et al. (2010) sections 10 and 14 along strike. The sandstone marker unit at this location has an undulatory lower contact with underlying dolostone and occurs at the *Nevadella*/*Bonnia-Olenellus* zonal boundary. This may also be a karsted surface.

These lithostatigraphic features at proximal locations coupled with biostratigraphic constraints are consistent with a regional uplift event (event I). This event was probably mostly mediated by uplift of the Redstone arch, although excess basinward subsidence may have also contributed (Fig. 3-12). Prior to event I, the Backbone Ranges Formation was deposited during the late Ediacaran to early Cambrian, and the Vampire Formation was deposited distally. The chronology of event I was as follows (Fig. 3-12): During Cambrian Age 3 (Fig 12B), the Sekwi Formation began deposition, but was confined to relatively distal areas, mostly overlying the Vampire Formation. During latest Age 3, Redstone arch uplift began, which (1) led to erosion of most of the upper member of the Backbone Ranges Formation in proximal locations, affecting the part that had been deposited during the early Cambrian, and (2) exposed and karsted the surface of the most proximal areas of the Sekwi Formation. Eroded material from the exposed Redstone arch and Backbone Ranges Formation was redeposited basinward as the regional sandstone marker unit. Contemporaneously, the relatively high slope angle (or slope failure) that was produced by event I resulted in the mass wastage of sediments, including archaeocyathan-microbialite mounds, in both shoreward and basinward locations. This material was redeposited as polymictic conglomerates/breccias and olistoliths. Uplift terminated prior to the middle or upper *Bonnia-Olenellus* Zone biochron, and either tectonic subsidence or raised sea level imparted enough accommodation space for the upper part of the Sekwi Formation to be deposited basinward and the silt-dominated Sekwi Formation to be deposited unconformably above the eroded Backbone Ranges Formation at proximal locations (Fig 3-12D).

3.7.3.2 Event II (late Stage 4 to early Wuliuan)

Evidence for event II lacks temporal constraints, isopach data, and lithostratigraphic data as compared to event I. It is based on the apparently rapid (biostratigraphically) transition from the Sekwi Formation to comparatively deeper water environments of the Rockslide Formation, and the absence of the *Plagiura-Poliella* Zone at section 19 (Fig. 3-7). This event is interpreted to involve an episode of enhanced subsidence (Fig. 3-12E). The Redstone arch could have subsided during this event, or outboard-only subsidence could have been the main expression of subsidence. This event heralded the onset of truly deep-water depositional conditions in the Selwyn basin close to the Redstone arch (Rockslide Formation) and started during the end of Cambrian Age 4 to early Wuliuan. Deep-water conditions persisted throughout the Selwyn basin from the late Cambrian to the Silurian after this event, as indicated by the nature of the Rabbitkettle and Duo Lake Formations (Roots et al. 2011). It is possible that event II was diachronous based on the presence of *Bonnia-Olenellus* Zone trilobites in the basal Rockslide Formation at Fritz 1979 sections 35 and 33 and middle Cambrian trilobites close to the Sekwi-Rockslide formational contact at section 36 (Fig. 3-10, Appendix 3B; Fritz 1979.

3.8 DISCUSSION

3.8.1 Deposition of the Sekwi Formation near the Redstone arch

MacNaughton and Fallas (2021) documented a sub-*Bonnia-Olenellus* Zone erosional unconformity in NTS 95M (Fig. 3-2) that truncates the upper member of the Backbone Ranges Formation. The upper member at Gabrielse et al. (1973) section 14 is 100 m thick, whereas at section 08MWB-S2 (MacNaughton and Fallas 2021) the upper member of the Backbone Ranges Formation is 501.5 m thick (Figs. 3-6, 3-8, 3-9, 3-11), indicating that the upper member thins southeastward. This erosional event may have also resulted in either the erosion or non-deposition of part of the Sekwi Formation and resulted in only faunas from the upper Dyeran/Cambrian Stage 4 being deposited there.

3.8.2 Onset of Rockslide Formation deposition

The contact between the Rockslide Formation and the underlying Sekwi Formation is abrupt and lithologically contrasting (MacNaughton and Fallas 2021, Fig. 3-13b), indicating a rapid change in paleoenvironment. The biostratigraphic constraints on the Sekwi and Rockslide formations indicate that this transition took place during latest Cambrian Age 4 or earliest Wuliuan (Figs. 3-6, 3-7). It is unclear if this transition was conformable. Given the relatively limited range of possible ages of onset, it is possible that this transition occurred rapidly. If it is accepted that the Sekwi-Rockslide formational contact is diachronous, it is unclear whether the character of its diachroneity is analogous to the geometry of the Sekwi-Hess River Formation contact in the Misty Creek embayment to the north. The Misty Creek embayment preserves a "steer head" rift profile (Cecile et al. 1997) in which the central axis of the embayment contains a significantly thicker amount of sediment than the margins. In addition, the Sekwi-Hess River formational contact is also older along the central, thicker axis of the embayment [middle *Bonnia-Olenellus* Zone centrally, and upper *Bonnia-Olenellus* Zone along the margins; Scott et al. (2022)]. The Sekwi – Hess River formational contact is of different character than the Sekwi-Rockslide formational contact, which appears to become older at distal locations, but does not have an axis where the contact age is oldest that is flanked by areas with younger contact ages, as is the case in the Misty Creek Embayment (Scott et al. 2022). This suggests that the Misty Creek

Embayment was a closed-sided basin (Cecile 1982) rather than open-sided, like the Selwyn basin. Despite the differences between the tectonically mediated Misty Creek embayment and the Wrigley Lake map area, it is plausible that the onset of Rockslide Formation was extensional, because slump structures and penecontemporaneous breccias are well documented in the Rockslide Formation (Gordey and Anderson 1993), indicating that it was deposited in an unstable, possibly tectonically active area.

The proximity, lateral relationship, similarity in paleoenvironment (both relatively deep-water environments), and similarity in age constraints between the Hess River and Rockslide formations also suggests a common origin that may have been influenced by activity of the Mackenzie and Redstone arches.

3.8.3. Regional context

A growing body of evidence suggests that the (present-day) western margin of Laurentia experienced an episode of extensional tectonism close to the time represented by the traditional lower-middle Cambrian boundary (Scott et al. 2022). Other locations in the Selwyn basin preserve evidence of synsedimentary tectonism. The Gull Lake Formation (Nahanni area, NTS 105I) contains a basal conglomerate with archaeocyathan clasts (constraining the bed to a maximum depositional age of Cambrian Age 4) and probable middle *Bonnia-Olenellus* Zone trilobites (Gordey and Anderson 1993; Abbot 1997) which may have been deposited by mass wastage. The Misty Creek embayment experienced a rapid subsidence event during late Cambrian Age 4 (Scott et al. 2022). In British Columbia, the Mount Roosevelt Formation (Kechika trough) contains conglomerate beds at several stratigraphic levels, which were interpreted to have been sourced from subaqueous fault scarps that formed by uplift/subsidence during Cambrian Age 4 to Wuliuan (Post and Long 2008). North of the Selwyn basin in the

Richardson trough, the Slats Creek Formation (Cambrian Age 4 to lower middle Cambrian) may record an episode of tectonic extension based on isopach patterns and abrupt facies changes. In the Coal Creek inlier (Yukon), the Shell Creek Formation has been argued to have been deposited in a basin that was experiencing active tectonism and is tentatively correlated with the Sekwi, Slats Creek, Illtyd, and Gull Lake formations (Busch et al. 2021). The onset of Rockslide Formation deposition (=event II) is contemporaneous with numerous other extensional events that occurred during the latest early Cambrian to earliest middle Cambrian along the ancestral margin of North America and is probably related to the same widespread extensional episode. The presence of slump structures and penecontemporaneous breccias provides further evidence for this hypothesis (Gordey and Anderson 1993). Lithostratigraphic and isopach data for the Rockslide Formation are sparse, and further research is needed to constrain and understand the nature of the Rockslide Formation.

Older Cambrian tectonic uplift/subsidence events are less well known than the extensional episodes that are tied to event II, and it is unclear whether event I is regional or if there are other, analogous events that occurred contemporaneously elsewhere. The Redstone, Mackenzie, Peel, and Husky Lakes[i] arches are apparently all geographically continuous (Cecile et al. 1997), and it is possible that they had similar Paleozoic histories. Aitken et al. (1973) hypothesized that the Mackenzie arch underwent uplift during the middle Cambrian based on the truncation of Precambrian strata proximal to the arch, and the unconformable lower contact that the Franklin Mountain Formation has with the Katherine Group. Lower Cambrian strata also thin towards the Mackezie arch (Aitken et al. 1973). The nature of the Mackenzie arch uplift event was probably not identical to that of the Redstone arch, based on the stratigraphic units that overlie the respective arches. The Redstone arch is overlain by the Broken Skull and Franklin

Mountain formations (MacNaughton and Fallas 2014), both of which are constrained to the late Cambrian to early Ordovician (MacNaughton 2011). Contrastingly, the Mackenzie arch is overlain by the Nainlin and Franklin Mountain formations, in ascending order (MacNaughton and Fallas 2014). The Nainlin Formation was probably deposited during the middle Cambrian (MacNaughton and Fallas 2014). This indicates that the episode of uplift that the Mackenzie arch experienced terminated earlier than the Redstone arch episode and/or was less pronounced, allowing for some accommodation space that the Nainlin Formation was deposited in. The Redstone arch must have become submerged enough for appreciable amounts of sediment to be deposited on top of it later in the Cambrian.

3.9 CONCLUSIONS

The Sekwi Formation in the Wrigley Lake map area (NTS 95M) was deposited during late Stage 4 (middle to upper *Bonnia-Olenellus* Zone) based on trilobite biostratigraphy. The Redstone arch underwent two discrete episodes of tectonism during the early Cambrian and the latest early Cambrian/earliest middle Cambrian. The first of these episodes (event I) involved protracted uplift of the Redstone arch during Cambrian Age 4 (late *Nevadella* to early *Bonnia-Olenellus* Zone) which resulted in erosion of early Cambrian to late Neoproterozoic strata closest to the arch, and subaerial exposure and karstification of inboard parts of the lower Sekwi Formation. Event I also resulted in the displacement of large archaeocyathan/microbialite olistoliths and the deposition of polymictic conglomerate/breccia beds. Eroded material from the Redstone arch and upper member of the Backbone Ranges Formation were also deposited as the sandstone marker unit in the Sekwi Formation. The second episode (event II) occurred from the end of Cambrian Age 4 to early Wuliuan. Event II consisted of widespread basinward subsidence that resulted in the transition from the carbonate slope of the Sekwi Formation to the deep-water environment of the Rockslide Formation. Evaluation of Gabrielse et al.'s (1973) Sekwi Formation trilobite collections show that in the Wrigley Lake area, the unit was deposited only during uppermost Age 4, a conclusion that would not be possible without the use of trilobite biostratigraphy. Additional trilobite collections are needed to constrain the depositional age of the Sekwi Formation in that area better. Comparison of these results with descriptions of correlative strata elsewhere in the region confirm that the early to middle Cambrian was a time of dramatic tectonic uplift/subsidence episodes along the western margin of Laurentia (Cecile et al. 1997, Busch et al. 2021, Scott et al. 2022). These events acted as major controls on the deposition and character of stratigraphic units in the Selwyn basin.

3.10 REFERENCES

Abbott, J.G. 1997. Geology of the upper Hart River area, Eastern Ogilvie Mountains, Yukon Territory (116A/10, 116A/11). Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada. Bulletin 9. 92 pp.

Aitken, J.D. 1989. Uppermost Proterozoic formations in central Mackenzie Mountains, Northwest Territories. Geological Survey of Canada. Bulletin 368. 26 pp.

Balley, A.W. 1989. Phanerozoic basins of North America. *In* The geology of North America; an overview. *Edited by* Bally, A.W., and Palmer, A.R. Geological Society of America.

Beecher, C.E. 1897. Outline of a natural classification of the trilobites. American Journal of Science **3**:89-106 and 181-207.

Betts, M.J., Paterson, J.R., Jacquet, S.M., Andrew, A.S., Hall, P.A., Jago, J.B., Jagodzinski, E.A., Preiss, W.V., Crowley, J.L., Brougham, T., Mathewson, C.P., García-Bellido, D.C., Topper, T.P., Skovsted, C.B., and Brock, G.A. 2018. Early Cambrian chronostratigraphy and geochronology of South Australia. Earth Science Reviews, **185**:498-543.

Bouchard, M.L., and Turner, E.C. Stratigraphy of the Mount Clark, Mount Cap and Saline River formations in the Hornaday River canyon, Northwest Territories (NTS 97A). Geological Survey of Canada. Open File 8180. 44 p.

Brasier, M.D., and Sukhov, S.S. 1998. The falling amplitude of carbon isotopic oscillations through the Lower to Middle Cambrian: northern Siberia data. Canadian Journal of Earth Sciences, **35**:353-373.

Busch, J.F., Rooney, A.D., Meyer, E.E., Town, C.F., Moynihan, D.P., and Strauss, J.V. 2021. Late Neoproterozoic-early Paleozoic basin evolustion in the Coal Creel inlier of Yukon, Canada: implications for the tectonic evolution of northwestern Laurentia. Canadian Journal of Earth Science, **58**:355-377.

Cecile, M.P., Morrow, D.W., and Williams, G.K. 1997. Early Paleozoic (Cambrian to early Devonian) tectonic framework, Canadian Cordillera. Bulletin of Canadian Petroleum Geology, **45**:54–74.

Chan, W.C., MacNaughton, R.B., and Fallas, K.M. 2019. Isopach maps for the Sekwi Formation (Cambrian Series 2), Mackenzie Mountains, Northwest Territories and Yukon. Geological Survey of Canada. Open File 8371. 18 pp.

Cobbold, E.S., and Pocock, R.W. 1934. The Cambrian area of Rushton (Shropshire). Philosophical Transactions of the Royal Society of London, **223**:305-409.

Crimes, T.P. 1992. Changes in the trace fossil biota across the Proterozoic-Phanerozoic boundary. Journal of the Geological Society, **149**: 637-646.

Dewing, K., Sharp, R.J., Ootes, L., Turner, E.C., and Gleeson, S. 2006. Geological assessment of known Zn-Pb showings, Mackenzie Mountains, Northwest Territories. Geological Survey of Canada, Current Research 2006-A4. 12 pp.

Dilliard, K.A. 2006. Sequence stratigraphy and chemostratigraphy of the lower Sekwi Formation, Northwest Territories, Canada. Unpublished PhD thesis, Washington State University, Pullman, Washington. 298 pp.

Dilliard, K.A., Pope, M.C., Coniglio, M., Hasiotis, S.T., and Lieberman, B.S. 2007. Stable isotope geochemistry of the Lower Cambrian Sekwi Formation, Northwest Territories, Canada: Implications for ocean chemistry and secular curve generation. Paleogeography, Paleoclimatology, Paleoecology, **256**:174–194.

Dilliard, K.A., Pope, M.C., Coniglio, M., Hasiotis, S.T., and Lieberman, B.S. 2010. Active synsedimentary tectonism on a mixed carbonate-siliciclastic continental margin: third-order sequence stratigraphy of a ramp to basin transition, lower Sekwi Formation, Selwyn Basin, Northwest Territories, Canada. Sedimentology, **57**: 513-542.

Dixon, J. 1997. Cambrian stratigraphy of the northern Interior Plains, Northwest Territories. Geological Survey of Canada. Open File 3510. 27 pp.

Dixon, J., and Stasiuk, L.D. 1998. Stratigraphy and hydrocarbon potential of Cambrian strata, northern Interior Plains, Northwest Territories. Bulletin of Canadian Petroleum Geology, **46**:445–470.

Fischer, B.J., and Pope, M.C. 2011. Lower Cambrian carbonate succession. *In* Geology of the central Mackenzie mountains of the northern Canadian Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories special volume 1, 142-149.

Fletcher, T.P., and Collins, D.H. 2003. The Burgess Shale and associate Cambrian formations west of the Fossil Gully Fault Zone Mount Stephen, British Columbia. Canadian Journal of Earth Science, **40**:1823-1838.

Fritz, W.H. 1972. Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Bulletin 212. 58 pp.

Fritz, W.H. 1976. Ten stratigraphic sections from the Lower Cambrian Sekwi Formation, Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 76-22. 42 pp.

Fritz, W.H. 1978. Fifteen stratigraphic sections from the Lower Cambrian of the Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 77-33. 19 pp.

Fritz, W.H. 1979. Eleven stratigraphic sections from the Lower Cambrian of the Mackenzie Mountains, Northwestern Canada. Geological Survey of Canada. Paper 78-23. 19 pp.

Fritz, W.H., 1981. Two Cambrian stratigraphic sections, Eastern Nahanni map area, Mackenzie Mountains, District of Mackenzie. *In* Current Research, Part A. Geological Survey of Canada. Paper 81- 1A. pp. 145-156.

Fritz, W.H., 1982. Vampire Formation, a new Upper Precambrian(?)/Lower Cambrian Formation, Mackenzie Mountains, Yukon and Northwest Territories. *In* Current Research, Part B. Geological Survey of Canada. Paper 82-1B. pp. 83-92.

Fritz, W.H. 1991. Lower Cambrian trilobites from the Illtyd Formation, Wernecke Mountains, Yukon Territory. Geological Survey of Canada. Bulletin 409. 77 pp.

Esteve, J., Zhao, Y., and Peng, J. 2017. Morphological assessment of the Cambrian trilobites Oryctocephalus indicus (Reed 1910) from China and Oryctocephalus “reticulatus” (Lermontova) from Siberia. Lethaia, **50**:175-193.

Gabrielse, H. 1967. Tectonic evolution of the northern Canadian cordillera. Canadian Journal of Earth Sciences, **4**:271-298.

Gabrielse, H., Blusson, S.L., and Roddick, J.A. 1973. Geology of flat river, Glacier Lake, and Wrigley Lake map areas, District of Mackenzie and Yukon Territory. Geological Survey of Canada. Memoir 366. 153 pp.

Geyer, G. 2019. A comprehensive Cambrian correlation chart. Episodes, **42**:1-12.

Goodfellow, W.D. 2007. Base metal metallogeny of the Selwyn basin, Canada. In Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods. Edited by Goodfellow, W.D. Geological Association of Canada Special Publication 5. pp. 553-579.

Gordey, S.P., and Anderson, R.G. 1993. Evolution of the northern cordilleran miogeocline, Nahanni map area (105I), Yukon and Northwest Territories. Geological Survey of Canada. Memoir 428. 214 pp.

Hadlari, T., Millar, R.A., and Lane, L.S. 2020. The Eskimo Lakes fault zone renamed Husky Lakes fault zone, Tuktoyaktuk Peninsula, Northwest Territories. Geological Survey of Canada. Open File 8740. 4 pp.

Handfield, R.C. 1968. Sekwi formation, a new lower Cambrian formation in the southern Mackenzie Mountains, District of Mackenzie. Geological Survey of Canada. Paper 68-47. 23 pp.

Hannigan, P.K., Morrow, D.W., and MacLean, B.C., 2011. Petroleum resource potential of the northern mainland of Canada (Mackenzie Corridor); Geological Survey of Canada, Open File 6757.

Harrington, H.J., Weller, J.M., Howell, B.F., Whittington, H.B., Sdzuy, K., Schmidt, H., Stubblefield, C.J., Richter, R., Richter, E., Lochman, C., Rasetti, F., Størmer, L., Henningsmoen, G., Poulsen, C., Moore, R.C., Jaanusson, V., Tripp, R., and Struve, W. 1959. Arthropoda 1. *In* Treatise on Invertebrate Paleontology Part O. Edited by Moore, R.C. 560 pp. Geological Society of America and University of Kansas Press, Lawrence, Kansas.

Howell, B.F. 1935. Cambrian and Ordovician trilobites from Hérault, southern France. Journal of Paleontology, **9**(3): 222-238.

Jaekel, O. 1909. Uber die Agnostiden. Zeitschrift deutsche geologische Gesellschaft, **61**:380-401.

Kindle, C.H., and Tasch, P. 1948. Lower Cambrian fauna of the Monkton Formation of Vermont. Canadian Field Naturalist, **62**:133-139.

Kobayashi, T. 1935. The Cambro-Ordovician formations and faunas of South Chosen. Paleontology, Part III. Cambrian faunas of south Chosen with special study on the Cambrian trilobite genera and families. Journal of the Faculty of Science, Imperial University of Tokyo section 2, **4**:49-344.

Kobayashi, T. 1939. On the agnostids (Part 1). Journal of the Faculty of Science, Imperial University of Tokyo section II, **5**:69-198.

Lieberman, B.S. 1998. Cladistic analysis of the Early Cambrian Olenelloid trilobites. Journal of Paleontology, **72**:59-78.

Lieberman, B.S. 1999. Systematic revision of the Oleneloidea (Trilobita, Cambrian). Bulletin of the Peabody Museum of Natural History, **45**:150 pp.

Lieberman, B.S. 2001. Phylogenetic analysis of the Olenellina Walcott, 1890 (Trilobita, Cambrian). Journal of Paleontology, **75**:96-115.

Lochman, C., and Duncan, D.C. 1944. Early Upper Cambrian faunas of central Montana. Geological Society of America Special Paper 54, 181 pp.

Lochman, C., and Wilson, J.L. 1958. Cambrian Biostratigraphy in North America. Journal of Paleontology, **32**:312-350.

MacLean, B.C. 2011. Tectonic and stratigraphic evolution of the Cambrian basin of northern Northwest Territories. Bulletin of Canadian Petroleum Geology, **59**:172–194.

MacNaughton, R.B. 2011. Lowest Paleozoic siliciclastic succession. *In* Geology of the central Mackenzie Mountains of the northern Canadian Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories special volume 1, 131-141.

MacNaughton, R.B., 2020a. Neoproterozoic–Cambrian stratigraphy of the Mackenzie Mountains, northwestern Canada, Part I: Ediacaran measured sections and updated lithostratigraphy, NE Sekwi Mountain map area (NTS 105-P). Geological Survey of Canada. Open File 7315. 22 pp.

MacNaughton, R.B. 2020b. Neoproterozoic–Cambrian stratigraphy of the Mackenzie Mountains, northwestern Canada, Part II: Archival stratigraphic data for the Backbone Ranges Formation and related units, Mackenzie Mountains, Northwest Territories, Canada (NTS 95-L and 105-P). Geological Survey of Canada. Open File 8668. 26 pp.

MacNaughton, R.B., and Fallas, K.M. 2021. Neoproterozoic-Cambrian stratigraphy of the Mackenzie Mountains, Northwestern Canada, part 4: a stratigraphic reference section for the Ediacara-Cambrian transition in NTS 95-M (Wrigley Lake map area). Geological Survey of Canada. Open File 8839. 56 pp.

MacNaughton, R.B., and Narbonne, G.M. 1999. Evolution and Ecology of Neoproterozoic-Lower Cambrian trace fossils, NW Canada. Palaios, **14**:97-115.

MacNaughton, R.B., Narbonne, G.M., and Dalrymple, R.W. 1999. A re-examination of the type section of the Backbone Ranges Formation, Mackenzie Mountains, NW Canada: Stratigraphic and Tectonic implications. *In* Slave-Northern Cordillera Transect and Cordilleran Tectonics Workshop Meeting. *Edited by* Cook, F., and Erdmer, P. Lithoprobe Report No. 69, pp. 99-111.

MacNaughton, R.B., Dalrymple, R.W., and Narbonne, G.M. 1997. Multiple orders of relative sea-level change in an earliest Cambrian passive-margin succession, Mackenzie Mountains, Northwestern Canada. Journal of Sedimentary Research, **67**:622-637.

MacNaughton, R.B., Narbonne, G.M., and Dalrymple, R.W., 1999. A re-examination of the type section of the Backbone Ranges Formation, Mackenzie Mountains, NW Canada: stratigraphic and tectonic implications; *in* Slave-Northern Cordillera Transect and Cordilleran Tectonics Workshop Meeting. *Edited* by Cook, F., and Erdmer, P. LITHOPROBE Report No. 69, pp. 99-111.

MacNaughton, R.B., Narbonne, G.M., and Dalrymple, R.W. 2000. Neoproterozoic slope deposits, Mackenzie Mountains, northwestern Canada: implications for passive-margin development and Ediacaran faunal ecology. Canadian Journal of Earth Sciences, **37**:997-1020.

MacNaughton, R.B., Fallas, K.M., and Zantvoort, W., 2008a. Qualitative assessment of the Plateau Fault (Mackenzie Mountains, NWT) as a conceptual hydrocarbon play. Geological Survey of Canada. Open File 5831. 29 pp.

MacNaughton, R.B., Fallas, K.M., Martell, J., and Edgeworth, I., 2018. Bedrock mapping, stratigraphy, and related studies, Bonnet Plume Lake (NTS 106-B) and Wrigley Lake (NTS 95-M) map areas, Northwest Territories and Yukon: GEM-2 Mackenzie Project, report of activities 2018. Geological Survey of Canada. Open File 8471. 17 pp.

MacNaughton, R.B., Moynihan, D.P., Roots, C.F., and Crowley, J.L. 2016. New Occurrences of Oldhamia in eastern Yukon, Canada: stratigraphic context and implications for Cambrian deep-marine biostratigraphy. Ichnos, **23**:33-52.

Matthew, G.F. 1887. Illustrations of the fauna of the St. John Group. No. IV- Pt. II. The smaller trilobites with eyes (Ptychopariidae and Ellipspcephalidae). Transactions of the Royal Society of Canada, **5**:123-166.

Morgan, C.A. 2021. Quantitative trilobite biostratigraphy of the middle Cambrian (Wuliuan Stage; Mialingian Series) and microfacies analysis of the Middle Cambrian Stephen Formation, southern Canadian Rocky Mountains. Unpublished PhD thesis, University of Calgary, Calgary, Alberta, 445 pp.

Mossop, G.D., Wallace-Dudley, K.E., Smith, G.G. and Harrison, J.C. (comp.) 2004. Sedimentary basins of Canada. Geological Survey of Canada Open File Map 4673. 1 sheet.

Öpik, A.A. 1979. Middle Cambrian agnostoids: systematics and biostratigraphy. Australian Bureau of Mineral Resources, Geology and Geophysics Branch Bulletin, **172**(1-2), 188 pp.

Ootes, L., Gleeson, S.A., Turner, E.C., Rasmussen, K., Gordey, S., Falck, H., et al. 2013. Metallogenic evolution of the Mackenzie Mountains of Canada's northern Cordillera, Northwest territories: a compilation and review. Geoscience Canada, **40**:40–69.

Pack, D.P., and Gayle, H.B. 1971. A new Olenellid trilobite, *Biceratops nevadensis*, from the lower Cambrian near Las Vegas, Nevada. Journal of Paleontology, **45**:893-898.

Palmer, A.R., and Halley, R.B. 1979. Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin. United States Geological Survey. Professional Paper 1047. 131 pp.

Palmer, A.R., and Repina, L.N. 1993. Through a glass darkly: taxonomy, phylogeny, and biostratigraphy of the Olenellina. The University of Kansas Paleontological Contributions, **3**:1-35.

Palmer, A.R. 1998. A proposed nomenclature for stages and series for the Cambrian of Laurentia. Canadian Journal of Earth Sciences, **35**:323-328.

Peng, S.C., Babcock, L.E., and Ahlberg, P. 2020. The Cambrian Period. *In* Geological Timescale 2020. Edited by Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M. Elsevier, Amsterdam, Netherlands.

Poulsen, C. 1927. The Cambrian, Ozarkian and Canadian faunas of Northwest Greenland. Meddelelser om Grønland, **70**:233–343.

Rasetti, F. 1948. Middle Cambrian trilobites from the conglomerates of Quebec (Exclusive of the Ptychopariidea). Journal of Paleontology, **22**:315-339.

Rasetti, F. 1951. Middle Cambrian stratigraphy and faunas of the Canadian Rocky Mountains. Smithsonian Miscellaneous Collections, **116**:277 pp.

Rasetti, F. 1966. Revision of the North American species of the Cambrian trilobite genus Pagetia. Journal of Paleontology, **40**:502-511.

Raymond, P.E. 1913. On the genera of the Eodiscidae. Ottawa Naturalist, **27**:101-106.

Reed, F.R.C. 1910. The Cambrian fossils of Spiti. Memoirs of the Geological Survey of India, **15**:1-70.

Resser, C.E. 1935. Nomenclature of some Cambrian trilobites. Smithsonian Miscellaneous Collections, **93**:46 pp.

Resser, C.E. 1936. Second contribution to the nomenclature of Cambrian trilobites. Smithsonian Miscellaneous Collections, **95**:25 pp.

Resser, C.E. 1937. Elkanah Billings' lower Cambrian trilobites and associated species. Journal of Paleontology, **11**:43-54.

Resser, C.E. 1939. The Ptarmigania strata of the northern Wasatch mountains. Smithsonian Miscellaneous Collections, **98**:72 p.

Richter, R. 1932. Crustacea (Paläontologie). *In* Handwörtenbuch der Naturwissenschaften. *Edited by* Dittler, R., Joos, G., Korschelt, E., Linek, G., Oltmanns, F. and Schaum, K. Gustav Fisher, Jena. 840-864 pp.

Robison, R.A. 1964. Late Middle Cambrian faunas from western Utah. Journal of Paleontology, **38**:510-566.

Rominger, C. 1887. Description of primordial fossils from Mount Stephens, N.W. territory of Canada. Proceedings of the Academy of Natural Sciences of Philadelphia, **37**:12-19.

Roots, C.F., MacNaughton, R.B., Martel, E., Gordey, S.P. 2011. Cambrian to Lower Devonian siliciclastic basin. *In* Geology of the central Mackenzie mountains of the northern Canadian

Cordillera. *Edited by* Martel, E., Turner, E.C., and Fischer, B.J. Northwest Territories special volume 1, 167-174.

Salter, J.W. 1864. Trilobites (chiefly Silurian). Figures and descriptions illustrative of British organic remains. Memoirs of the Geological Survey of the United Kingdom, Decade 11.

Scott, R.W., Turner, E.C., MacNaughton, R.B., and Fallas, K. 2022. Biostratigraphic evidence for incremental tectonic development of early Cambrian deep-water environments in the Misty Creek embayment (Selwyn basin, Northwest Territories, Canada). Canadian Journal of Earth Sciences, **59**:216-231.

Sommers, M.J., Gingras, M.K., MacNaughton, R.B., Fallas, K.M., and Morgan, C.A. 2020. Subsurface analysis and correlation of Mount Clark and Lower Mount Cap formations (Cambrian), Northern Interior Plains, Northwest Territories. Bulletin of Canadian Petroleum Geology, **68**:1–29.

Sundberg, F.A. 2018. Trilobite biostratigraphy of the Cambrian 5 and Drumian stages, Series 3 (Laurentian Delamaran, Topazan, and Marjuman stages, Lincolnian Series) of the lower Emigrant Formation at Clayton Ridge, Esmeralda County Nevada. Journal of Paleontology, Vol. **92**:44 pp.

Sundberg, F.A., and McCollum, L.B. 2000. Ptychopariid trilobites of the lower-middle Cambrian boundary interval, Pioche Shale, southeastern Nevada. Journal of Paleontology, **74:**604-630.

Sundberg, F.A., and Webster, M. 2022. "Ptychoparioid" trilobites of the Harkless Formation and Mule Spring Limestone (Cambrian Series 2, Stage 4), Clayton Ridge, Nevada. Journal of Paleontology, **96**:886-920.

Sundberg, F.A., Zhao, Y., Yuan, J., and Lin, J. 2011. Detailed trilobite biostratigraphy across the proposed GSSP for Stage 5 ("Middle Cambrian" boundary) at the Wuliu-Zengjiayan section, Guizhou, China. Bulletin of Geosciences, **86**:423-464.

Swinnerton, H.H. 1915. Suggestions for a revised classification of trilobites. Geological Magazine, **2**:407-496, 538-545.

Taylor, J.F., Repestski, J.E., Loch, J.E., and Leslie, S.A. 2012. Biostratigraphy and chronostratigraphy of the Cambrian-Ordovician Great American Carbonate Bank. *In* The great American carbonate bank: the geology and economic resources of the Cambrian-Ordovician Sauk megasequence of Laurentia. Edited by Derby, J.R., Fritz, R.D., Longacre, S.A., Morgna, W.A., and Sternbach, C.A. AAPG memoir 98, 15-35.

Thiessen, E., Gleeson, S.A., Bennett, V., and Creaser, R.A. 2016. The tiger deposit: a carbonate-hosted magmatic-hydrothermal gold deposit, central Yukon, Canada. Economic Geology, **111**: 421–446.

Walch, J.E.I. 1771. Die Naturgeschichte der Versteinerungen, zur Erläuterung der Knorrischen Sammlung von Merkwürdigkeiten der Natur. Dritter Theil. P.J. Felecker, Nürnberg, 235 pp.

Walcott, C.D. 1886. Second contribution to the studies on the Cambrian faunas of North America. Bulletin of the United States Geological Survey, **30**:369 pp.

Walcott, C.D. 1888. Cambrian fossils from Mt. Stephens, Northwest Territory of Canada. American Journal of Science Third Series, **36**:163-166.

Walcott, C.D. 1889. Description of new genera and speciemens of fossils from the Middle Cambrian. Proceedings of the United States National Museum, **11**:441-446.

Walcott, C.D. 1890. The fauna of the Lower Cambrian or *Olenellus* Zone. *In* 10th Annual Report of the Director of the U.S. Geological Survey for 1888-1889. **1**:509-774.

Walcott, C.D. 1910. Cambrian geology and paleontology No. 6- Olenellus and other genera of the Mesonidae. Smithsonian Miscellaneous Collections, **53**:422 pp.

Walcott, C.D. 1916. Cambrian trilobites. Smithsonian Miscellaneous Publications, **64**:303-456.

Walcott, C.D. 1924. Cambrian and lower Ozarkian trilobites, Cambrian geology and paleontology V. Smithsonian Miscellaneous Collections, **75**:61-146.

Westergård, A.H. 1946. Agnostoidea of the Middle Cambrian of Sweden. Sveriges Geologiska Undersokning, Series C. **477**:141 pp.

Webster, M. 2007. Paranephrolenellus, a new genus of Early Cambrian olenelloid trilobite. Memoirs of the Association of Australasian Palaeontologists, **34**:31-59.

Webster, M. 2011. Trilobite biostratigraphy and sequence stratigraphy of the Upper Dyeran (traditional Laurentian "Lower Cambrian") in the southern Great Basin, U.S.A. *In* Cambrian Stratigraphy and Paleontology of Northern Arizona and Southern Nevada. Edited by J.S. Hollingsworth, F.A. Sundberg, and J.R. Foster. Museum of Arizona Bulletin 67. pp. 121–152.

Webster, M., and Landing, E. 2016. Geological context, biostratigraphy, and systematic revision of late early Cambrian olenelloid trilobites from the Parker and Monkton formations, northwestern Vermont, U.S.A. Australasian Palaeontological Memoirs, **49**:193-240.

Williams, G.K. 1987. Cambrian geology of the Mackenzie corridor. Geological Survey of Canada. Open File 1429. 58 pp.

3-11 FIGURES

Figure 3-1. The configuration of major basins and syndepositional topographic features that were present on the ancestral western margin of Laurentia during the Cambrian. The study area is far south of the Misty Creek embayment and west of the Redstone arch in NTS 95M. A suite of arches and "platforms" separate the Selwyn basin from the intracratonic basin. Adapted and compiled from Cecile et al. (1997), Mossop et al. (2004), Goodfellow (2007), Hannigan et al. (2011), and Bouchard and Turner (2017).

Figure 3-2. Stratigraphic correlation chart of upper Ediacaran to lower Cambrian (Series 2) strata in the June Lake/Sekwi Brook and Sheepbed Creek/Natla structural panels (areas with a common structural history, such as an anticline, or thrust sheet). June Lake/Sekwi Brook and Sheepbed Creek/Natla columns are adapted from MacNaughton and Fallas (2021). If the carbonate marker unit is accepted as a "tongue" of the Risky Formation, the Ediacaran/Cambrian boundary occurs mid-way through the upper member of the Backbone Ranges Formation. Middle and lower Backbone Ranges Formation members are only tentatively correlated. Dotted lines indicate tentative boundaries, and grey areas indicate strata eliminated by erosion and/or not deposited during depositional hiatuses. Question marks indicate tentative unconformities or correlations.

Figure 3-3.Locations of sections in NTS 95M and 105P (Wrigley Lake and Sekwi Mountain) adapted from Gabrielse et al. (1973) and Fritz (1979). Gabrielse et al. 1976 sections 14/18, 16, and 19 and section 08MWB-S2/08MWB-S3 (from MacNaughton and Fallas 2021) are shown in the Wrigley Lake area (=arch-proximal sections) and form cross section A-A' shown in Figs. 8 and 11. Fritz (1979) sections 33, 35, and 36 are shown west of Wrigley Lake in the Sekwi Mountain area (=arch distal sections) and form cross section B-B' is shown in Figs. 10 and 11. Placement of the Redstone arch reflects its position during the early-middle Cambrian.

Figure 3-4. Chronostratigraphy, chemostratigraphy, and biostratigraphy of the late early Cambrian to earliest middle Cambrian adapted from Palmer (1998), Taylor et al. (2012), Geyer (2019), Peng et al. (2020), and Morgan (2021). (A) Global series and stage names. (B) Regional Laurentian series and stage names. (C) Great Basin (Nevada, California and Arizona) Stage 3-4 species-based biozones [Webster (2011) and Hollingsworth (2011); *Esmeraldina rowei* to *Amecephalus arrojosensis* zones] and other Laurentian biozones Peng et al. 2020]. (D) Traditional, genus-based Laurentian trilobite biozones. (E) Stable carbon isotope excursions are given as bars at approximate stratigraphic levels and sourced from Geyer (2019). Red=positive excursions, blue=negative excursions. CARE= Cambrian Arthropod Radiation Carbon isotope Exursion, MICE= MIngxinsi Carbon isotope Excursion, AECE= Archaeocyathid Extinction Carbon isotope Excursion, ROECE=, Redlichiid-Olenellid Extinction Carbon isotope Excursion, and DICE= DrumIan Carbon Isotope Excursion. The EAREZE does not have a formal acronym, but corresponds to the *Repinaella* Zone of the Siberian platform, close to the first appearance of trilobites.

Figure 3-5. Lithostratigraphy of Gabrielse et al. (1973) sections 14/18 and 19 and Fritz (1979) sections 33, 35, and 36. Section locations are given in Fig. 3-3.

Figure 3-6. Gabrielse et al. (1973) section 14/18 biostratigraphy and lithostratigraphy. GSC locations are labelled on the right-hand side of section 14, and stratigraphic levels at which trilobites were collected are indicated by black circles. Section 14/18 includes the Backbone Ranges, Sekwi, Rockslide, and Broken Skull Formations and spans the Ediacaran to upper

Cambrian. Legend as in Fig. 3. No biostratigraphic data are shown in the Rockslide Formation of Section 18 because the trilobite taxa reported in Gabrielse et al.'s (1973) faunal list (*Syspacephalus* and *Caborcella*) are not age-diagnostic, and probably only indicate the traditional middle Cambrian.

Figure 3-7. Gabrielse et al. (1973) section 19 biostratigraphy and lithostratigraphy. GSC locations are indicated to the right of the column, and stratigraphic levels at which trilobites were collected are indicated by black circles. No trilobite data from the Broken Skull Formation were acquired for this study. Positions of tentatively assigned taxa are indicated by white circles. Section 19 includes the Sekwi, Rockslide, and Broken Skull Formations, spanning the lower early Cambrian to late Cambrian. Note apparent absence of *Plagiura-Poliella* Zone (star).

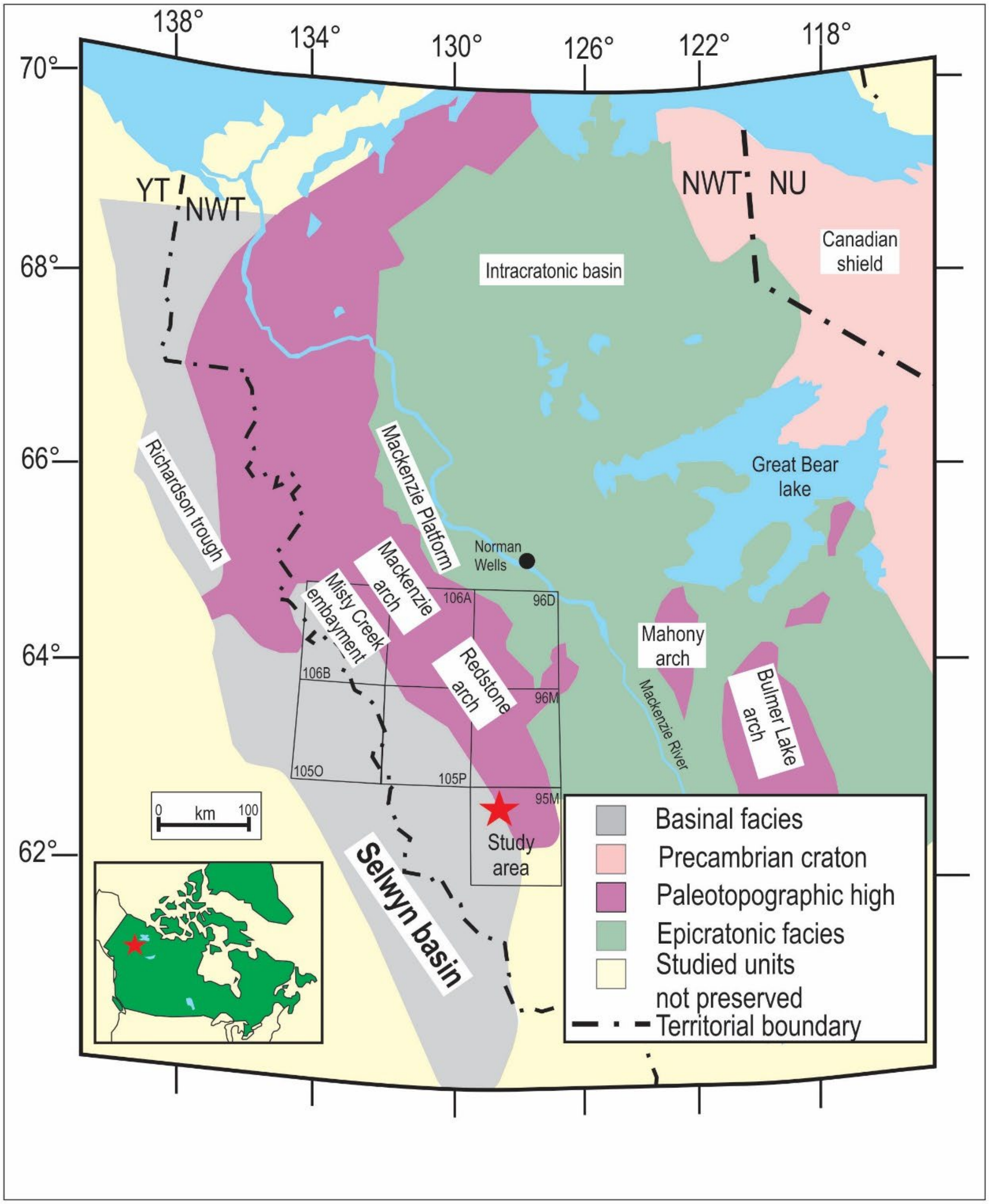
Figure 3-8. Panel near the Redstone arch showing biostratigraphic control points, stratigraphic units, and biozones. The upper member of the Backbone Ranges Formation is truncated towards the east, leaving Ediacaran strata unconformably underlying the lower Sekwi Formation at Section 14/18. The uppermost Rockslide Formation also may have been eroded, resulting in the presence of the *Bolaspidella* Zone at Section 19 but not Section 16. Sections 14/18, 16, and 19 are adapted from Gabrielse et al. (1973). Section 08MWB-S2/08MWB-S3 is adapted from MacNaughton and Fallas (2021). See Fig. 3 for sections location.

Figure 3-9. Location of measured section 08MWBs03 (black line). Stratigraphic contacts are indicated by white dashed lines. At this location (63.440335 N, -127.579625 W), the Sekwi Formation unconformably overlies the partially truncated upper Backbone Ranges Formation and is conformably overlain by the Rockslide Formation. View is to north-northwest. Photograph taken by and courtesy of Karen Fallas.

Figure 3-10. Figure 9. Panel of sections distal to the Redstone arch showing biostratigraphic control points, stratigraphic units, and biozones. The entire upper member of the Backbone Ranges Formation is present at these distal locations, and the Vampire Formation conformably underlies the Sekwi Fm. The Sekwi Formation is significantly thicker at distal locations than in proximal locations and is carbonate-dominated. The Rockslide Formation contact with the Rabbitkettle Formation and is probably conformable at distal locations. Sections 33, 35 and 36 are adapted from Fritz (1979). Although these sections are roughly along strike (<10 km east or west from one another), three distal sections were chosen because tectonic signals may be expressed more subtly in deep-water environments. See Fig. 3 for section locations.

Figure 11. Composite panel of arch-proximal and arch-distal sections. Siltstone-dominated Sekwi Formation is present only in arch-proximal locations, and presumably grades into carbonate-dominated Sekwi Formation between sections 08MWB-S2/08MWB-S3 and 19. Neither the sandstone marker unit nor the Vampire Fm. is present in proximal sections. The lower and middle members of the Backbone Ranges Formation are assumed to taper distally from the Redstone arch. Sections 14/18, 16, and 19 are adapted from Gabrielse et al. (1973). Section 08MWB-S2/08MWB-S3 is adapted from MacNaughton and Fallas (2021). Sections 33, 35 and 36 are adapted from Fritz (1979). See Fig. 3 for section locations. Lateral distances between sections are not reflective of real world distances. Fritz sections 36 and 35 are ~4 km (east-west) from one another; Fritz sections 33 and 35 are ~3.5 km (east-west) from one another. Gabrielse sections 14/18 to 19 occur along a ~32 km (east-west) transect.

Figure 3-12. Interpreted evolution of the Selwyn basin adjacent to the Redstone arch from the late Ediacaran to middle Cambrian. (A) The lower, middle, and upper members of the Backbone Ranges Formation are deposited basin-wide, and the Vampire Formation is deposited distally from the late Ediacaran to earliest early Cambrian (Fortunian to Stage 2) and is equivalent to the upper member of the Backbone Ranges Formation based on trace fossil data. The lower and middle members of the Backbone Ranges Formation are assumed to taper distally from the shoreline (B) Deposition of the Sekwi Formation begins distally during Cambrian Stage 3. Arch-distal, carbonate-dominated Sekwi Formation exposures overlie the Vampire Formation conformably. (C) A regional uplift event around the Redstone arch (event I) results in the erosion of the upper member of the Backbone Ranges Formation and karstification of some of the Sekwi Formation. Olistoliths are deposited in arch-distal settings. Material from the Redstone arch is subsequently deposited as the Sekwi Formation sandstone marker unit and arch-proximal siliciclastic material of the Mount Clark and Mount Cap formations in the intracratonic basin (latest Cambrian Stage 3, *Nevadella* Zone biochron). (D) Either subsidence or eustatic sea level rise results in the deposition of the proximal, silty Sekwi Formation unconformably overtop the Backbone Ranges Formation and distal, carbonate-dominated Sekwi Formation during Stage 4 (latest *Bonnia-Olenellus* Zone). (E) A regional subsidence event (event II) initiates deep-water (Rockslide Formation) deposition (latest Stage 4-earliest Wuliuan). Deep-water conditions persist until the end of the Miaolingian.


138°
134°
130°
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118°
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66°
64°
62°
YT
NWT
NWT
NU
Canadian shield
Intracratonic basin
Richardson trough
Mackenzie Platform
Great Bear lake
Norman Wells
Mackenzie arch
Misty Creek embayment
106A
96D
Mahony arch
106B
Redstone arch
96M
Mackenzie River
Bulmer Lake arch
105O
105P
95M
Study area
0 km 100
Selwyn basin
Basinal facies
Precambrian craton
Paleotopographic high
Epicratonic facies
Studied units not preserved
Territorial boundary

Figure 3-1

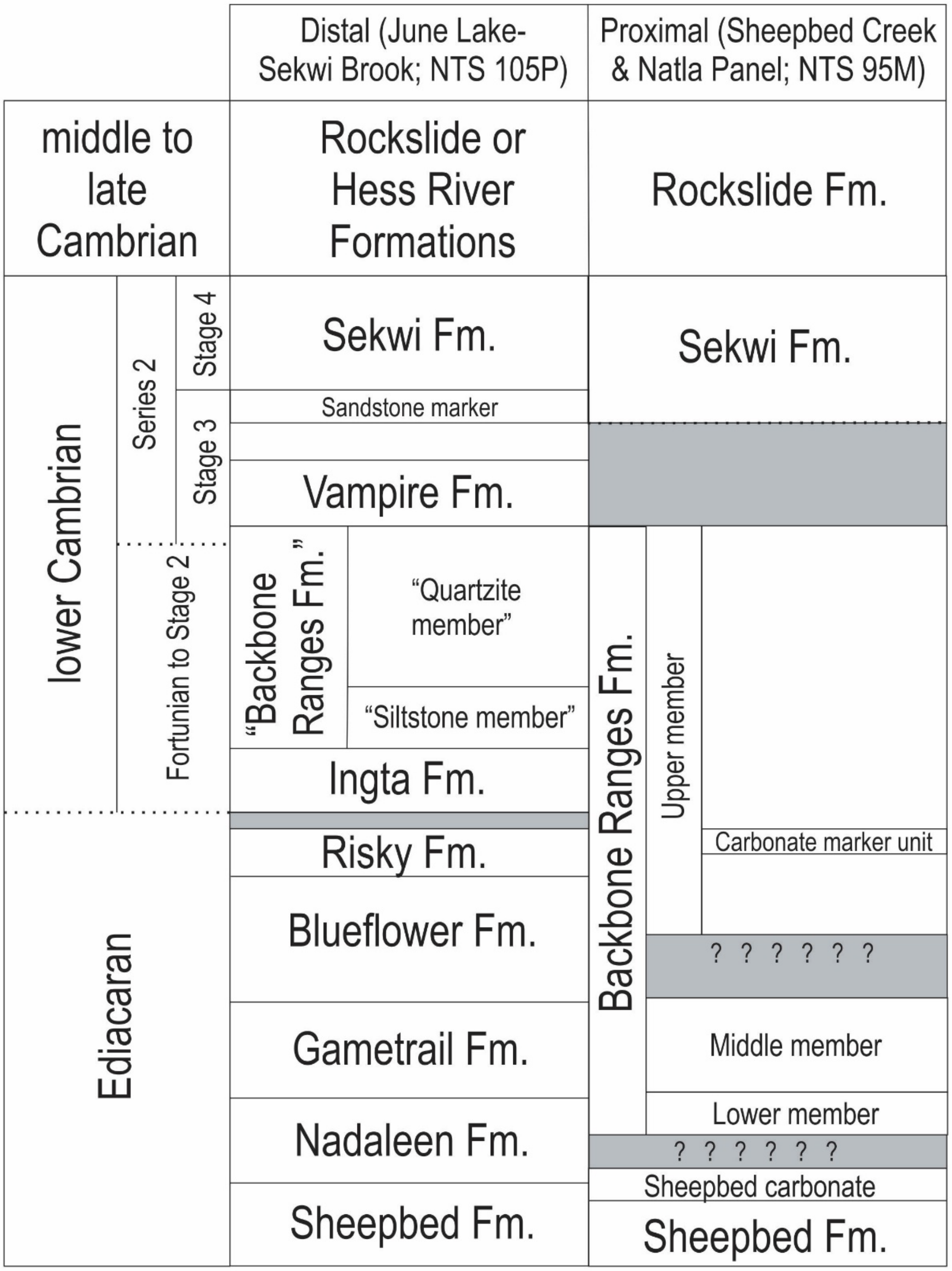
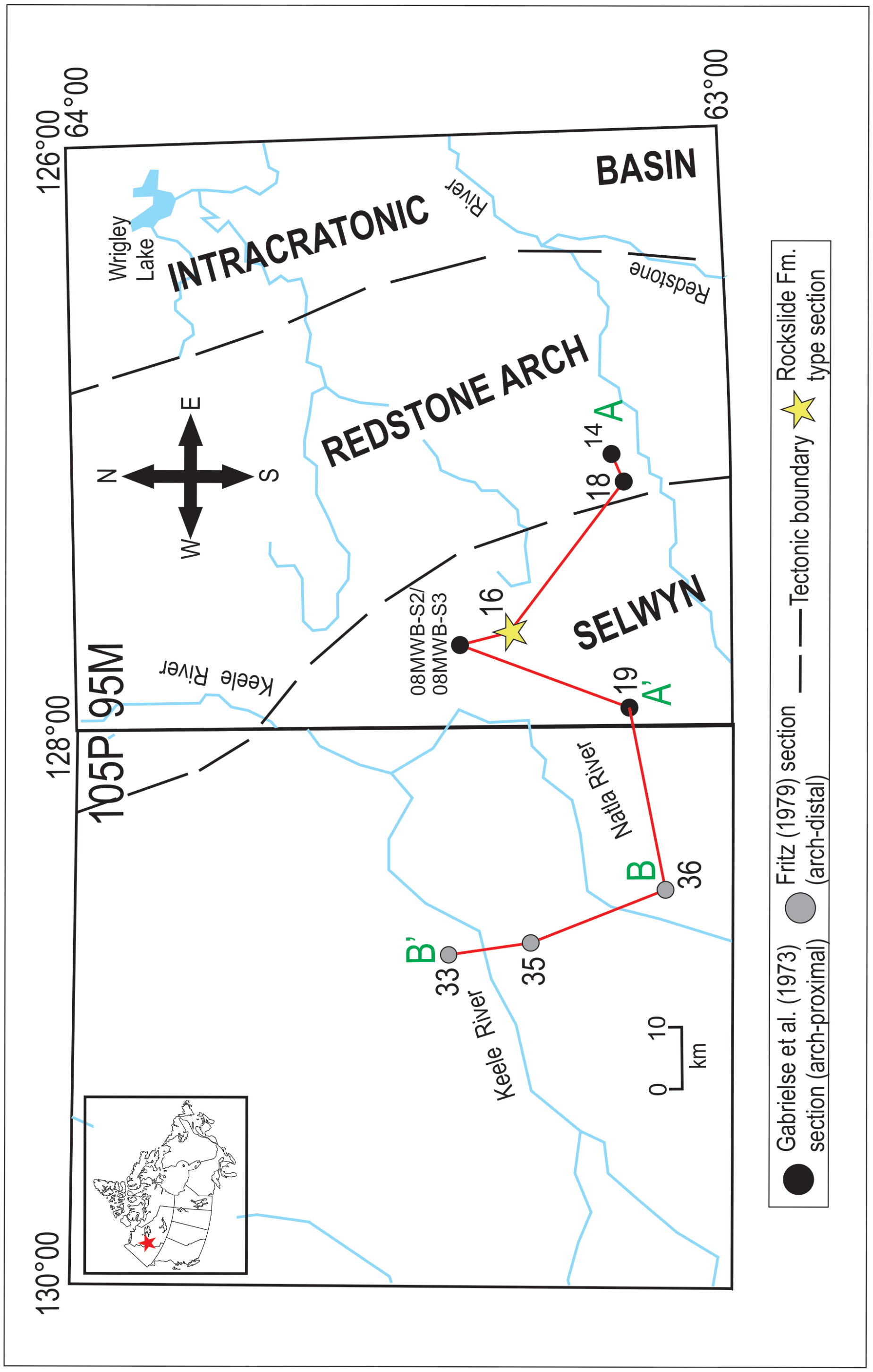

Distal (June Lake-Sekwi Brook; NTS 105P)
Proximal (Sheepbed Creek & Natla Panel; NTS 95M)
middle to late Cambrian
Rockslide or Hess River Formations
Rockslide Fm.
lower Cambrian
Series 2
Stage 4
Stage 3
Fortunian to Stage 2
Sekwi Fm.
Sekwi Fm.
Sandstone marker
Vampire Fm.
“Backbone Ranges Fm.”
“Quartzite member”
“Siltstone member”
Ingta Fm.
Backbone Ranges Fm.
Upper member
Carbonate marker unit
? ? ? ? ? ?
Middle member
Lower member
? ? ? ? ? ?
Sheepbed carbonate
Ediacaran
Risky Fm.
Blueflower Fm.
Gametrail Fm.
Nadaleen Fm.
Sheepbed Fm.
Sheepbed Fm.

Figure 3-2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INTRACRATONIC
BASIN
REDSTONE ARCH
SELWYN
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Redstone River
Keele River
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N
E
S
W
A
A'
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14
18
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36
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33
08MWB-S2/
08MWB-S3
0
10
km
● Gabrielse et al. (1973) section (arch-proximal)
● Fritz (1979) section (arch-distal)
Tectonic boundary
★ Rockslide Fm. type section

Figure 3-3

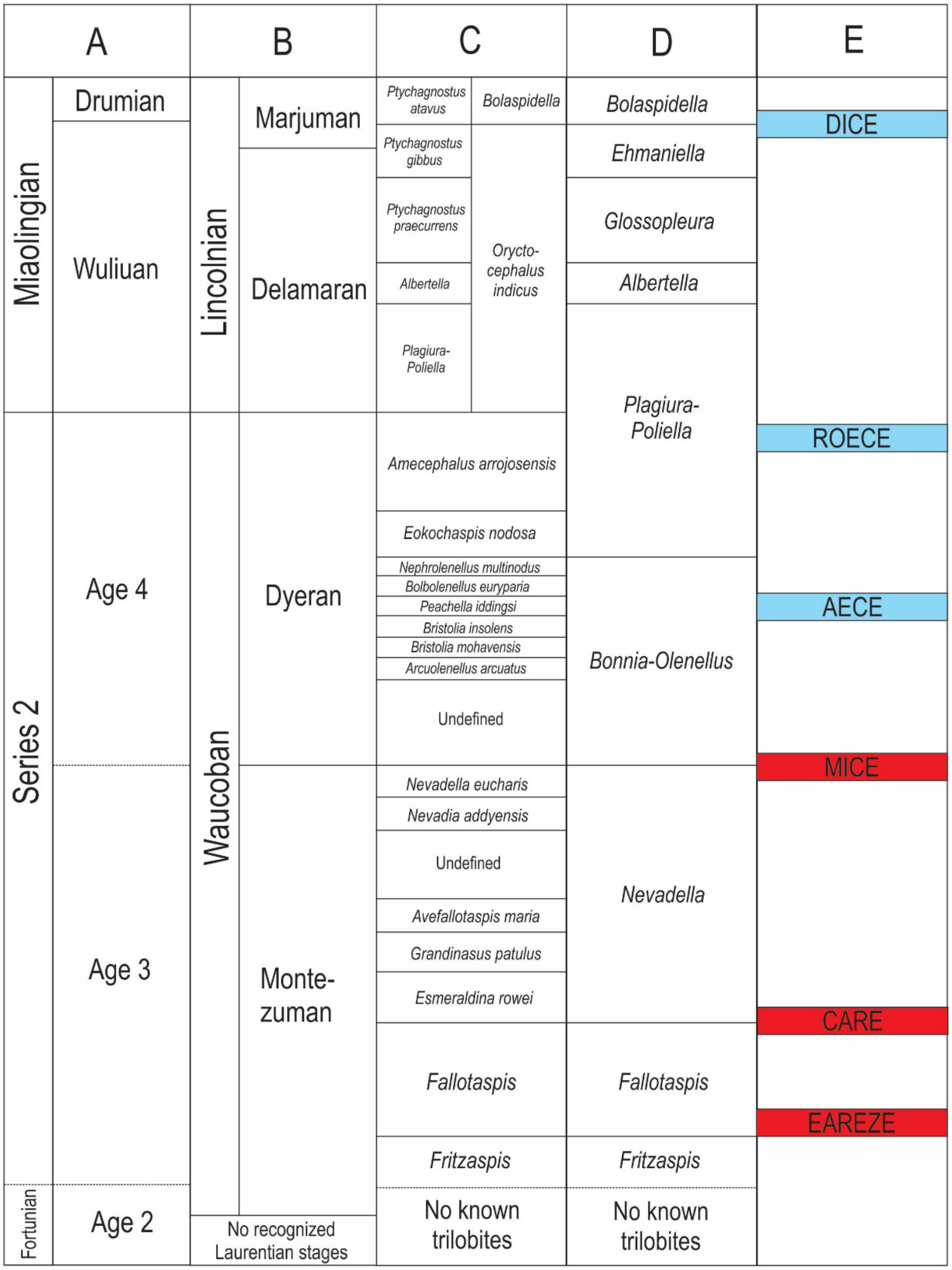

A
B
C
D
E
Miaolingian
Drumian
Wuliuan
Series 2
Age 4
Age 3
Fortunian
Age 2
Lincolnian
Marjuman
Delamaran
Waucoban
Dyeran
Monte-
zuman
No recognized
Laurentian stages
Ptychagnostus
atavus
Bolaspidella
Ptychagnostus
gibbus
Ptychagnostus
praecurrens
Albertella
Plagiura-
Poliella
Orycto-
cephalus
indicus
Amecephalus arrojosensis
Eokochaspis nodosa
Nephrolenellus multinodus
Bolbolenellus euryparia
Peachella iddingsi
Bristolia insolens
Bristolia mohavensis
Arcuolenellus arcuatus
Undefined
Nevadella eucharis
Nevadia addyensis
Undefined
Avefallotaspis maria
Grandinasus patulus
Esmeraldina rowei
Fallotaspis
Fritzaspis
No known
trilobites
Bolaspidella
Ehmaniella
Glossopleura
Albertella
Plagiura-
Poliella
Bonnia-Olenellus
Nevadella
Fallotaspis
Fritzaspis
No known
trilobites
DICE
ROECE
AECE
MICE
CARE
EAREZE

Figure 3-4

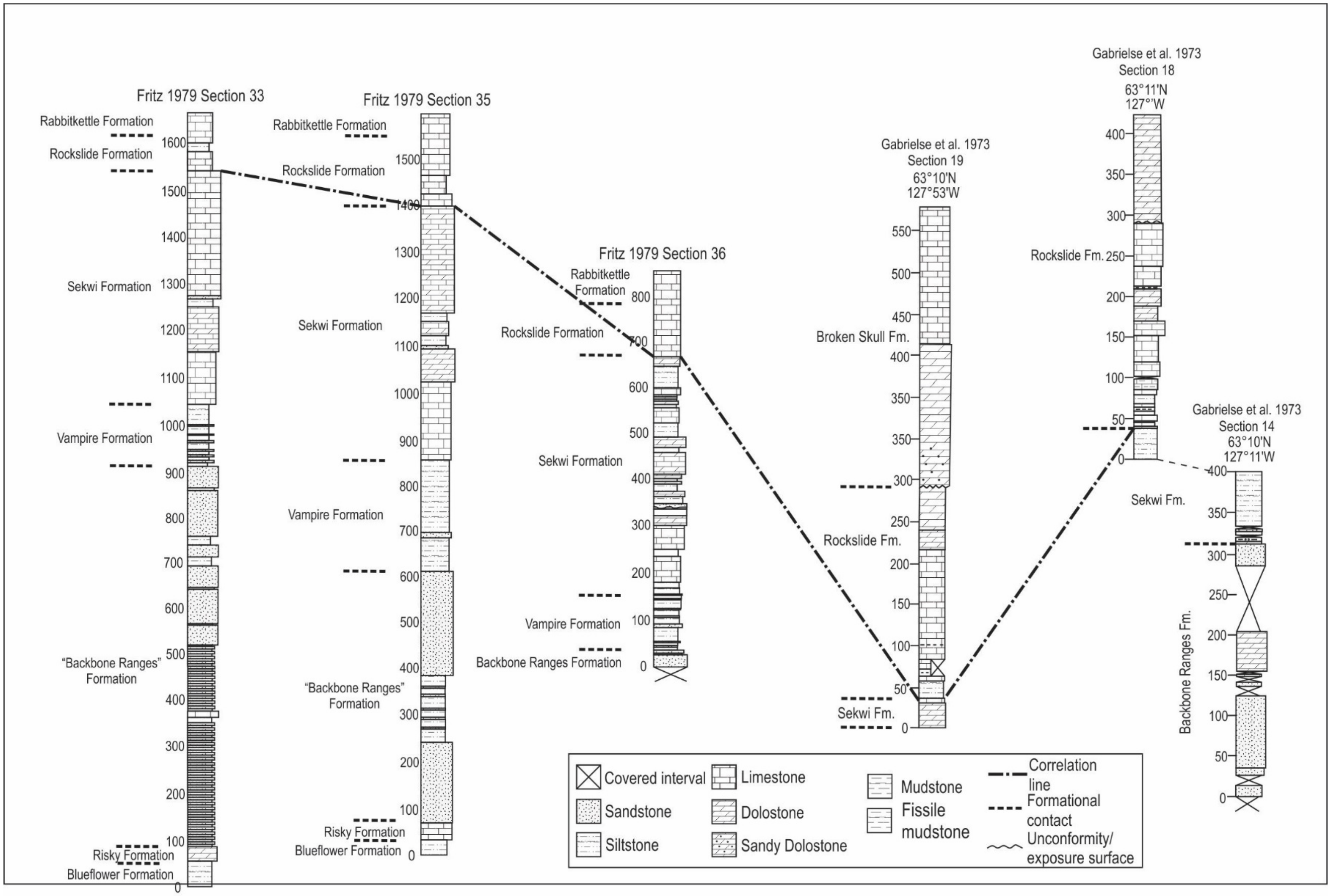

Fritz 1979 Section 33
Rabbitkettle Formation
Rockslide Formation
Sekwi Formation
Vampire Formation
"Backbone Ranges" Formation
Risky Formation
Blueflower Formation
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Fritz 1979 Section 35
Rabbitkettle Formation
Rockslide Formation
Sekwi Formation
Vampire Formation
"Backbone Ranges" Formation
Risky Formation
Blueflower Formation
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Fritz 1979 Section 36
Rabbitkettle Formation
Rockslide Formation
Sekwi Formation
Vampire Formation
Backbone Ranges Formation
800
700
600
500
400
300
200
100
0
Gabrielse et al. 1973
Section 19
63°10'N
127°53'W
Broken Skull Fm.
Rockslide Fm.
Sekwi Fm.
550
500
450
400
350
350
300
250
200
150
100
50
0
Gabrielse et al. 1973
Section 18
63°11'N
127°'W
Rockslide Fm.
400
350
300
250
200
150
100
50
0
Gabrielse et al. 1973
Section 14
63°10'N
127°11'W
Sekwi Fm.
Backbone Ranges Fm.
400
350
300
250
200
150
100
50
0
Covered interval
Sandstone
Siltstone
Limestone
Dolostone
Sandy Dolostone
Mudstone
Fissile mudstone
Correlation line
Formational contact
Unconformity/ exposure surface

Figure 3-5

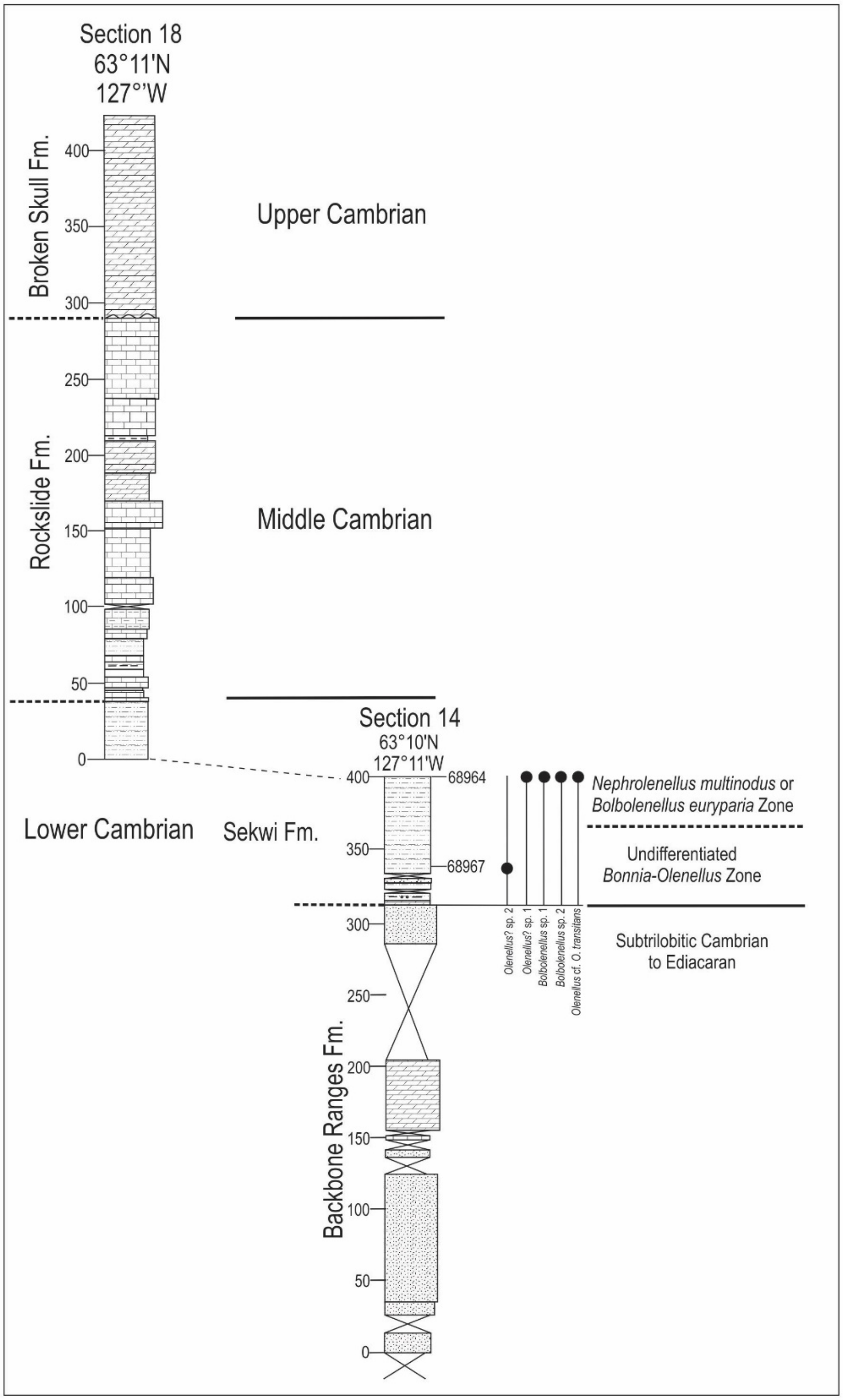
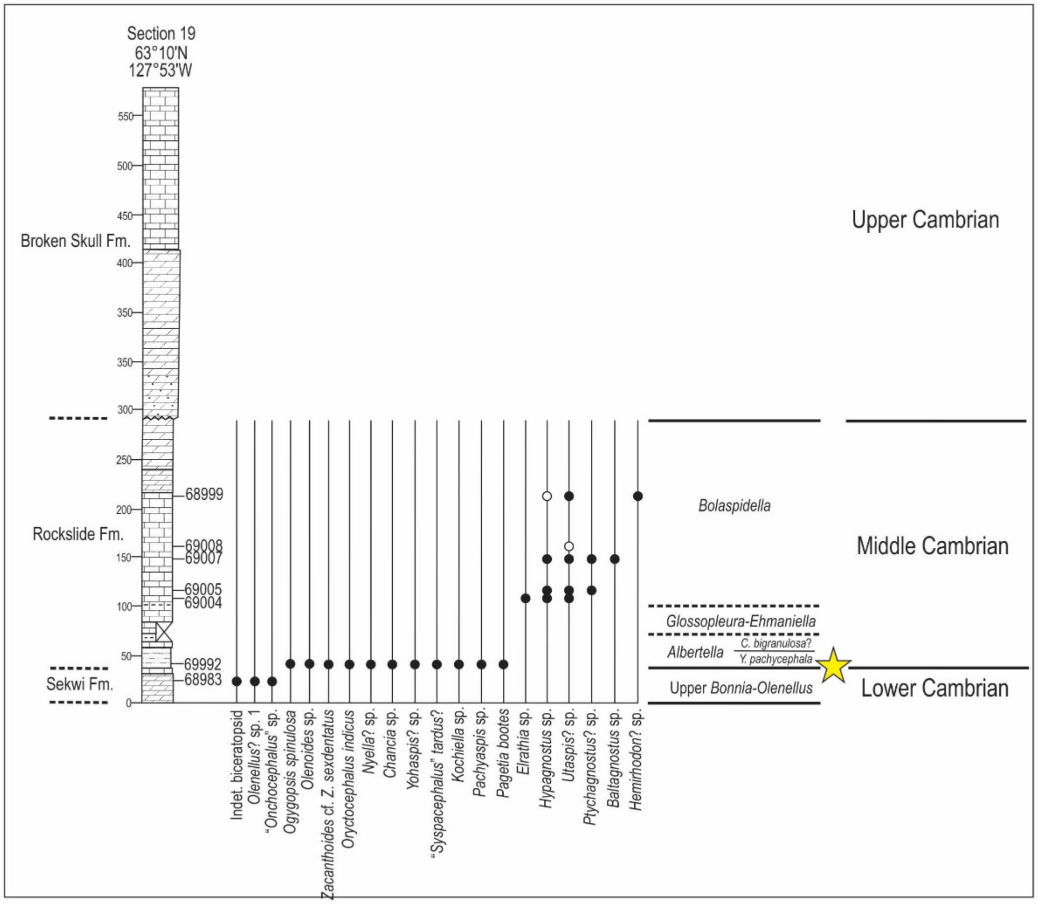

Section 18
63°11'N
127°'W
Broken Skull Fm.
400
350
300
250
200
150
100
50
0
Rockslide Fm.
Upper Cambrian
Middle Cambrian
Lower Cambrian
Sekwi Fm.
Section 14
63°10'N
127°11'W
400
350
300
250
200
150
100
50
0
68964
68967
Backbone Ranges Fm.
Olenellus? sp. 2
Olenellus? sp. 1
Bolbolenellus sp. 1
Bolbolenellus sp. 2
Olenellus cf. O. transitans
Nephrolenellus multinodus or
Bolbolenellus euryparia Zone
Undifferentiated
Bonnia-Olenellus Zone
Subtrilobitic Cambrian
to Ediacaran

Figure 3-6



Section 19
63°10'N
127°53'W
550
500
450
400
350
350
300
250
200
150
100
50
0
Broken Skull Fm.
Rockslide Fm.
Sekwi Fm.
68999
69008
69007
69005
69004
69992
68983
Indet. biceratopsid
Olenellus? sp. 1
"Onchocephalus" sp.
Ogygopsis spinulosa
Olenoides sp.
Zacanthoides cf. Z. sexdentatus
Oryctocephalus indicus
Nyella? sp.
Chancia sp.
Yohaspis? sp.
"Syspacephalus" tardus?
Kochiella sp.
Pachyaspis sp.
Pagetia bootes
Elrathia sp.
Hypagnostus sp.
Utaspis? sp.
Ptychagnostus? sp.
Baltagnostus sp.
Hemirhodon? sp.
Bolaspidella
Glossopleura-Ehmaniella
Albertella
C. bigranulosa?
Y. pachycephala
Upper Bonnia-Olenellus
Upper Cambrian
Middle Cambrian
Lower Cambrian

Figure 3-7

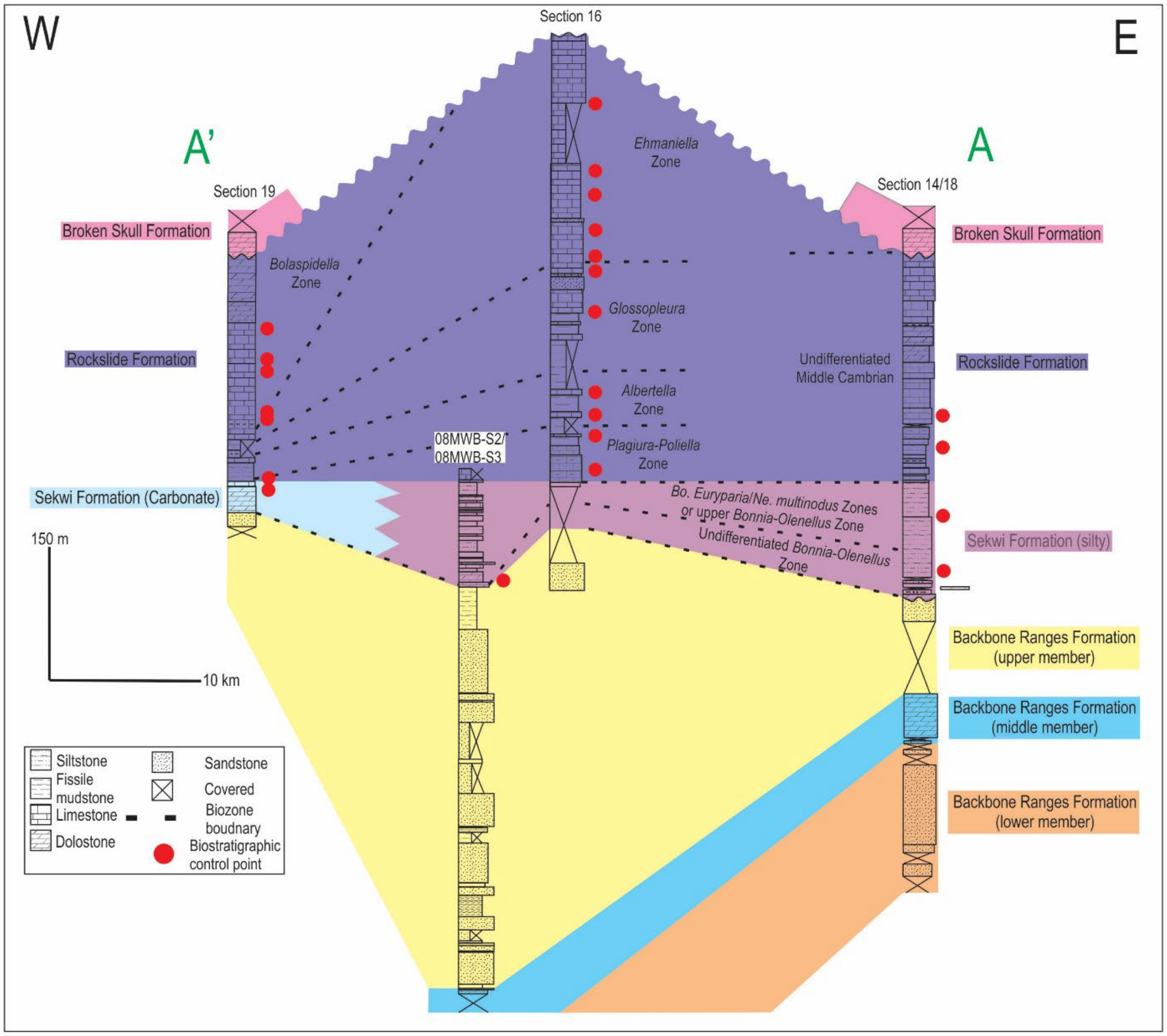

W
E
Section 16
A’
A
Section 19
Section 14/18
Broken Skull Formation
Broken Skull Formation
Ehmaniella Zone
Bolaspidella Zone
Glossopleura Zone
Rockslide Formation
Undifferentiated Middle Cambrian
Rockslide Formation
Albertella Zone
08MWB-S2/ 08MWB-S3
Plagiura-Poliella Zone
Sekwi Formation (Carbonate)
Bo. Euryparia/Ne. multinodus Zones or upper Bonnia-Olenellus Zone
Undifferentiated Bonnia-Olenellus Zone
Sekwi Formation (silty)
150 m
10 km
Backbone Ranges Formation (upper member)
Backbone Ranges Formation (middle member)
Backbone Ranges Formation (lower member)
Siltstone
Fissile mudstone
Limestone
Dolostone
Sandstone
Covered
Biozone boudnary
Biostratigraphic control point

Figure 3-8

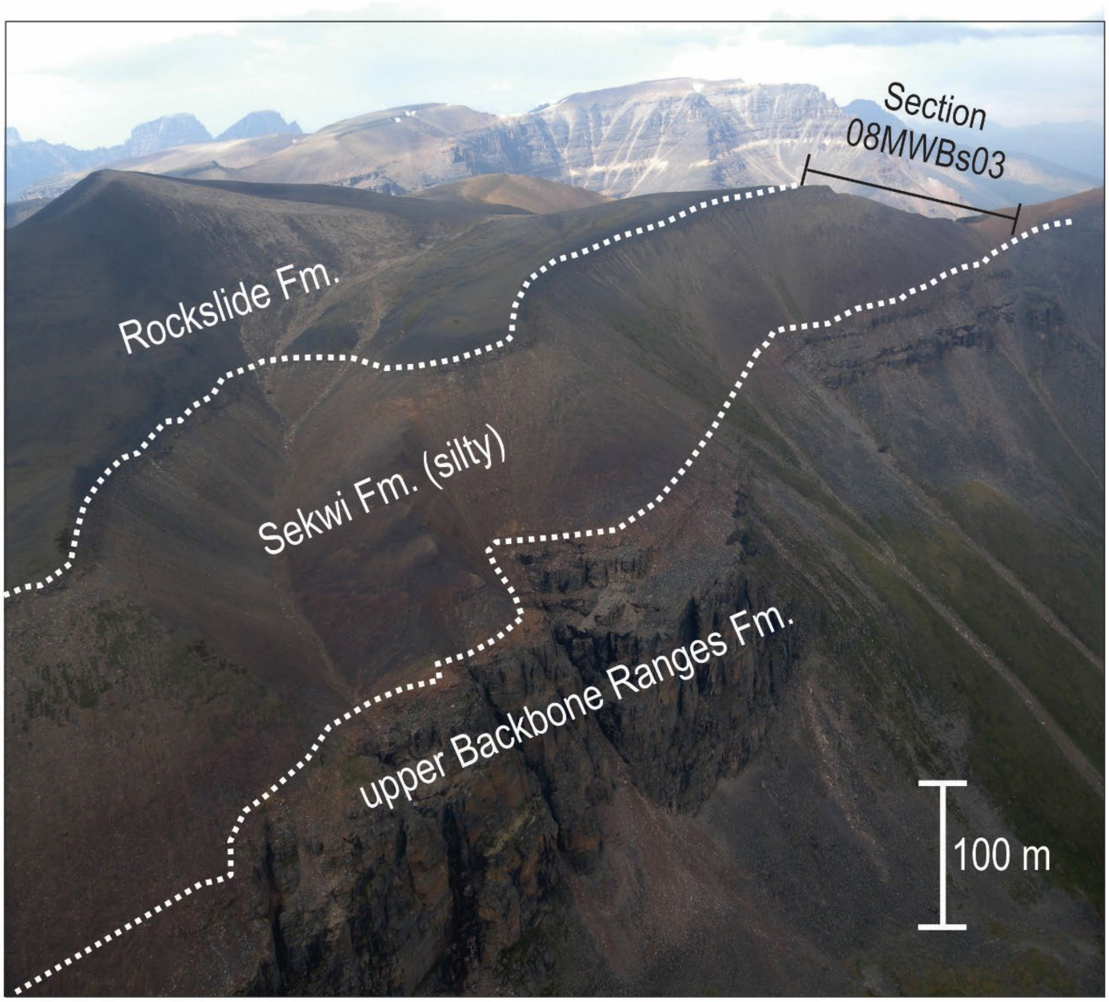

Section
08MWBs03
Rockslide Fm.
Sekwi Fm. (silty)
upper Backbone Ranges Fm.
100 m

Figure 3-9

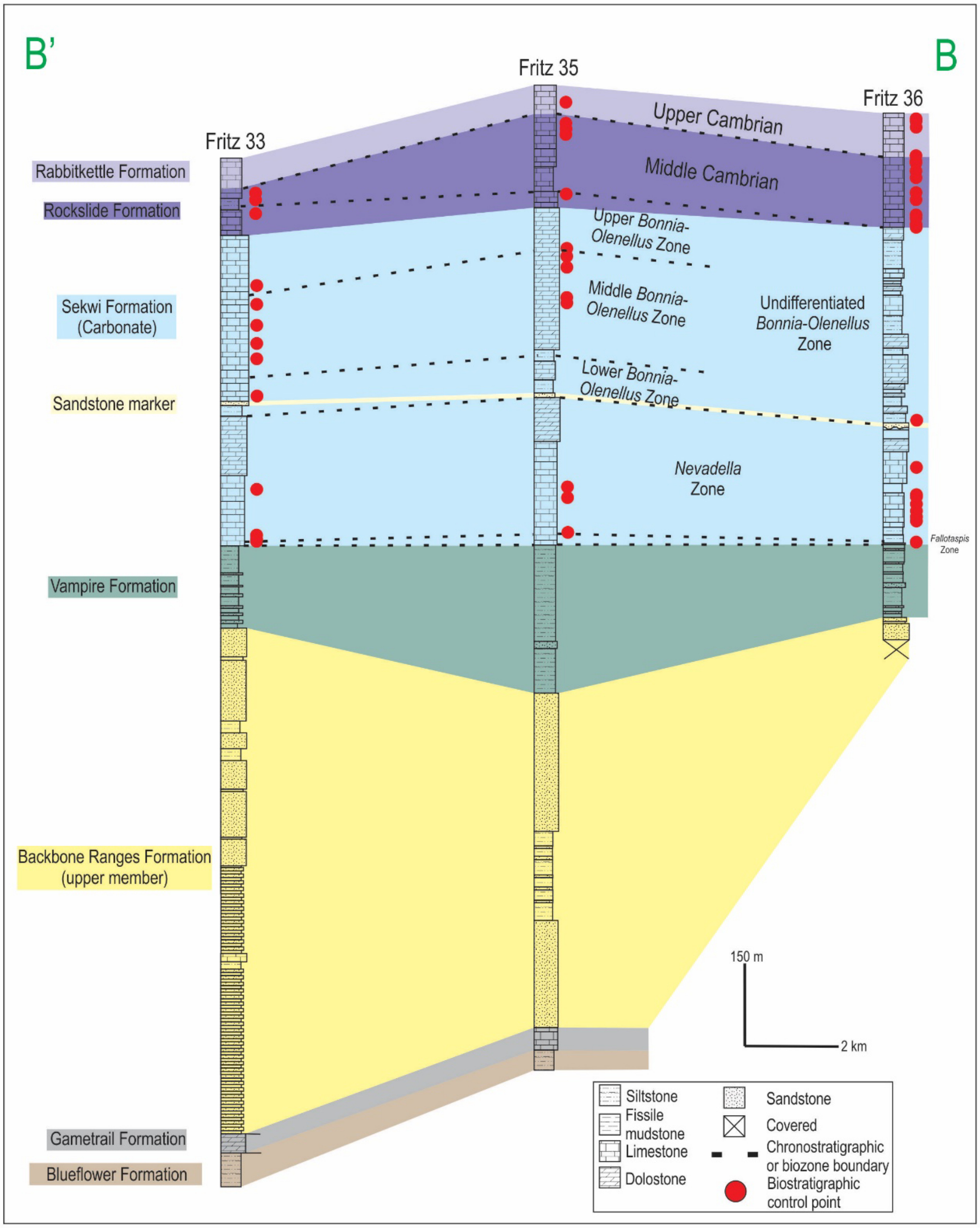

B'
B
Fritz 33
Fritz 35
Fritz 36
Upper Cambrian
Middle Cambrian
Rabbitkettle Formation
Rockslide Formation
Upper Bonnia-Olenellus Zone
Middle Bonnia-Olenellus Zone
Undifferentiated Bonnia-Olenellus Zone
Sekwi Formation (Carbonate)
Lower Bonnia-Olenellus Zone
Sandstone marker
Nevadella Zone
Fallotaspis Zone
Vampire Formation
Backbone Ranges Formation (upper member)
150 m
2 km
Gametrail Formation
Blueflower Formation
Siltstone
Fissile mudstone
Limestone
Dolostone
Sandstone
Covered
Chronostratigraphic or biozone boundary
Biostratigraphic control point

Figure 3-10

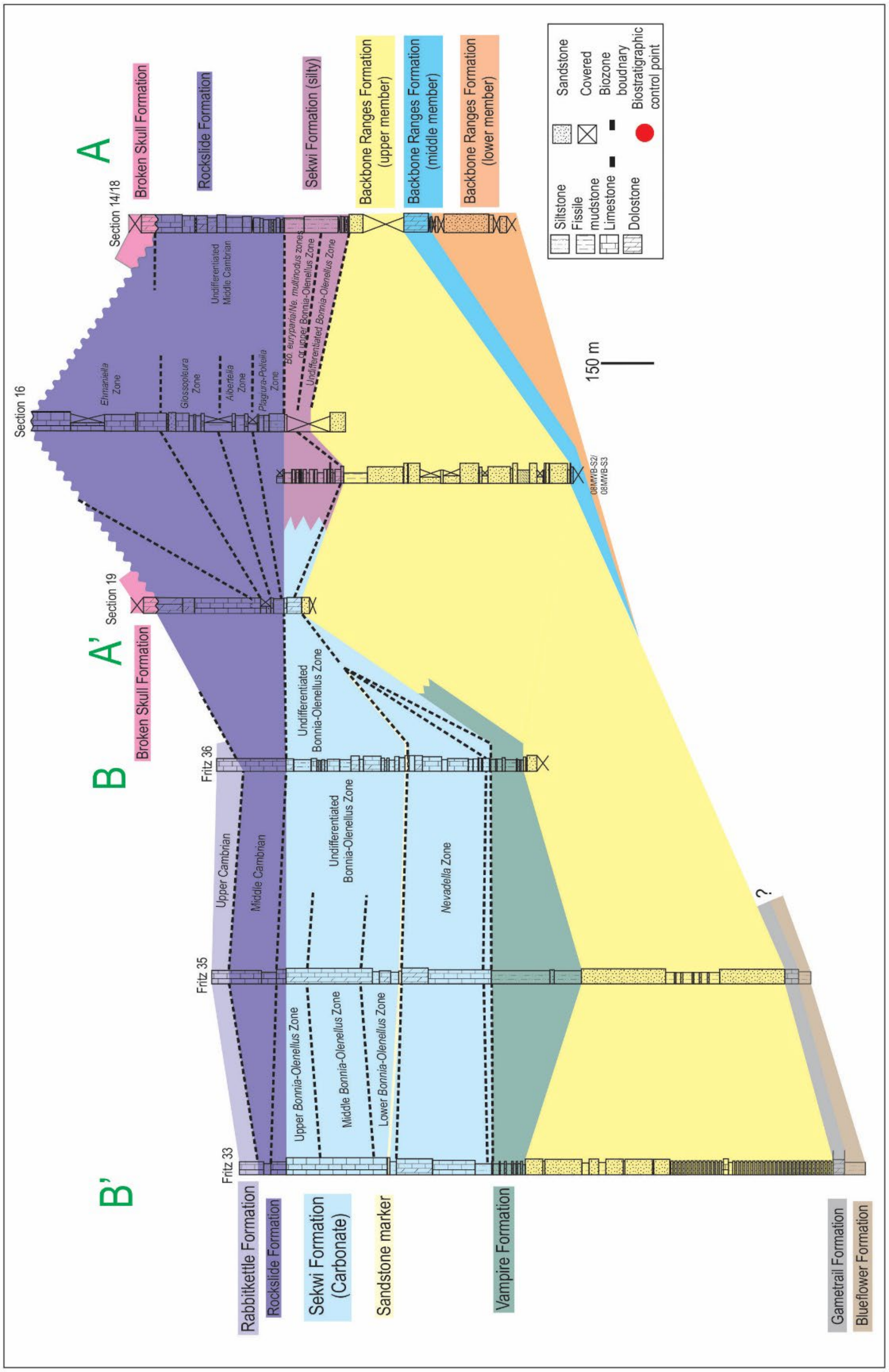

A
A'
B
B'
Section 14/18
Section 16
Section 19
Fritz 36
Fritz 35
Fritz 33
08MWB-S2/
08MWB-S3
Broken Skull Formation
Rockslide Formation
Sekwi Formation (silty)
Backbone Ranges Formation (upper member)
Backbone Ranges Formation (middle member)
Backbone Ranges Formation (lower member)
Rabbitkettle Formation
Sekwi Formation (Carbonate)
Sandstone marker
Vampire Formation
Gametrail Formation
Blueflower Formation
Undifferentiated Middle Cambrian
Ehmaniella Zone
Glossopleura Zone
Albertella Zone
Plagiura-Poliella Zone
Bo. eurypanai/Ne. multinodus zone or upper Bonnia-Olenellus Zone
Undifferentiated Bonnia-Olenellus Zone
Upper Cambrian
Middle Cambrian
Upper Bonnia-Olenellus Zone
Middle Bonnia-Olenellus Zone
Lower Bonnia-Olenellus Zone
Nevadella Zone
?
150 m
Siltstone
Fissile mudstone
Limestone
Dolostone
Sandstone
Covered
Biozone boudnary
Biostratigraphic control point

Figure 3-11

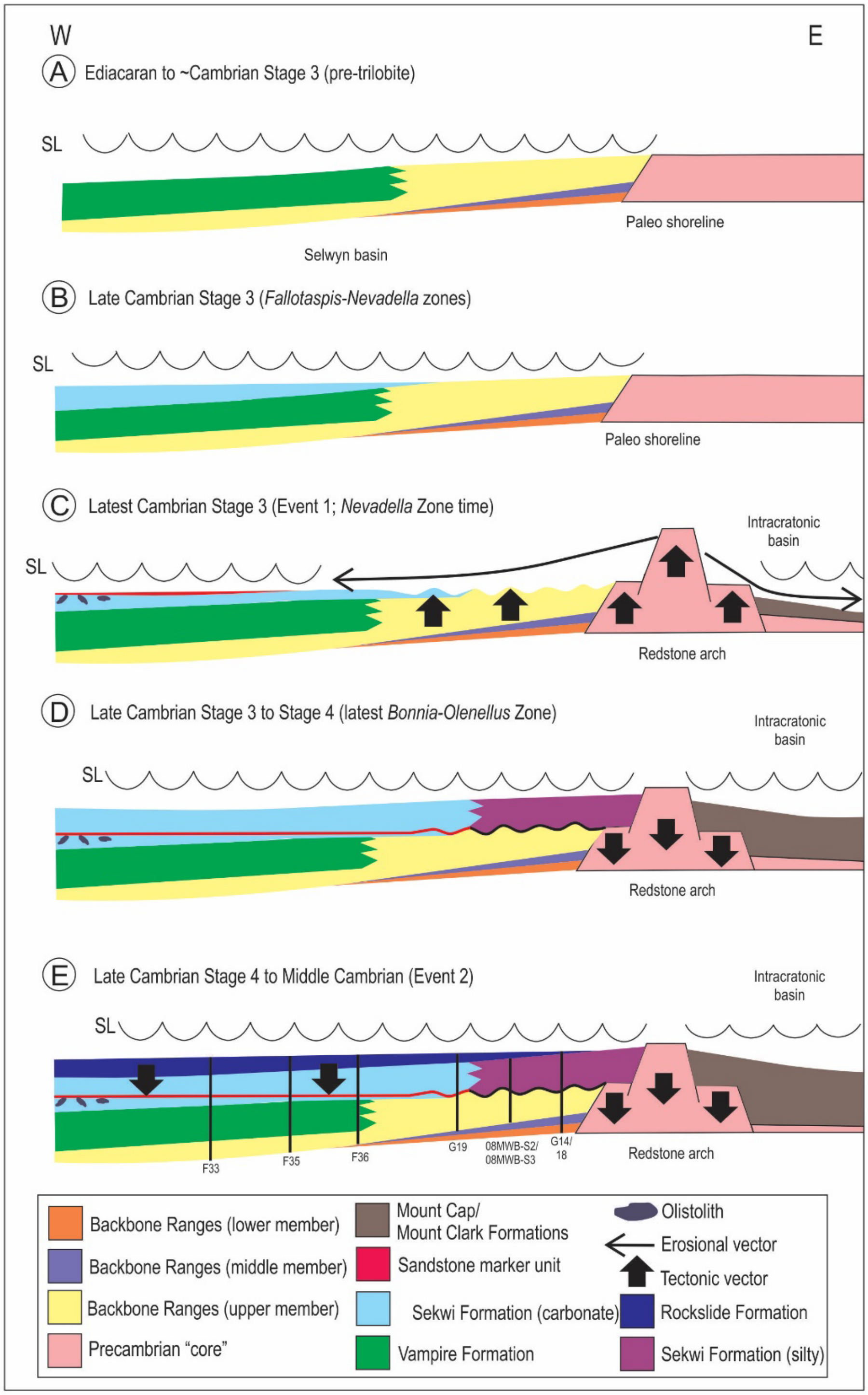

W
E
A Ediacaran to ~Cambrian Stage 3 (pre-trilobite)
SL
Paleo shoreline
Selwyn basin
B Late Cambrian Stage 3 (*Fallotaspis-Nevadella* zones)
SL
Paleo shoreline
C Latest Cambrian Stage 3 (Event 1; *Nevadella* Zone time)
Intracratonic basin
SL
Redstone arch
D Late Cambrian Stage 3 to Stage 4 (latest *Bonnia-Olenellus* Zone)
Intracratonic basin
SL
Redstone arch
E Late Cambrian Stage 4 to Middle Cambrian (Event 2)
Intracratonic basin
SL
F33
F35
F36
G19
08MWB-S2/ 08MWB-S3
G14/ 18
Redstone arch
Backbone Ranges (lower member)
Backbone Ranges (middle member)
Backbone Ranges (upper member)
Precambrian "core"
Mount Cap/ Mount Clark Formations
Sandstone marker unit
Sekwi Formation (carbonate)
Vampire Formation
Olistolith
Erosional vector
Tectonic vector
Rockslide Formation
Sekwi Formation (silty)

Figure 3-12

3.12 TABLES

Table 3-1. Taxonomy and abundance of trilobite material from Gabrielse et al. (1973) Section 14/18.

Table 3-2. Taxonomy and abundance of trilobite material from Gabrielse et al. (1973) Section 19.

Tables 3-1 and 3-2.

Table 1 (Section 14)

Distance from base of unit				
Metres	**Feet**	**Unit**	**GSC location**	**Taxa**
88	289'	Sekwi Fm.	68964	*Bolbolenellus* sp. 1 (51 cephala, 2 cephala with associated partial thoraxes, 1 near-complete individual, 2 juvenile cephala, 3 genae, 4 glabellae, and 3 worn, tentatively assigned cephala) *Bolbolenellus* sp. 2 (3 cephala, one with a partial thorax) *Olenellus* cf. *O. transitans* (7 cephala, 6 cephala with associated thoraxes, 1 juvenile cephalon, 1 thorax, 2 genae, and 2 glabellae)
14.9	49'	Sekwi Fm.	68967	*Olenellus*? sp. (2 partial cephala)

Table 2 (Section 19)

Distance from base of unit				
Metres	**Feet**	**Unit**	**GSC location**	**Taxa**
177.7-178.3	583'-585'	Rockslide Fm.	68999	*Hypagnostus* sp. (1 worn, tentatively assigned pygidium) *Homagnostus*? sp. (1 pygidium) *Utaspis*? sp. (4 cranidia, 3 partial pygidia, and 1 partial glabella) *Hemhirodon*? sp. (2 partial pygidia)
125	410'	Rockslide Fm.	69008	*Utaspis*? sp. (1 badly weathered individual)
86.9	285'	Rockslide Fm.	69007	*Hypagnostus* sp. (4 cranidia, 4 pygidia) *Utaspis*? sp. (2 cranidia, 1 glabella) *Itagnostus*? sp. (6 cranidia) and *Baltagnostus*? sp. (3 cranidia, 4 pygidia)
80.7	265'	Rockslide Fm.	69005	*Hypagnostus* sp. (4 cranidia, 2 pygidia, and 1 complete but very worn individual) *Utaspis*? sp. (2 complete individuals, 2 worn cranidia, and 2 small cranidia) *Itagnostus*? sp. (4 cranidia) *Eldoradia*? sp. (2 cranidia)
71.6	235'	Rockslide Fm.	69004	*Hypagnostus* sp. (2 cranidia) *Elrathia* sp. (1 small cranidium) *Utaspis*? sp. (1 complete individual with a worn cranidium and 2 small cranidia)
0.6-1.5	2'-5'	Rockslide Fm.	68992	*Ogygopsis spinulosa* Rasetti 1951 (1 nearly complete individual, 8 cranidia, 1 glabella, and 22 pygidia) *Olenoides* sp. (2 tentatively assinged cranidia and 10 pygidia) *Zacanthoides* cf. *Z. sexdentatus* Rasetti 1951 (9 cranidia, 2 associated pygidia) *Oryctocephalus indicus* Reed 1910 (3 cranidia, 1 partial thorax and pygidium, and 1 partial pygidium) *Nyella*? sp. (2 partial cranidia) *Chancia* sp. (1 cranidium with partial thorax and exuviated librigena; 1 partial cranidium with partial thorax) *Yohoaspis*? sp. (8 cranidia) "*Syspacephalus*" *tardus*? Rasetti 1951 (24 cranidia) *Kochiella* sp. (5 cranidia, 2 pygidia) *Pachyaspis* sp. (7 cranidia, 1 glabella) *Pagetia bootes* Walcott 1916 (45 cranidia, 69 pygidia)
29.0-29.6	95'-97	Sekwi Fm.	68983	*Olenellus*? sp. 1 (3 genae, 1 partial juvenile cephalon) "*Onchocephalus*" sp. (5 cranidia) indet. Biceratopsid (3 genae, 1 partial cephalon)

APPENDICES

APPENDIX 2A: Plates of representative *Fallotaspis* and *Nevadella* zone trilobites from sections 2 and 10.

Plate 2A-1. Representative fallotaspidid and dorypygid trilobites from Fritz sections 2 and 10.

A) Indet fallotaspidoid. Partial glabella. Fritz (1972) section 2, GSC location 83299. Specimen SM2-99-1.

B) Indet fallotaspidoid. Associated opisthothorax. Fritz (1972) section 2, GSC location 83299. Specimen SM2-99-2.

C) Indet fallotaspidoid. Partial cephalon. Fritz (1972) section 2, GSC location 83299. Specimen SM2-99-3.

D) Indet fallotaspidoid. GSC location Fritz (1972) section 2, 83300. Specimen SM2-00-1.

E) Indet fallotaspidoid. GSC location Fritz (1972) section 2, 84302. Specimen SM2-02-1.

F) Indet fallotaspidoid. GSC location 84304. Fritz (1972) section 2, Partial glabella and ocular lobe. Specimen SM2-04-1.

G) *Parafallotaspis grata*. Worn, partial cephalon. Fritz (1972) section 2, GSC location 84301. Specimen SM2-01-1.

H) *Parafallotaspis grata*. Worn, partial cephalon. Fritz (1972) section 2, GSC location 84303. Specimen SM2-03-1.

I) *Parafallotaspis grata*. Glabella and ocular lobes. Fritz (1972) section 2, GSC location 84303. Specimen SM2-03-2.

J) *Parafallotaspis grata*. Glabella and ocular lobe. Fritz (1972) section 10, GSC location 73025. Specimen SM10-25-1.

K) *Parafallotaspis grata*. Partial glabella and ocular lobe. Fritz (1972) section 10, GSC location 73025. Specimen SM10-25-1.

L) *Parafallotaspis grata*. Partial cephalon. Fritz (1972) section 10, GSC location 73025. Specimen SM10-25-2.

M) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-1.

N) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-1.

O) *Kootenia diutina*. CranidiuM. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-2.

P) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-1.

Q) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-2.

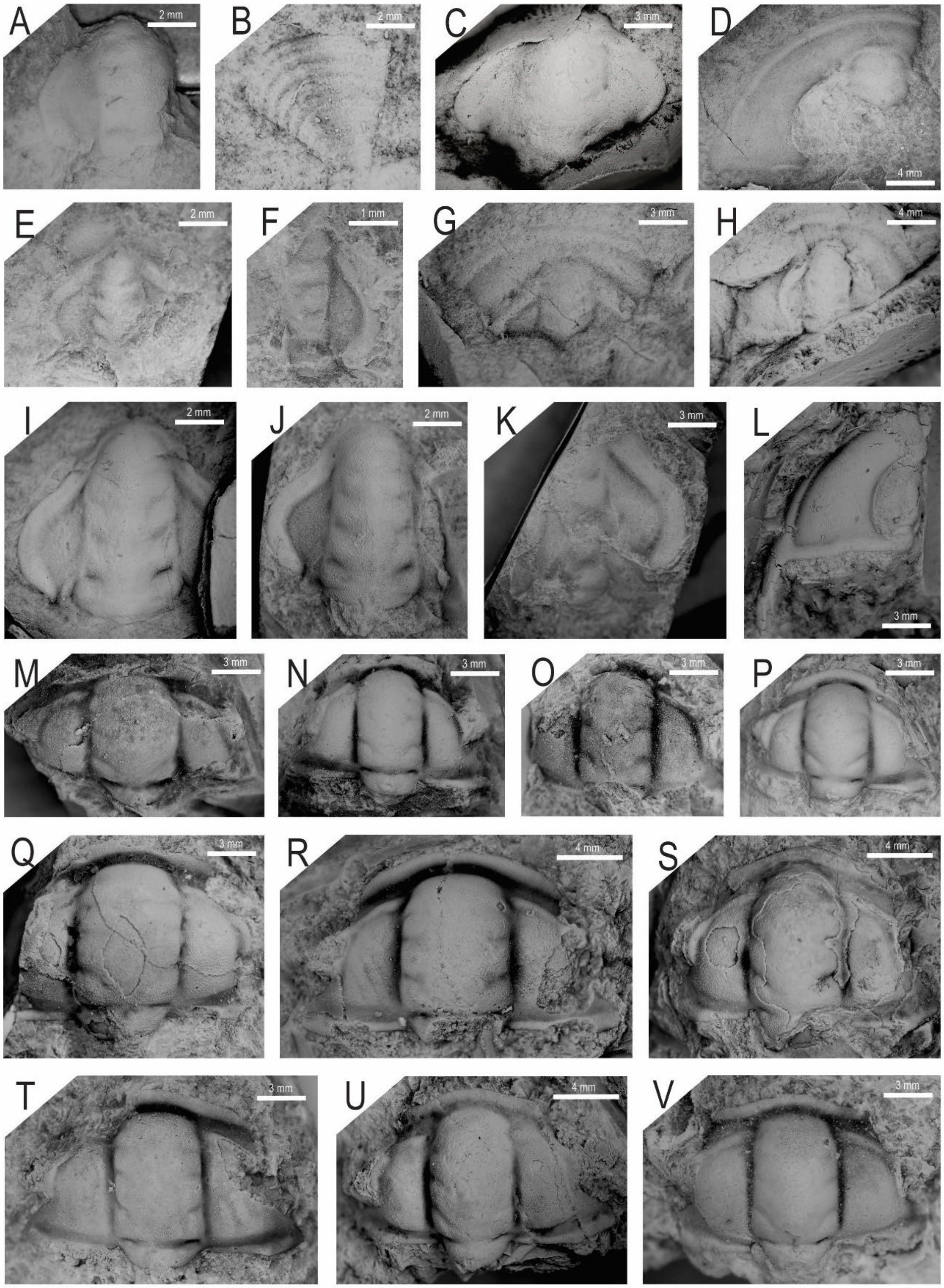
R) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-3.

S) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-1.

T) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-1.

U) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-32-2.

V) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-2.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U
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V
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Plate 1

Plate 2A-2. Representative dorypygids (*Nevadella* Zone) from Friz section 10.

A) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-1.

B) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-2.

C) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-3.

D) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73039. Specimen SM10-39-1.

E) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73038. Specimen SM10-38-1.

F) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73039. Specimen SM10-39-2.

G) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-1.

H) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-2.

I) *Kootenia diutina*. Cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-3.

J) *Kootenia diutina*. Small cranidium. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-2.

K) *Kootenia diutina*. Small cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-3.

L) *Kootenia diutina*. Pygidium. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-3.

M) *Kootenia diutina*. Pygidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-4.

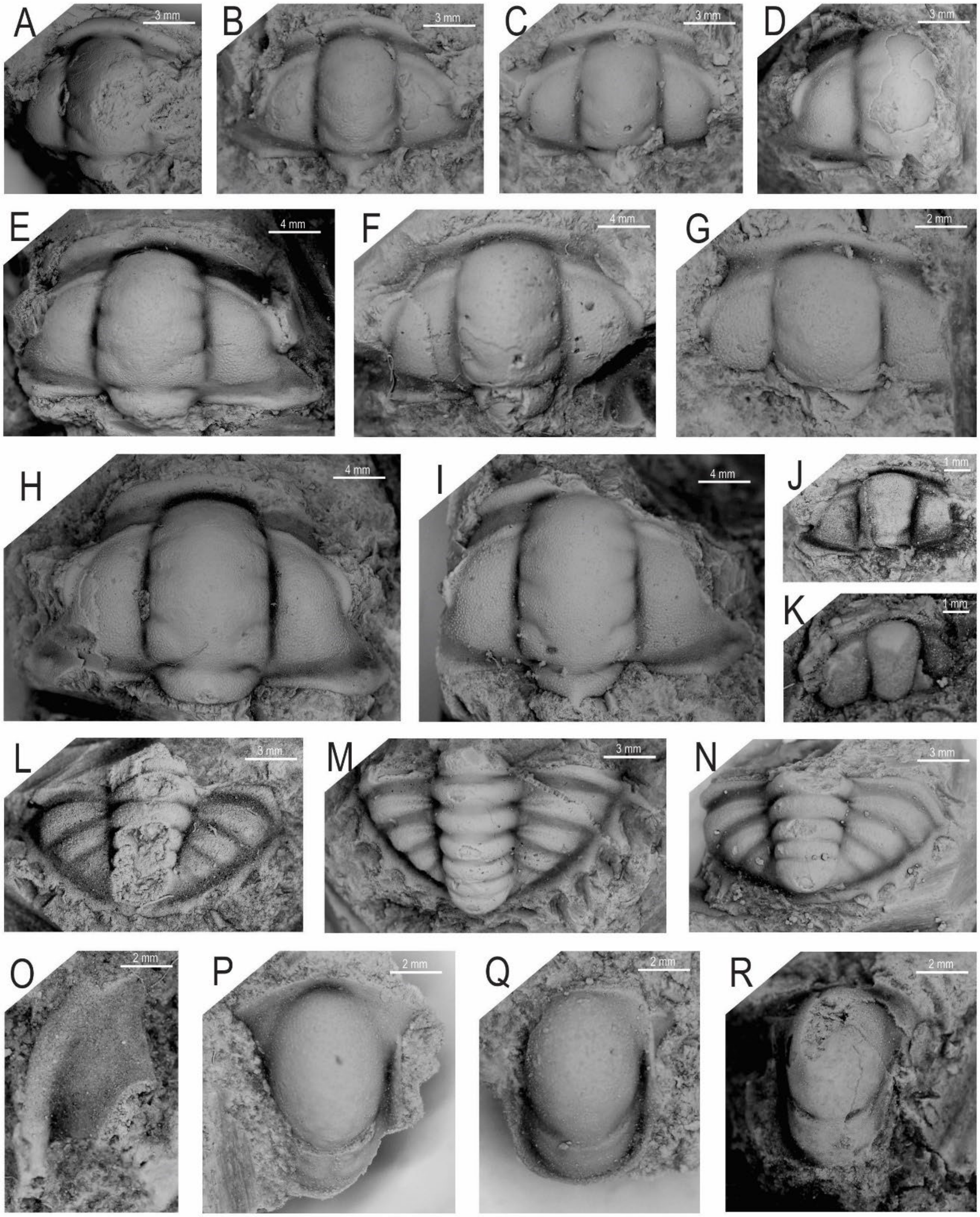
N) *Kootenia diutina*. Pygidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-4.

O) *Kootenia diutina*. Librigena. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-4.

P) *Kootenia diutina*. Hypostome. Fritz (1972) section 10, GSC location 73039. Specimen SM10-39-3.

Q) *Kootenia diutina*. Hypostome. Fritz (1972) section 10, GSC location 73039. Specimen SM10-39-3.

R) *Kootenia diutina*. Hypostome. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-3.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J
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K
1 mm
L
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M
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N
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O
2 mm
P
2 mm
Q
2 mm
R
2 mm

Plate 2

Plate 2A-3. Representative eodiscenids (*Nevadella* Zone) from Fritz section 10.

A) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-5.

B) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-2.

C) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73030. Specimen SM10-30-1.

D) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-4.

E) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-5.

F) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-6.

G) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-4.

H) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-2.

I) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-5.

J) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-6.

K) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-7.

L) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-8.

M) *Pagetides spinulus*. Pygidium. Fritz (1972) section 10, GSC location 73026. Specimen SM10-26-6.

N) *Pagetides spinulus*. Pygidium. Fritz (1972) section 10, GSC location 73030. Specimen SM10-30-2.

O) *Pagetides spinulus*. Pygidium. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-9.

P) *Pagetides spinulus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-3.

Q) *Yukonides lacrinus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-4.

R) *Yukonides lacrinus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-5.

S) *Yukonides lacrinus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-6.

T) *Yukonides lacrinus*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-7.

U) *Yukonides lacrinus*. Cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-4.

V) *Yukonides lacrinus*. Pygidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-8.

W) *Yukonides lacrinus*. Pygidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-9.

X) *Yukonides lacrinus*. Pygidium. Fritz (1972) section 10, GSC location 73035. Specimen SM10-35-1.

Y) *Yukonides lacrinus*. Pygidium. Fritz (1972) section 10, GSC location 73038. Specimen SM10-38-2.

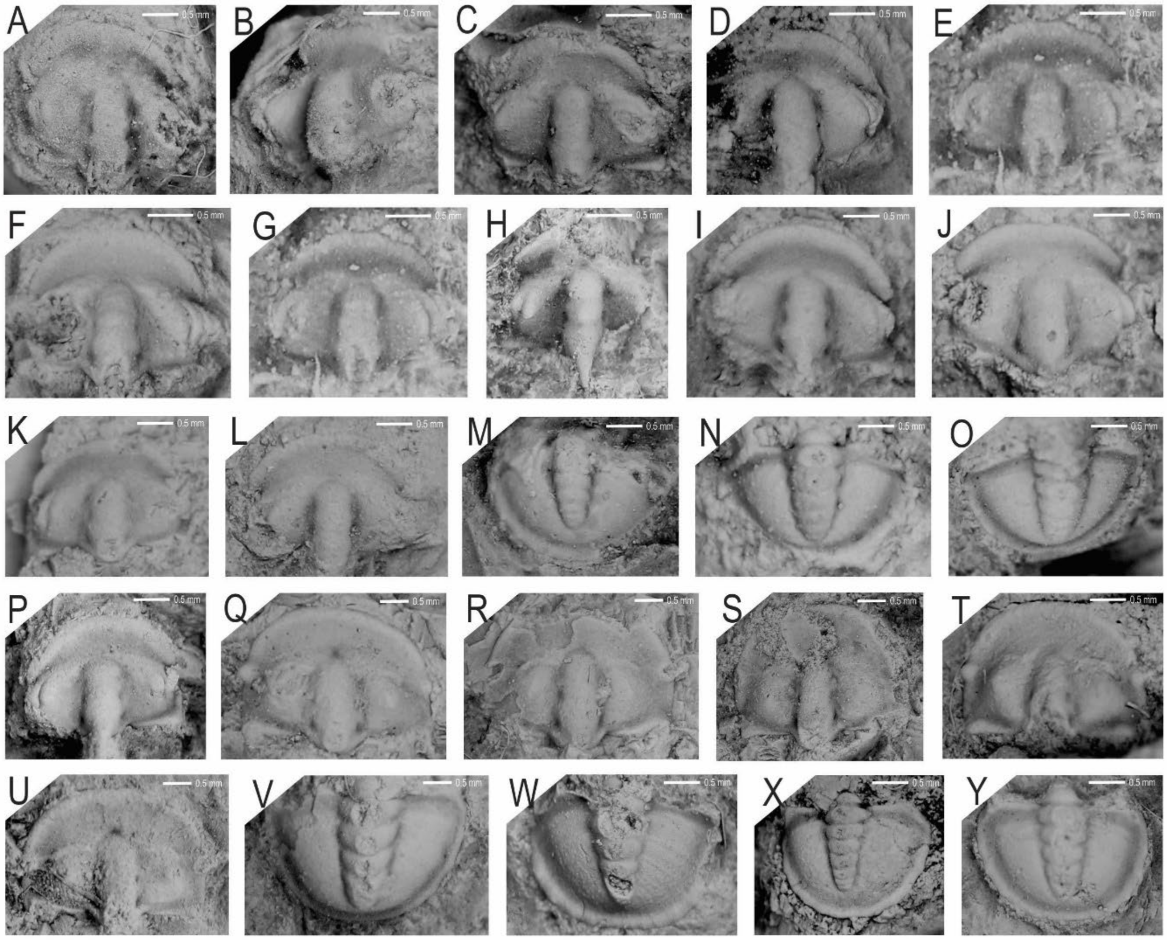

Plate 3

Plate 2A-4. Nevadiids (*Nevadella* Zone) from Fritz (1972) section 2 and 10.

A) *Nevadella bacculenta*. Partial cephalon. Fritz (1972) section 10, GSC location 73030. Specimen SM10-30-3.

B) Associated hypostome. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-5.

C) Associated hypostome. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-6.

D) *Nevadella faceta*. Partial cephalon. Fritz (1972) section 10, GSC location 73036. Specimen SM10-36-10.

E) *Nevadella faceta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-10.

F) *Nevadella faceta*. Latex cast of partial cephalon. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-3.

G) *Nevadella faceta*. Gena. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-4.

H) *Nevadella faceta*. Partial cephalon. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-7.

I) *Nevadella* cf. *N. bacculenta* Fritz 1972. Fritz (1976) section 2, GSC location 84312. Specimen SM2-12-1.

J) *Nevadia addyensis*. Cephalon. Fritz (1976) section 2, GSC location 84313. Specimen SM2-13-1.

K) *Nevadia addyensis*. Cephalon. Fritz (1976) section 2, GSC location 84313. Specimen SM2-13-2.

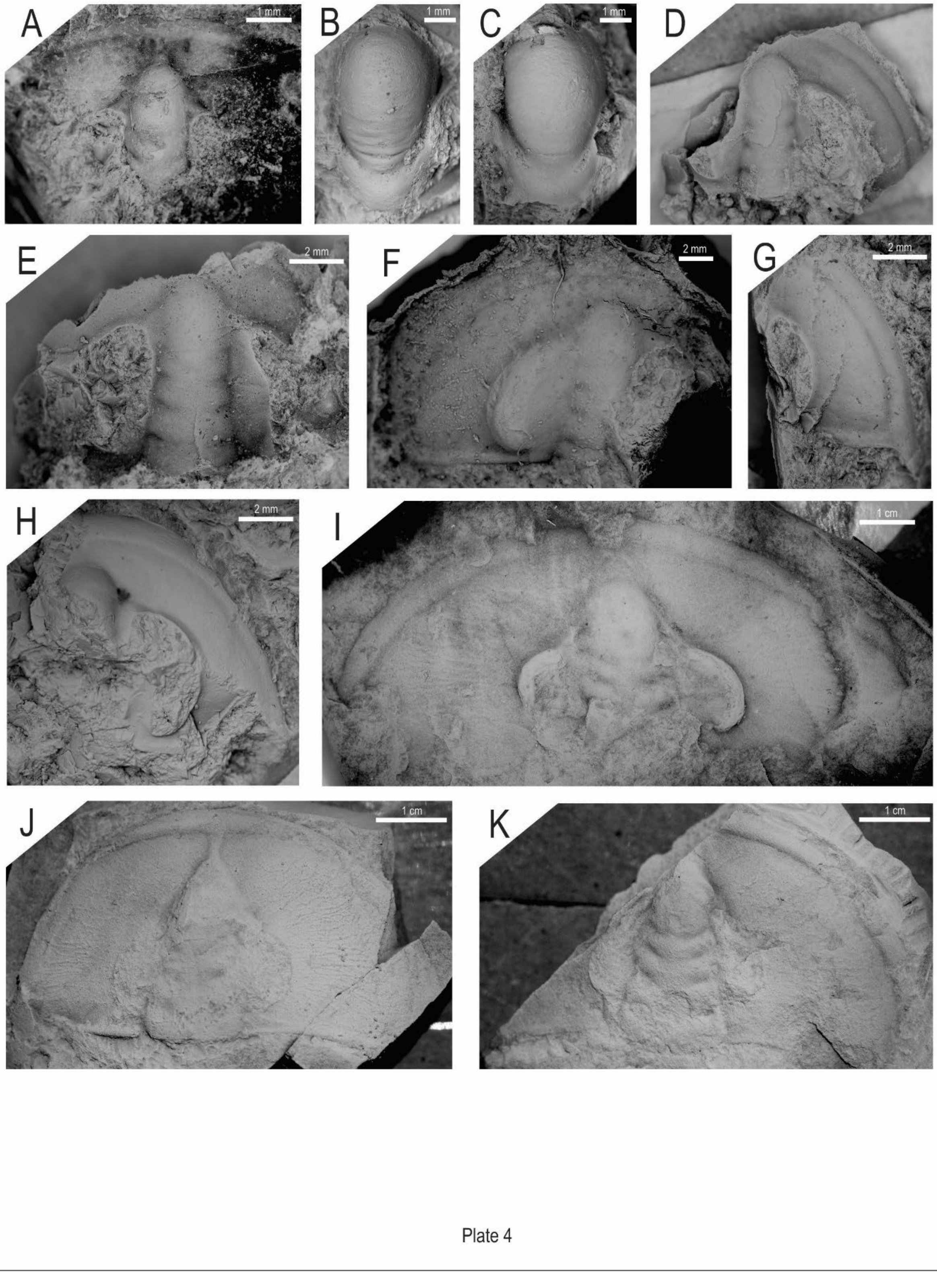

Plate 4

Plate 2A-5. Nevadiids, holmiids, and possible fallotaspidids (*Nevadella* Zone) from Fritz sections 2 and 10.

A) *Nevadella eucharis*. Cephalon. Fritz (1976) section 2, GSC location 84315. Specimen SM2-15-1.

B) *Nevadella* sp. Partial cephalon. Fritz (1976) section 2, GSC location 84314. Specimen SM2-14-1.

C) *Nevadella* sp. Librigena. Fritz (1976) section 2, GSC location 84314. Specimen SM2-14-2.

D) indet. Olenellid sp. 1. Partial, worn cephalon. Fritz (1976) section 2, GSC location 84306. Specimen SM2-06-1.

E) *Montezumaspsis*? sp. 1. Partial cephalon. Fritz (1976) section 2, GSC location 84307. Specimen SM2-07-1.

F) *Montezumaspsis*? sp. 1. Cephalon. Fritz (1976) section 2, GSC location 84307. Specimen SM2-07-2.

G) *Montezumaspsis*? sp. 1. Partial cephalon. Fritz (1976) section 2, GSC location 84307. Specimen SM2-07-3.

H) *Montezumaspsis*? sp. 1. Cephalon. Fritz (1976) section 2, GSC location 84309. Specimen SM2-09-1.

I) *Montezumaspsis*? sp. 1. Worn, associated hypostome. Fritz (1976) section 2, GSC location 84309. Specimen SM2-09-2.

J) *Montezumaspsis*? sp. 2. Partial cephalon. Fritz (1976) section 2, GSC location 84307. Specimen SM2-07-4.

K) *Montezumaspsis*? sp. 2. Partial cephalon. Fritz (1976) section 2, GSC location 84309. Specimen SM2-09-3.

L) *Esmeraldina*? sp. Partial cephalon. Fritz (1976) section 2, GSC location 84312. Specimen SM2-12-2.

M) *Nevadella* cf. *N. keelensis* Abe et al. 2010. Partial cephalon. Fritz (1976) section 2, GSC location 84305. Specimen SM2-05-1.

N) *Nevadella* cf. *N. keelensis* Abe et al. 2010. Partial cephalon. Fritz (1976) section 2, GSC location 84305. Specimen SM2-05-2.

O) *Nevadella* cf. *N. keelensis* Abe et al. 2010. Cephalon. Fritz (1976) section 2, GSC location 84305. Specimen SM2-05-3.

P) Indet. fallotaspidid? Cephalon. Fritz (1976) section 2, GSC location 84305. Specimen SM2-05-4.

Q. Indet. trilobite sp. 1. Partial cephalon. Fritz (1976) section 2, GSC location 84305. Specimen SM2-05-5.

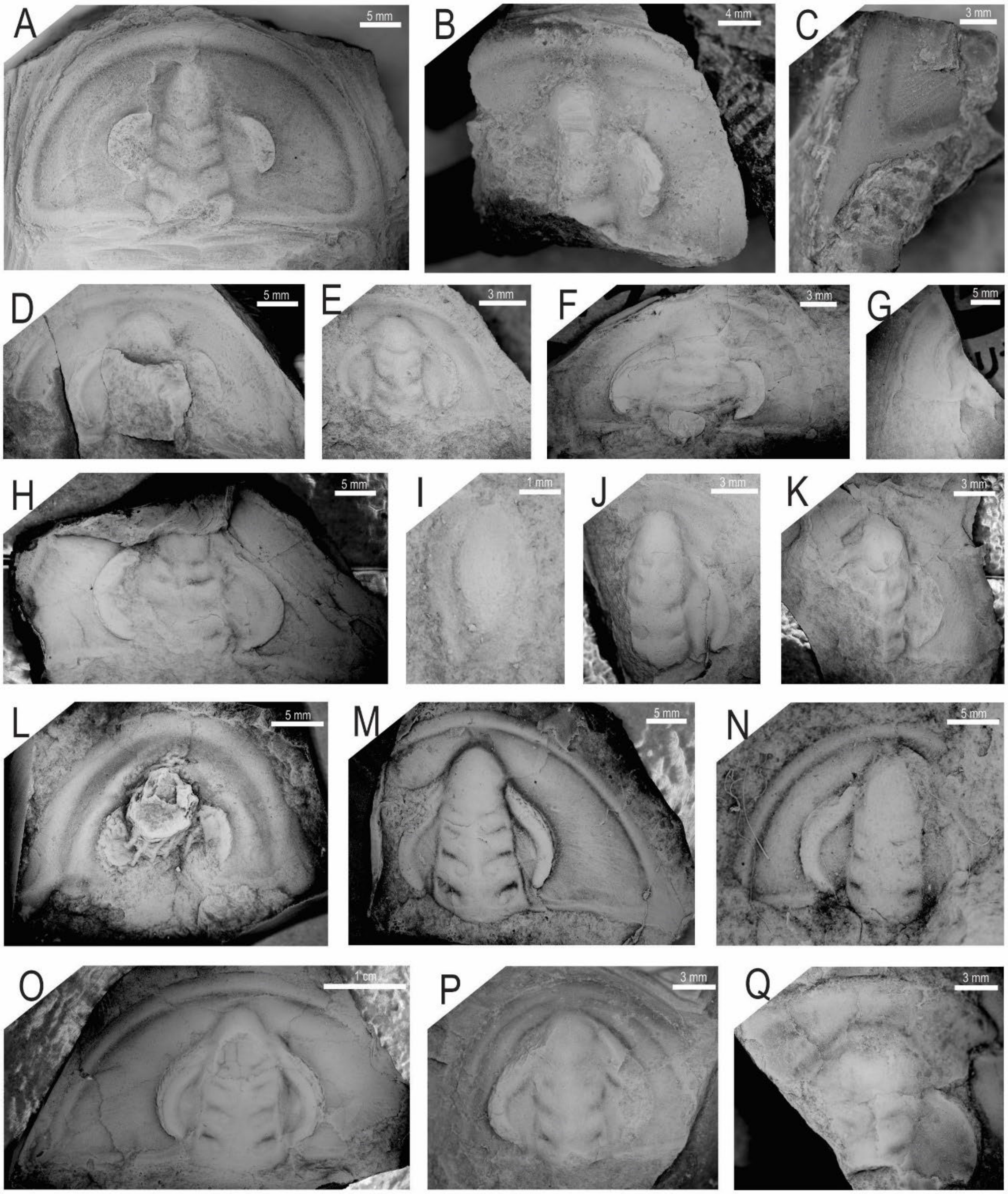

Plate 5

Plate 2A-6. Holmiids and indeterminate olenellids (*Nevadella* Zone) from Fritz sections 2 and 10.

A) Indeterminate olenellid sp. 2. Cephalon. Fritz (1976) section 2, GSC location 84308. Specimen SM2-08-1.

B) Indeterminate olenellid sp. 2. Partial cephalon. Fritz (1976) section 2, GSC location 84308. Specimen SM2-08-2.

C) Indeterminate olenellid sp. 2. Partial cephalon. Fritz (1976) section 2, GSC location 84308. Specimen SM2-08-3.

D) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-11.

E) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-12.

F) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-13.

G) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-14.

H) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-15.

I) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-16.

J) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-17.

K) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-18.

L) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-19.

M) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73037. SM10-37-8.

N) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73037. SM10-37-9.

O) *Holmiella falcuta*. Cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-20.

P) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-21.

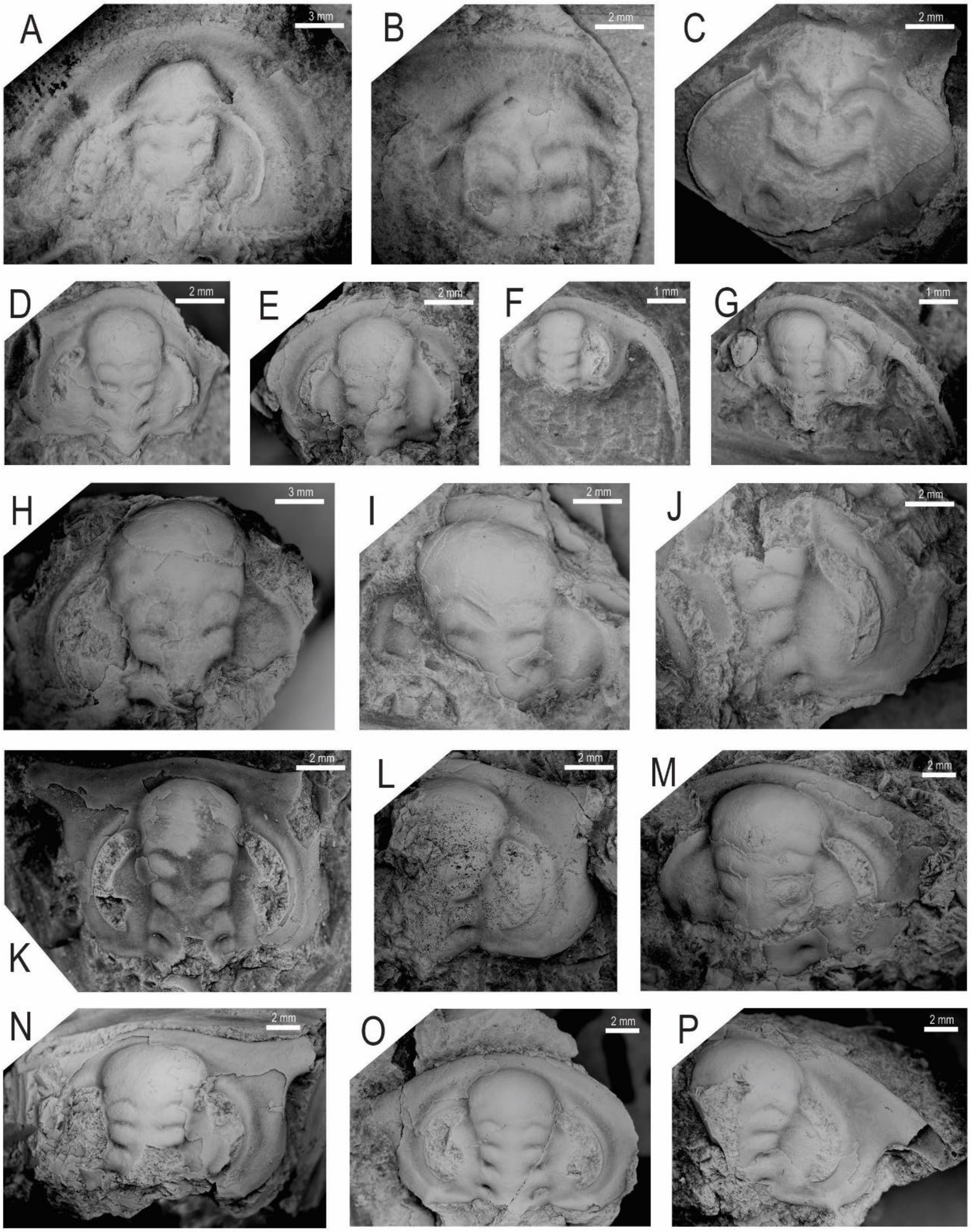
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Plate 6

Plate 2A-7. Holmiids, archaespidids, and “ptychopariids” (*Nevadella* Zone) from Fritz section 10

A) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-10.

B) *Holmiella falcuta*. Partial cephalon. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-11.

C) *Holmiella falcuta*. Small cephalon. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-12.

D) *Holmiella falcuta*. Small cephalon. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-13.

E) *Holmiella falcuta*. Pygidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-22.

F) *Holmiella falcuta*. Pygidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-23.

G) *Holmiella falcuta*. Pygidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-24.

H) *Holmiella preancora*. Partial cephalon. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-5.

I) *Holmiella preancora*. Partial cephalon. Fritz (1972) section 10, GSC location 73030. Specimen SM10-30-4.

J) *Holmiella preancora*. Partial cephalon. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-7.

K) *Holmiella preancora*. Partial cephalon. Fritz (1972) section 10, GSC location 73030. Specimen SM10-33-5.

L) *Bradyfallotaspis fusa*. Partial cephalon. Fritz (1972) section 10, GSC location 73030. Specimen SM10-30-7.

M) *Bradyfallotaspis patula*. Partial cephalon. Fritz (1972) section 10, GSC location 73027. Specimen SM10-30-8.

N) *Keeleaspis gratia*. Cranidium. Fritz (1972) section 10, GSC location 73038. Specimen SM10-38-3.

O) *Keeleaspis gratia*. Cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-25.

P) *Keeleaspis gratia*. Partial cranidium. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-26.

Q) *Keeleaspis gratia*. Partial cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-14.

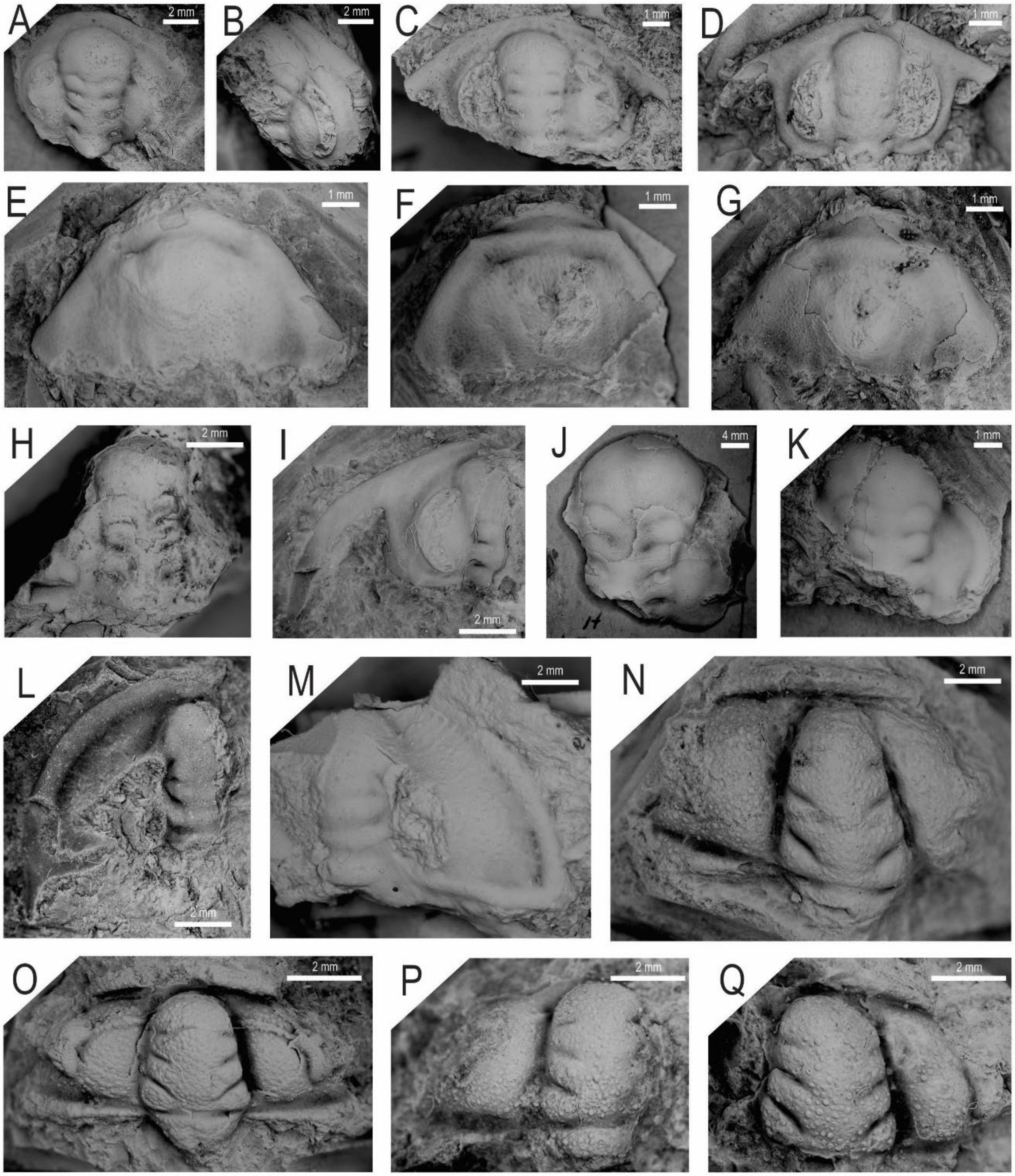

Plate 7

Plate 2A-8. “Ptychopariids” (*Nevadella* Zone) from Fritz section 10.

A) *Keeleaspis gratia*. Partial cranidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-15.

B) *Keeleaspis gratia*. Glabella. Fritz (1972) section 10, GSC location 73034. Specimen SM10-34-27.

C) *Keeleaspis gratia*. Glabella. Fritz (1972) section 10, GSC location 73038. Specimen SM10-38-4.

D) *Keeleaspis gratia*. Librigena. Fritz (1972) section 10, GSC location 73032. Specimen SM10-32-7.

E) *Keeleaspis gratia*. Pygidium. Fritz (1972) section 10, GSC location 73027. Specimen SM10-27-9.

F) *Keeleaspis gratia*. Pygidium. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-16.

G) *Keeleaspis pustula*. Cranidium. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-5.

H) *Keeleaspis pustula*. Cranidium. Fritz (1972) section 10, GSC location 73038. Specimen SM10-38-5.

I) *Keeleaspis pustula*. Glabella. Fritz (1972) section 10, GSC location 73033. Specimen SM10-33-6.

J) *Keeleaspis pustula*. Glabella. Fritz (1972) section 10, GSC location 73037. Specimen SM10-37-17.

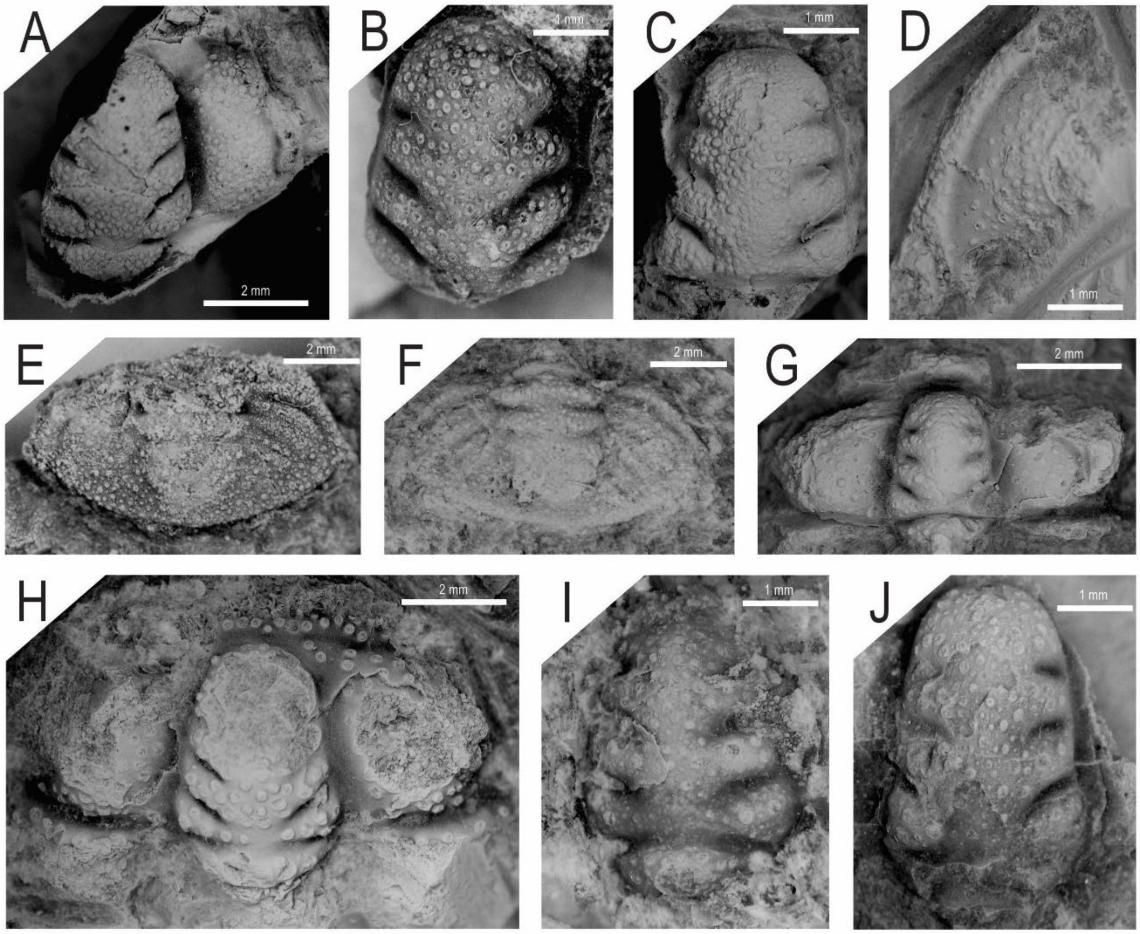

Plate 8

Plate 2A-9. Olenellids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone) from Fritz section 10.

A) *Elliptocephala walcotti*. Cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen Specimen SM10-40-1.

B) *Elliptocephala walcotti*. Cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-2.

C) *Elliptocephala walcotti*. Cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-3.

D) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-4.

E) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-5.

F) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-6.

G) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-7.

H) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-8.

I) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-9.

J) *Elliptocephala walcotti*. Partial cephalon. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-10.

K) *Elliptocephala walcotti*. Associated macropleural thoracic segment. Fritz (1972) Section 10, GSC location 73040. Specimen SM10-40-11.

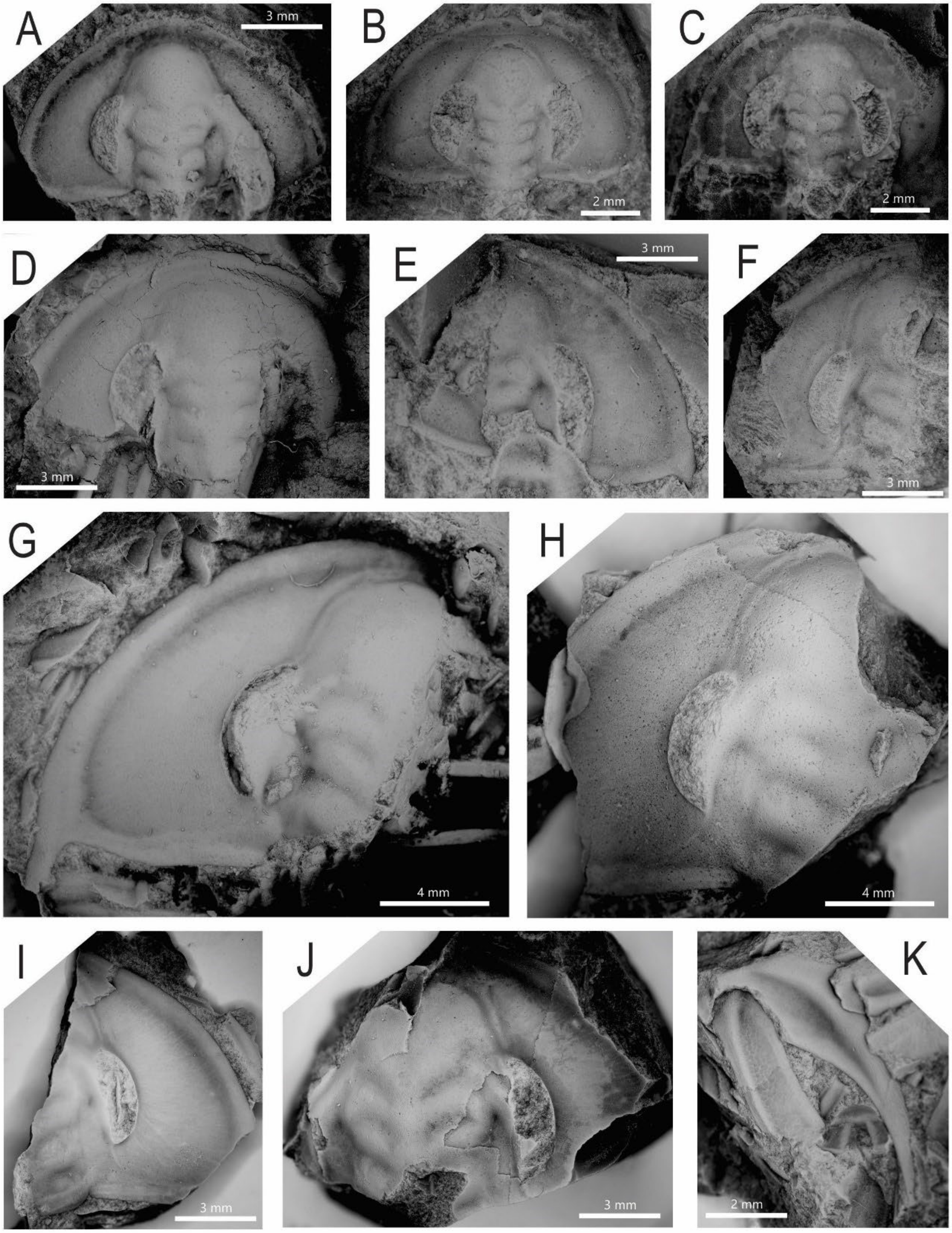

Plate 9

Plate 2A-10. Olenellids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone) from Fritz section 10.

A) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-1.

B) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-2.

C) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-3.

D) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-4.

E) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Moderately sized cephalon bearing faint parafrontal band. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-5.

F) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-6.

G) *Fritzolenellus* cf. *F. truemani* Walcott 1913. Small, poorly preserved cephalon with partial thorax. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-7.

H) *Lochmanolenellus* sp. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-8.

I) *Lochmanolenellus* sp. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-9.

J) *Lochmanolenellus* sp. Partial cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-10.

K) *Lochmanolenellus* sp. Small cephalon. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-11.

L) *Lochmanolenellus* sp. Large partial cephalon bearing a polygonal caecal network. Fritz (1976) section 2, GSC location 84316. Specimen SM2-16-12.

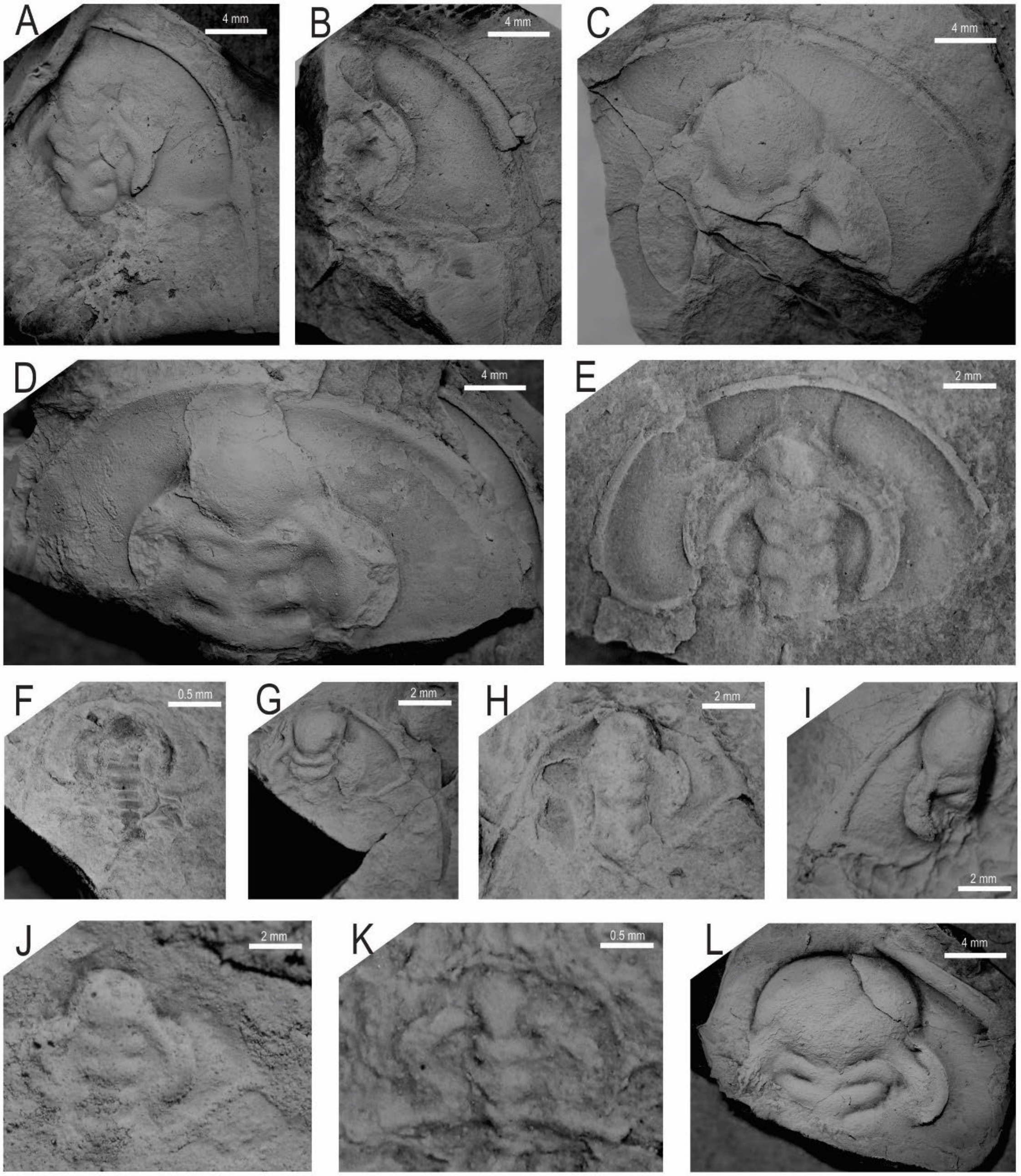
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Plate 10

Plate 2A-11. Olenellids, indeterminate olenellids, and ptychopariids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone) from Fritz sections 2 and 10.

A) Indet. Olenellid sp. 3. Cephalon. Fritz (1976) section 2. GSC location 84317. Specimen SM2-17-1.

B) Indet. Olenelid sp. 5. Cephalon. Fritz (1972) section 10, GSC location 73046. Specimen SM2-46-1.

C) *Fritzolenellus*? sp. Worn cephalon. Fritz (1976) section 2. GSC location 84318. Specimen SM2-18-1.

D) *Fritzolenellus* sp. 1 Fritz 1972. Partial cephalon. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-1.

E) *Fritzolenellus* sp. 1 Fritz 1972. Partial cephalon. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-2.

F) *Fritzolenellus* sp. 3 Fritz 1972. Partial cephalon. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-3.

G) *Fritzolenellus* sp. 1 Fritz 1972. Partial cephalon. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-4.

H) *Fritzolenellus* sp. 1 Fritz 1972. Glabella. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-5.

I) *Fritzolenellus* sp. 1 Fritz 1972. Glabella. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-6.

J) *Fritzolenellus* sp. 1 Fritz 1972. Glabella. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-7.

K) *Fritzolenellus* sp. 1 Fritz 1972. Hypostome. Fritz (1972) section 10. GSC location 73043. Specimen SM10-43-8.

L) "*Proliostracus*" *depressus*. Cranidium. Fritz (1972) section 10, GSC location 73040. Specimen SM10-40-12.

M) "*Proliostracus*" *depressus*. Partial cranidium. Fritz (1972) section 10, GSC location 73040. Specimen SM10-40-13.

N) "*Proliostracus*" *depressus*. Cranidium. Fritz (1972) section 10, GSC location 73040. Specimen SM10-40-14.

O) "*Proliostracus*" *depressus*. Partial cranidium. Fritz (1972) section 10, GSC location 73040. Specimen SM10-40-15.

P) "*Variopelta*" *laevis*. Cranidium. Fritz (1972) section 10. GSC location 73045. Specimen SM10-45-1.

Q) “*Variopelta*” *laevis*. Cranidium. Fritz (1972) section 10. GSC location 73045. Specimen SM10-45-2.

R) “*Variopelta*” *laevis*. Cranidium. Fritz (1972) section 10. GSC location 73045. Specimen SM10-45-3.

S) “*Variopelta*” *laevis*. Cranidium. Fritz (1972) section 10. GSC location 73045. Specimen SM10-45-4.

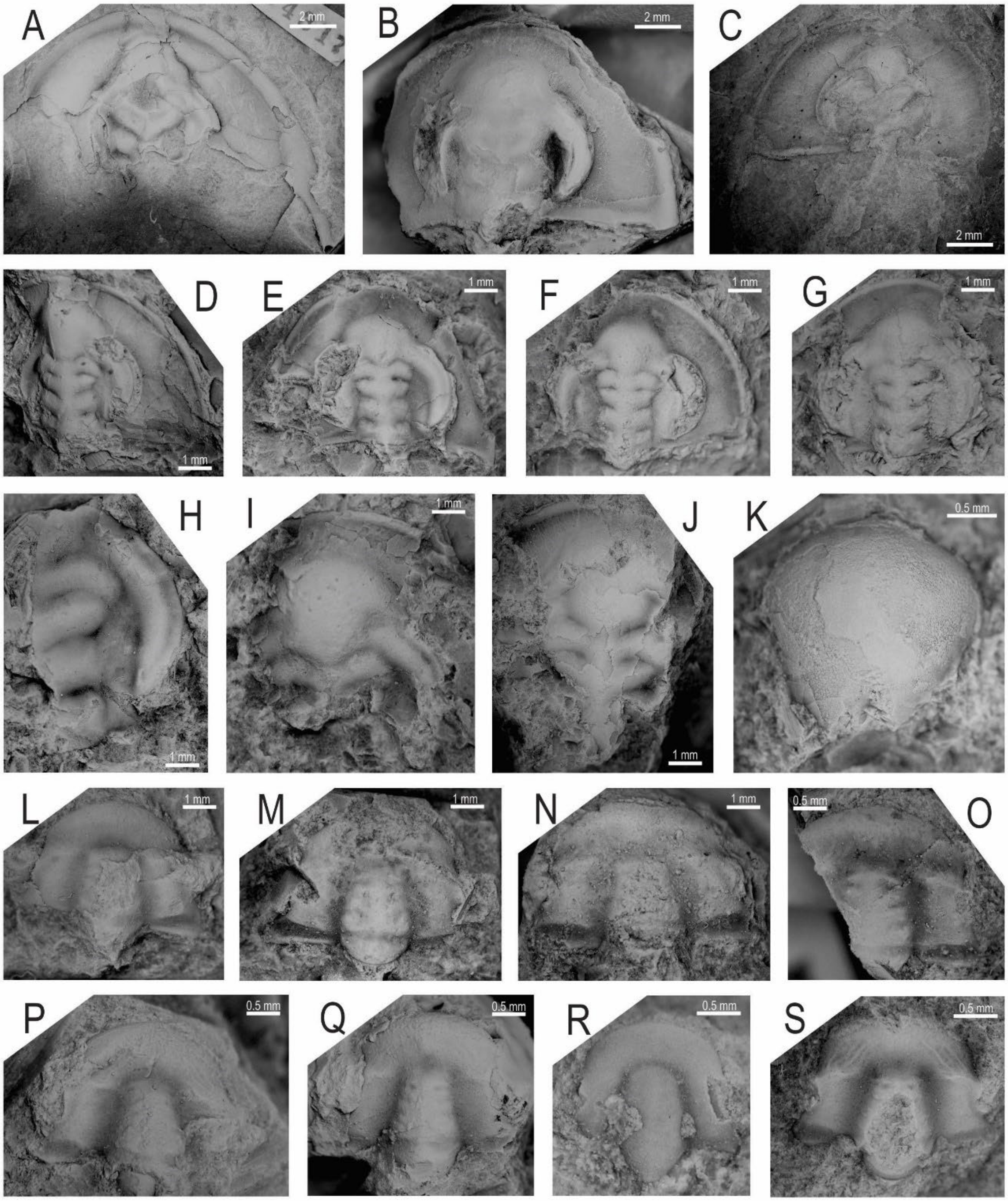
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Plate 11

Plate 2A-12. Representative ptychopariids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* Subzone) from Fritz section 10.

A) "*Variopelta*" *laevis*. Cranidium. Fritz (1972) section 10. Specimen SM10-45-5.

B) "*Variopelta*" *laevis*. Partial cranidium. Fritz (1972) section 10. Specimen SM10-45-6.

C) "*Variopelta*" *laevis*. Partial cranidium. Fritz (1972) section 10. Specimen SM10-45-7.

D) "*Variopelta*" *laevis*. Partial cranidium. Fritz (1972) section 10. Specimen SM10-45-8.

E) "*Proliostracus*" *annosus*. Cranidium. Fritz (1972) section 10. GSC location 73044. Specimen SM10-44-1.

F) "*Proliostracus*" *annosus*. Cranidium. Fritz (1972) section 10. GSC location 73044. SM10-44-2.

G) "*Proliostracus*" *annosus*. Partial cranidium. Fritz (1972) section 10. GSC location 73044. SM10-44-3.

H) "*Proliostracus*"*s annosus*. Partial cranidium. Fritz (1972) section 10. GSC location 73044. SM10-44-4.

I) "*Proliostracus*" *annosus*. Cranidium. Fritz (1976) section 2, GSC location 84327. Silicified cranidium from silty coquina interval.

J) "*Proliostracus*" *annosus*. Cranidium. Fritz (1976) section 2, GSC location 84327. Silicified cranidium from silty coquina interval.

K) "*Proliostracus*" *annosus*. Partial cranidium. Fritz (1976) section 2, GSC location 84327. Specimen SM2-27-1.

L) "*Proliostracus*"*s annosus*. Tentatively assigned partial cranidium. Fritz (1976) section 2, GSC location 84328. Specimen SM2-28-1.

M) "*Proliostracus*" sp. Cranidium. Fritz (1976) section 2, GSC location 84323. Specimen SM2-23-1.

N) "*Proliostracus*" sp. Cranidium. Fritz (1976) section 2, GSC location 84323. Specimen SM2-23-2.

O) "*Proliostracus*" sp. Cranidium. Fritz (1976) section 2, GSC location 84323. Specimen SM2-23-3.

P) "*Proliostracus*" sp. Cranidium. Fritz (1976) section 2, GSC location 84324. Specimen SM2-24-1.

Q) "*Proliostracus*" cf. *P. contractus*. Cranidium. Fritz (1976) section 2, GSC location 84325. Specimen SM2-25-2.

R) “*Proliostracus*” cf. *P*. *contractus*. Cranidium. Fritz (1976) section 2, GSC location 84325. Specimen SM2-25-1.

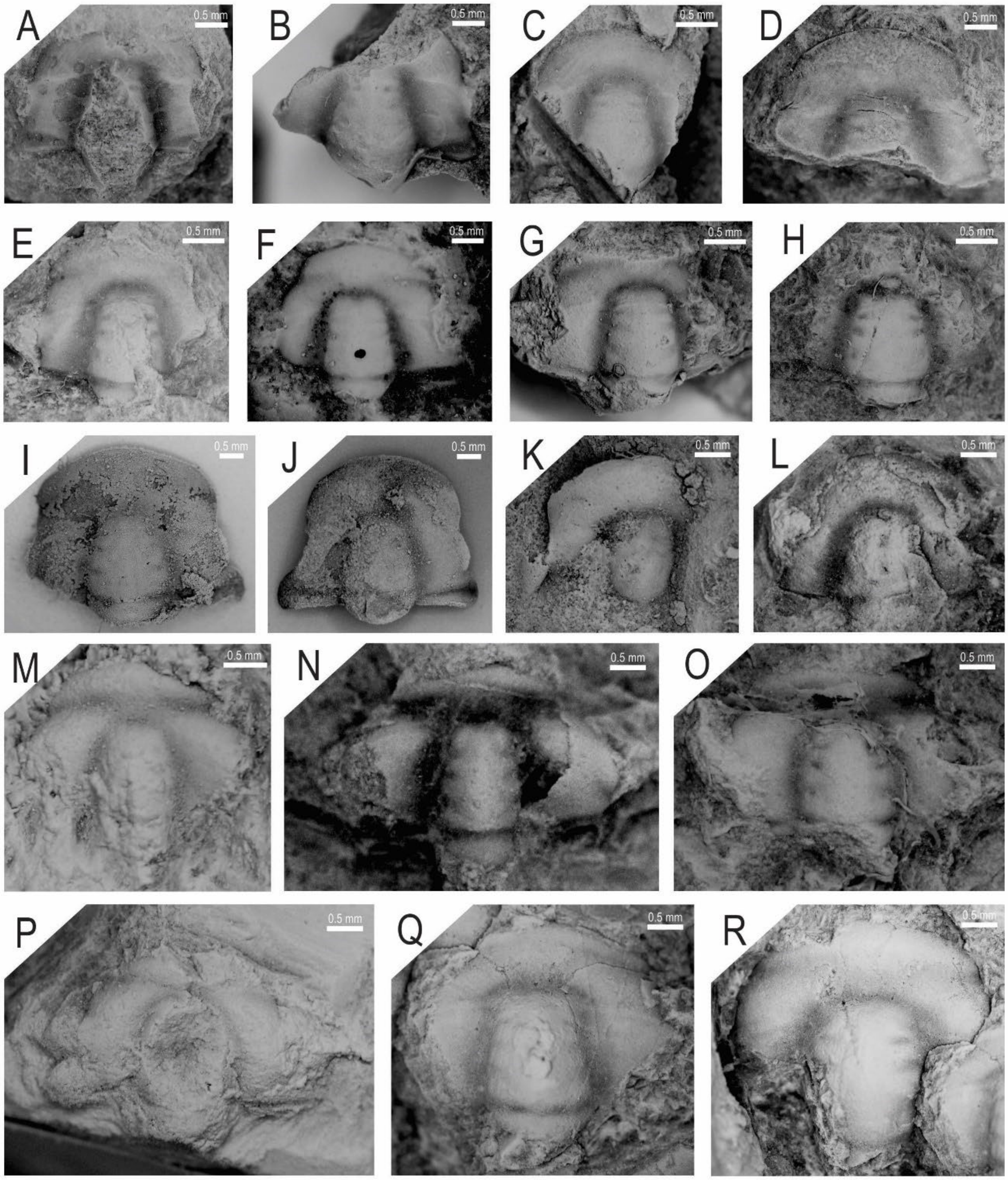

Plate 12

Plate 2A-13: Determinate and indeterminate olenellids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* and *Wanneria* subzones) from Fritz sections 2 and 10.

A) *Fritzolenellus* sp. 1 Fritz 1972. Small cephalon. Fritz (1972) section 10. GSC location 73053. Specimen SM10-53-1.

B) *Fritzolenellus* sp. 1 Fritz 1972. Small cephalon. Fritz (1972) section 10. GSC location 73053. Specimen SM10-53-2.

C) *Fritzolenellus* sp. 1 Fritz 1972. Small cephalon. Fritz (1972) section 10. GSC location 73052. Specimen SM10-52-1.

D) *Fritzolenellus* sp. 1 Fritz 1972. Small cephalon. Fritz (1972) section 10. GSC location 73054. Specimen SM-54-1.

E) *Olenellus*? sp. Worn cephalon. Fritz (1976) section 2. GSC location 84330. Specimen SM2-30-1.

F) Indet. Olenellid sp. 4. Worn cephalon. Fritz (1976) section 2. GSC location 84332. Specimen SM2-32-1.

G) *Wanneria logani*. Cephalon. Fritz (1976) section 2. GSC location 73057. Specimen SM-57-1.

H) *Wanneria logani*. Partial cephalon. Fritz (1976) section 2. GSC location 73057. Specimen SM-57-2.

I) *Wanneria logani*. Partial cephalon. Fritz (1976) section 2. GSC location 73053. Specimen SM10-53-3.

J) *Wanneria logani*. Partial cephalon. Fritz (1976) section 2. GSC location 73062. Specimen SM10-62-1.

K) *Wanneria logani*. Partial cephalon. Fritz (1976) section 2. GSC location 73051. Specimen SM10-51-1.

L) *Wanneria logani*. Gena. Fritz (1976) section 2. GSC location 73051. Specimen SM10-51-2.

M) *Wanneria logani*. Gena. Fritz (1976) section 2. GSC location 73057. Specimen SM-57-3.

N) *Wanneria logani*. Pleura. Fritz (1976) section 2. GSC location 73062. SM10-62-2.

O) *Wanneria parvifrons*. Partial cephalon. Fritz (1976) section 2, GSC location 84336. Specimen SM2-36-1.

P) *Wanneria* cf. *W. parvifrons*. Partial cephalon. Fritz (1976) section 2, GSC location 84335. Specimen SM2-35-1.

Q) *Wanneria* cf. *W. parvifrons*. Partial cephalon. Fritz (1976) section 2, GSC location 84337. Specimen SM2-37-1.

R) *Elliptocephala*? sp. Small cephalon. Fritz (1976) section 2, GSC location 84335. Specimen SM2-35-2.

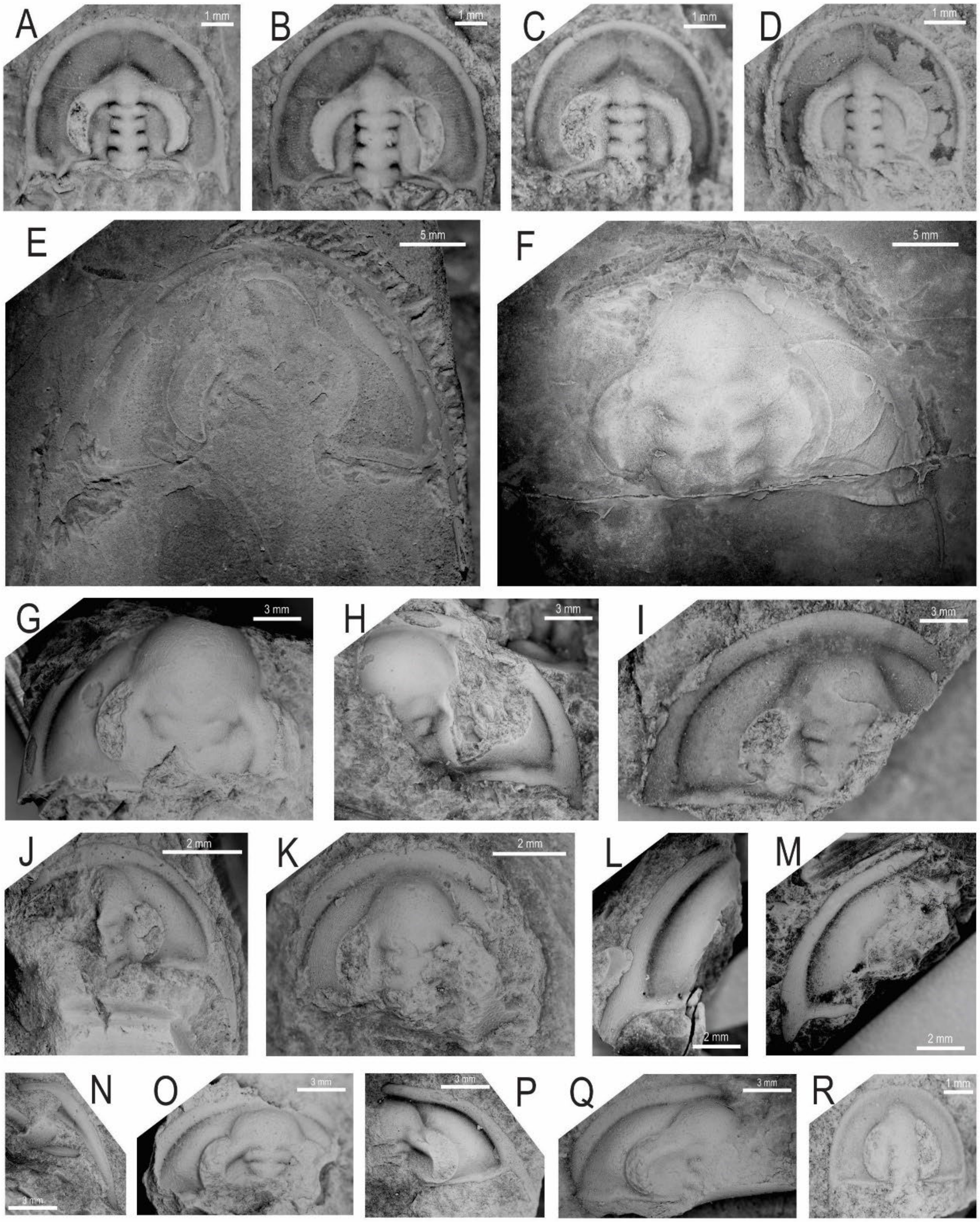
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Plate 13

Plate 2A-14. Olenellids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Wanneria* Subzone) from Fritz section 10.

A) *Elliptocephala sequomalus*. Partial cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-1.

B) *Elliptocephala sequomalus*. Partial cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-2.

C) *Elliptocephala sequomalus*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-3.

D) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location73049. Specimen SM10-49-4.

E) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-5.

F) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location73049. Specimen SM10-49-6.

G) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location73049. Specimen SM10-49-7.

H) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-8.

I) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-9.

J) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-10.

K) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-1.

L) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-12.

M) *Elliptocephala laxocules*. Cephalon crosscut and displaced by vein. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-13.

N) *Elliptocephala laxocules*. Cephalon. Fritz (1972) section 10, GSC location73049. Specimen SM10-49-14.

O) *Elliptocephala laxocules*. Small cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-15.

P) *Elliptocephala laxocules*. Small cephalon. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-16.

Q) *Elliptocephala laxocules*. Hypostome. Fritz (1972) section 10, GSC location 73049. Specimen SM10-49-17.

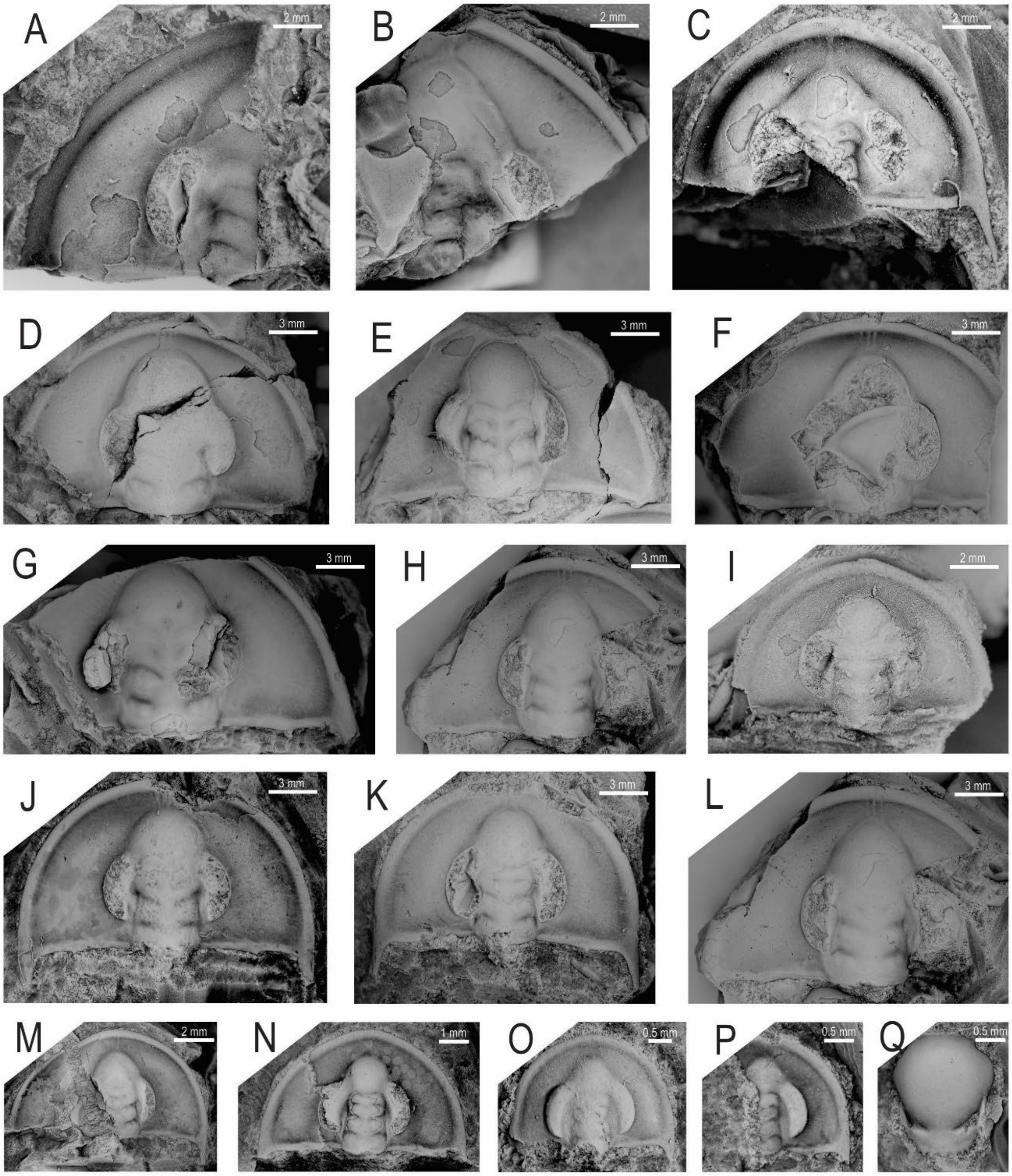

Plate 14

Plate 2A-15. Olenellids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Wanneria* Subzone) from Fritz sections 2 and 10.

A) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73058. Specimen SM10-58-1.

B) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73058. Specimen SM10-58-2.

C) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73060. Specimen SM10-60-1.

D) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73061. Specimen SM10-61-1.

E) *Elliptocephala paraoculus*. Partial cephalon. Fritz (1972) section 10, GSC location 73061. Specimen SM10-61-2.

F) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73061. Specimen SM10-61-3.

G) *Elliptocephala paraoculus*. Cephalon. Fritz (1972) section 10, GSC location 73060. Specimen SM10-60-1.

H) *Elliptocephala paraoculus*. Glabella exhibiting strong venation. Fritz (1972) section 10, GSC location 73061. Specimen SM10-61-4.

I) *Olenellus* sp. 2 Fritz 1972. Glabella. Fritz (1972) section 10, GSC location 73065. Specimen SM10-65-1.

J) *Olenellus* sp. 2 Fritz 1972. Small cephalon. Fritz (1972) section 10, GSC location 73062. SM10-62-3.

K) *Olenellus* sp. 2 Fritz 1972. Small cephalon. Fritz (1972) section 10, GSC location 73057. Specimen SM-57-4.

L) *Olenellus* sp. 2 Fritz 1972. Gena. Fritz (1972) section 10, GSC location 73062. SM10-62-4.

M) *Wanneria*? sp. Cephalon. Fritz (1976) section 2, GSC location 84331. Specimen SM2-31-1.

N) *Elliptocephala* cf. E. sp. 2 Fritz 1972. Fritz (1976) section 2, GSC location 84333. Specimen SM2-33-1.

O) *Gabriellus*? sp. Weathered glabella. Fritz (1976) section 2, GSC location 84334. Specimen SM2-34-1.

P) *Elliptocephala* sp. 1. Cephalon. Fritz (1976) section 2, GSC location 84339. Specimen SM2-39-1.

Q) *Olenellus* cf. *O. clarki* Resser 1938. Partial cephalon. Fritz (1976) section 2, GSC location 84338. Specimen SM2-38-1.

R) *Olenellus* cf. *O. clarki* Resser 1938. Partial cephalon. Fritz (1976) section 2, GSC location 84338. Specimen SM2-38-2.

S) *Olenellus* cf. *O. clarki* Resser 1938. Partial cephalon. Fritz (1976) section 2, GSC location 84338. Specimen SM2-38-2.

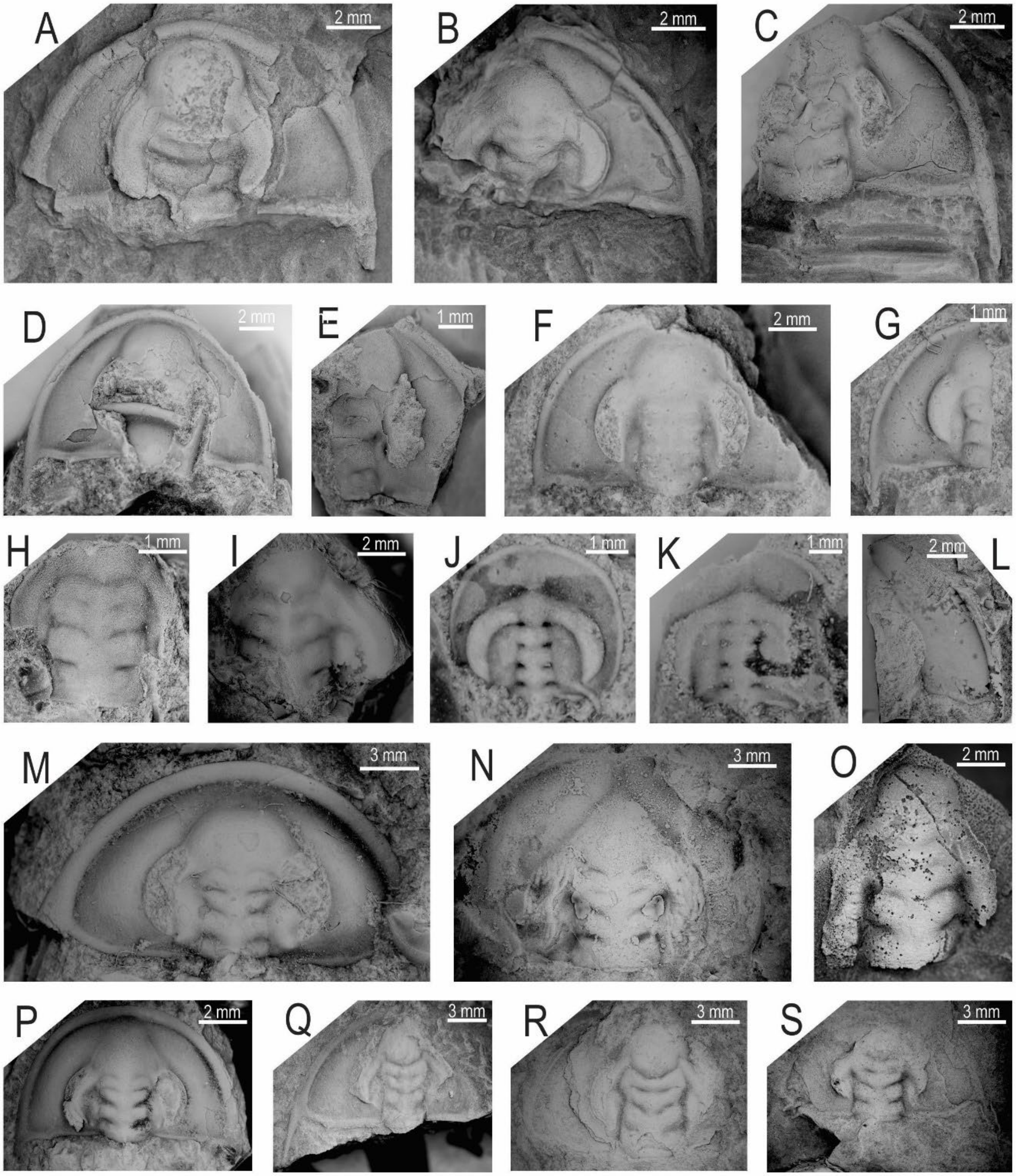
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Plate 15

Plate 2A-16. Dorypygids (*Bonnia-Olenellus* Zone; *Elliptocephala* Zone, *Fritzolenellus-Lochmanolenellus* and *Wanneria* subzones) from Fritz sections 2 and 10.

A) *Bonnia laterispina*. Cranidium. Fritz (1976) section 2, GSC location 84336. Specimen SM2-36-2.

B) *Bonnia laterispina*. Cranidium. Fritz (1976) section 2, GSC location 84336. Specimen SM2-36-3.

C) *Bonnia laterispina*. Partial cranidium. Fritz (1972) section 10, GSC location 73057. Specimen SM-57-5.

D) *Bonnia laterispina*. Partial cranidium. Fritz (1972) section 10, GSC location 73057. Specimen SM-57-6.

E) *Bonnia laterispina*. Tentatively assigned, worn pygidium. Fritz (1976) section 2, GSC location 84334. Specimen SM2-34-2.

F) *Bonnia laterispina*. Pygidium. Fritz (1976) section 2, GSC location 84335. Specimen SM2-35-3.

G) *Bonnia laterispina*. Partial pygidium. Fritz (1972) section 10, GSC location 73057. Specimen SM-57-7.

H) *Bonnia* sp. Cranidium. Fritz (1976) section 2, GSC location 84339. Specimen SM2-39-1.

I) *Bonnia* sp. Cranidium. Fritz (1976) section 2, GSC location 84339. Specimen SM2-39-2.

J) *Bonnia* sp. Pygidium. Fritz (1976) section 2, GSC location 84339. Specimen SM2-39-3.

K) *Bonnia* sp. 2 Fritz 1972. Cranidium. Fritz (1972) section 10. GSC location 73067. Specimen SM2-67-1.

L) *Bonnia columbensis*. Pygidium. Fritz (1972) section 10. GSC location 73073. Specimen SM10-73-12.

M) *Bonnia columbensis*. Pygidium. Fritz (1972) section 10. GSC location 73073. Specimen SM10-73-13.

N) *Bonnia columbensis*. Pygidium. Fritz (1972) section 10. GSC location 73073. Specimen SM10-73-14.

O) *Bonnima* sp. nov. Cranidium. Fritz (1972) section 10. GSC location 73068. SM10-68-2.

P) *Bonnima* sp. nov. Partially exfoliated cranidium. Fritz (1972) section 10. GSC location 73068. SM10-68-3.

Q) *Bonnima* sp. nov. Partially exfoliated cranidium. Fritz (1972) section 10. GSC location 73068. SM10-68-4.

R) *Bonnima* sp. nov. Pygidium. Fritz (1972) section 10. GSC location 73071. Specimen SM10-71-8.

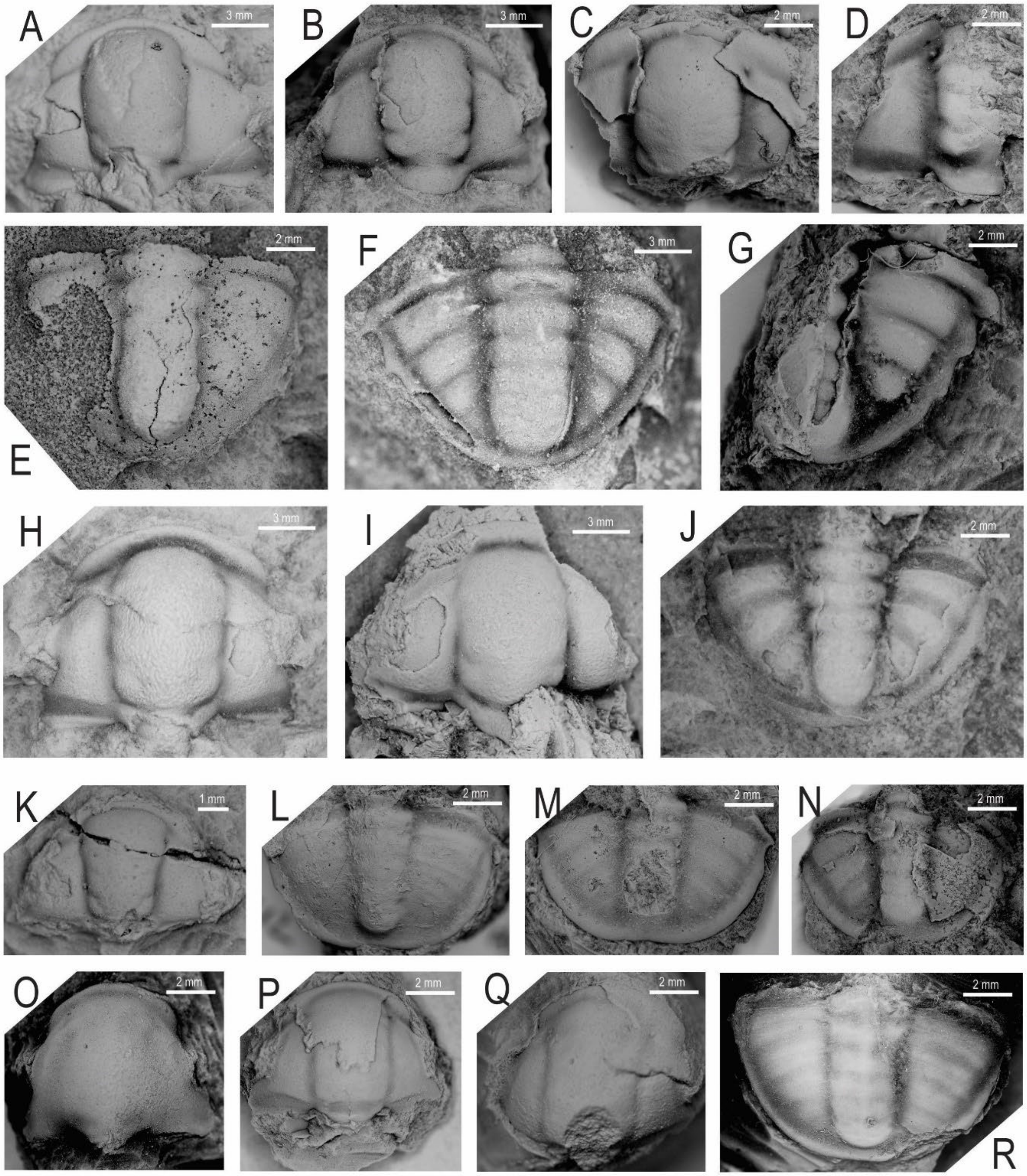
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Plate 16

Plate 2A-17. Olenellids and oryctocephalids (*Bonnia-Olenellus* Zone) from Fritz sections 2 and 10.

A) *Olenellus puertoblancoensis*. Partial cephalon. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-1.

B) *Olenellus puertoblancoensis*. Partial cephalon. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-2.

C) *Olenellus puertoblancoensis*. Partial cephalon. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-3.

D) *Olenellus puertoblancoensis*. Pathologized cephalon bearing a healed wound on its left gena. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-4.

E) *Olenellus puertoblancoensis*. Partial cephalon. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-5.

F) *Olenellus puertoblancoensis*. Glabella. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-6.

G) *Olenellus puertoblancoensis*. Glabella. Fritz (1972) section 10, GSC location 73071. Specimen SM10-71-7.

H) *Olenellus puertoblancoensis*. Worn, partial thorax. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-8.

I) *Olenellus puertoblancoensis*. Gena. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-2.

J) *Olenellus* sp. 5 Fritz (1972). Glabella. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-2.

K) *Olenellus* sp. 5 Fritz (1972). Glabella. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-2.

L) *Olenellus* sp. 5 Fritz (1972). Glabella. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-2.

M) *Olenellus* sp. 5 Fritz (1972). Glabella. Fritz (1972) section 10, GSC location 73072. Specimen SM10-72-2.

N) *Olenellus* cf. *O. puertoblancoensis* Fritz 1972. Fritz (1976) section 2, GSC location 84340. Specimen SM2-40-1.

O) *Goldfieldia pacifica*. Partial thorax. Fritz (1976) section 2, GSC location 84340. Specimen SM2-40-2.

P) *Goldfieldia pacifica*. Cranidium. Fritz (1976) section 2, GSC location 84340. Specimen SM2-40-3.

Q) *Goldfieldia pacifica*. Cranidium. Fritz (1976) section 2, GSC location 84340. Specimen SM2-40-4.

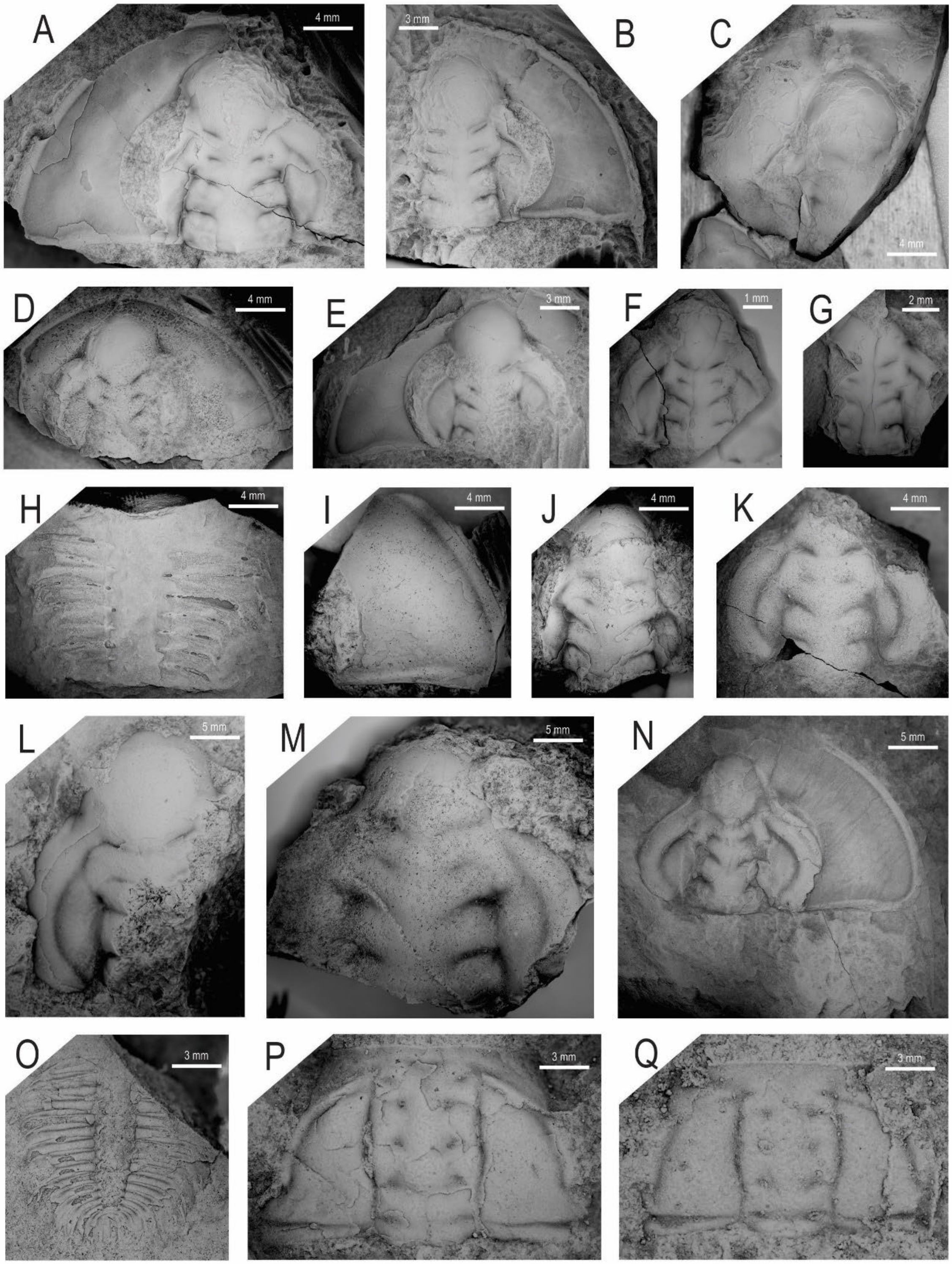
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Plate 17

Plate 2A-18. Ptychopariids and dorypygids (*Bonnia-Olenellus* Zone) from Fritz section 10.

A) "*Piaziella*" *pia*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-12.

B) "*Antagmus*" *truncatus*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-13.

C) "*Antagmus*" *truncatus*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-14.

D) "*Antagmus*" *truncatus*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-15.

E) "*Syspacephalus*" *vapidus*. Cranidium. Fritz section 10, GSC location 73075. Sample SM10-75-2.

F) "*Syspacephalus" vapidus*. Cranidium. Fritz section 10, GSC location 73075. Sample SM10-75-3.

G) "*Syspacephalus" vapidus*. Cranidium. Fritz section 10, GSC location 73075. Sample SM10-75-4.

H) *Bonnia columbensis*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-3.

I) *Bonnia columbensis*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-4.

J) *Bonnia columbensis*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-5.

K) *Bonnia columbensis*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-6.

L) *Bonnia columbensis*. Cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-7.

M) *Bonnia columbensis*. Pygidium. Fritz section 10, GSC location 73073. Specimen SM10-73-8.

N) *Bonnia columbensis*. Pygidium. Fritz section 10, GSC location 73073. Specimen SM10-73-9.

O) *Bonnia columbensis*. Pygidium. Fritz section 10, GSC location 73073. Specimen SM10-73-10.

P) *Bonnia columbensis*. Hypostome. Fritz section 10, GSC location 73073. Specimen SM10-73-11.

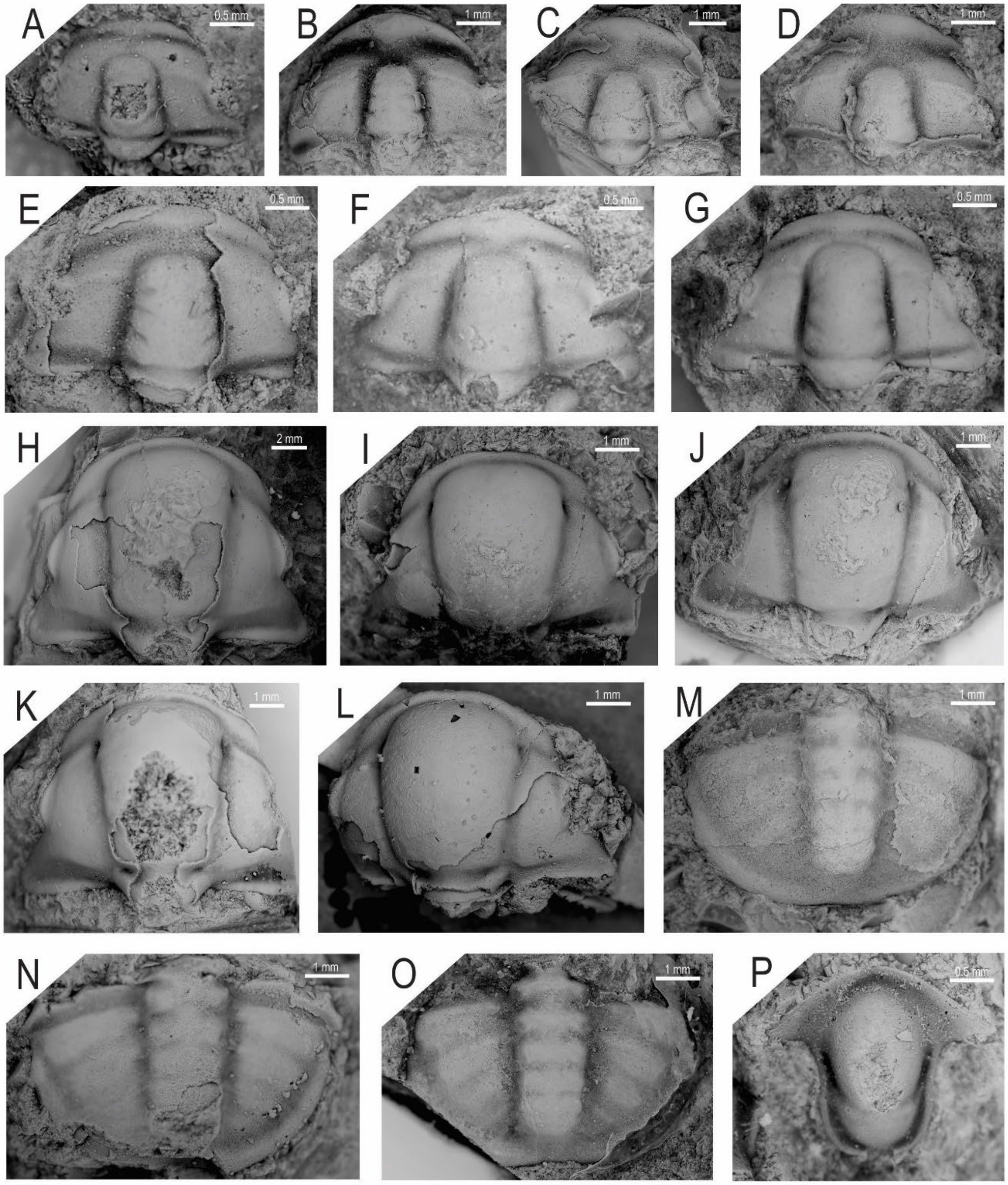
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Plate 18

Plate 2A-19. Zacanthoidids, dorypygids, ptychopariids, and an olenellid (*Bonnia-Olenellus* Zone) from section 10.

A) *Zacanthopsis stribuccus*. Partial cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-1.

B) *Zacanthopsis stribuccus*. Partial cranidium. Fritz section 10, GSC location 73073. Specimen SM10-73-2.

C) *Zacanthopsis stribuccus*. Partial cranidium. Fritz section 10, GSC location 73068. Specimen SM10-68-1.

D) *Ogygopsis*? sp. Badly weathered cranidium. Fritz section 2, GSC location 84341. SM2-41-1.

E) Indeterminate ptychopariid. Weathered cranidium. Fritz section 10, GSC location 73074. Specimen SM10-74-1.

F) Indeterminate, badly weathered ptychopariid cranidia. Fritz section 10, GSC location 73075.

G) Indeterminate olenellid gena. Fritz section 10, GSC location 73075. Sample SM10-75-1.

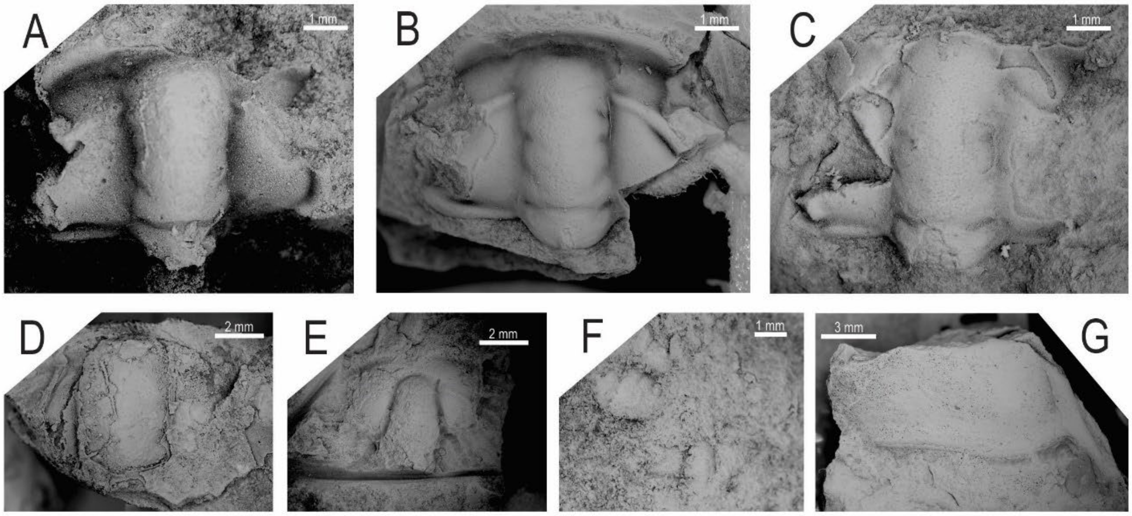

Plate 19

APPENDIX 2B

Carbon and Oxygen Isotopes of Carbonates

Analysis of C, O stable isotopes in carbonate using GasBench II-IRMS

The measurement is performed using a GasBench II (Thermo Finnigan^{TM}) coupled to a Delta V Plus Isotope-Ratio Mass-Spectrometer (IRMS, Thermo Finnigan^{TM}) via an open-split interface (ConFlo IV, Thermo Finnigan^{TM}) at the Stable Isotope Laboratory (SIL) of the Department of Geological Sciences, University of Manitoba, Canada. The GC-PAL autosampler (CTC Analytics^{TM}) is connected to the GasBench II for automated transfer of sample gas to IRMS.

An aliquot of sample power (typically, ~0.5 mg for pure calcite and dolomite) is weighed onto a small sheet of weighing paper using a microbalance. The weighed sample powder is carefully poured into a 12 mL borosilicate Exetainer vial (Labco^{TM} Ltd.). The sample vial is tightly capped with a rubber septum (pierceable rubber wad, Labco^{TM} Ltd.).

The prepared sample vials are loaded into the autosampler heating block, which is set to a constant temperature (70±0.1°C). The vials are flushed with He (>99.9999%) at 100 mL/min for 10 mins. Once the He flushing is completed, about 0.1 mL of anhydrous phosphoric acid is added manually to each vial using a disposable syringe. The vials are left to react with the acid at the set temperature (70±0.1°C) for ~≥3 hrs for calcite and ~≥4 hrs for dolomite.

The headspace gases in the vial are automatically delivered to the GasBench II as they are flushed out from the vial (at the rate of 0.5 mL/min). The gases pass through the water removal system (hygroscopic Nafion® tubing) and then to the Valco^{TM} loop for multiple gas injections. The gases are then separated from each other by passing through the fused silica GC column (PoraPlot Q®). The gases are transferred to the open split interface, and finally through a transfer capillary introduced into the IRMS.

Carbon and oxygen isotope data are reported as differences in parts per thousand (per mill or ‰) from their respective reference material. The δ value is defined as

$$\delta_X = \left(\frac{R_X - R_{std}}{R_{std}} - 1\right) \times 1000\ ,$$

Where $R_x = (C^{13}/C^{12})_X$ or $(O^{18}/O^{16})_X$ for the sample X, and R_{std} is the corresponding stable isotope ratio in the reference standard. The $\delta^{13}C$ values are reported relative to VPDB (*Vienna Peedee Belemnite*). The $\delta^{18}O$ values are reported relative to VPDB and VSMOW (*Vienna Standard Mean Ocean Water*).

Sample normalization was performed using the two-point. Two international standards (NBS18 and NBS19) were analyzed at the beginning, middle and end of each run. A calibration line was calculated for each run by least-squares linear regression using the known and measured isotope values of the calibration standards.

To monitor the analysis performance, the internal standards CHI (calcite; $\delta^{13}C$ = -8.01‰ VPDB and $\delta^{18}O$ = -11.67‰ VPDB) and Tytyri (dolomite; $\delta^{13}C$ = +0.78±0.01‰ VPDB and $\delta^{18}O$ = +7.07±0.04‰ VPDB) are analyzed as unknowns. The oxygen isotope offset of the Tytyri dolomite standard from the calibration line is applied to dolomite samples to correct their oxygen isotope values.

The analytical precisions are ≤ ±0.1‰ for $\delta^{13}C$ and $\delta^{18}O$ analysis.

Prepared by Misuk Yun, Stable Isotope Lab (SIL)

APPENDIX 3A: Representative trilobites from sections 14/18 and 19.

Plate 3A-1. Representative olenellids from the *Bonnia-Olenellus* Zone.

1. *Bolbolenellus* sp. 1. GSC location 68964, 64-3A. Cephalon.
2. *Bolbolenellus* sp. 1. GSC location 68964, 64-3B. Cephalon.
3. *Bolbolenellus* sp. 1. GSC location 68964, 64-13A. Latex cast of external mould of cephalon.
4. *Bolbolenellus* sp. 1. GSC location 68964, 64-24A. Partial cephalon.
5. *Bolbolenellus* sp. 1. GSC location 68964, 64-20A. Partial cephalon.
6. *Bolbolenellus* sp. 1. GSC location 68964, 64-22A. Partial cephalon.
7. *Bolbolenellus* sp. 1. GSC location 68964, 64-7A. Partial cephalon.
8. *Bolbolenellus* sp. 1. GSC location 68964, 64-39A. Latex cast of external mould of cephalon.
9. *Bolbolenellus* sp. 1. GSC location 68964, 64-43A. Partial cephalon.
10. *Bolbolenellus* sp. 1. GSC location 68964, 64-43A. Partial cephalon.
11. *Bolbolenellus* sp. 1. GSC location 68964, 64-7B. Heavily compacted cephalon.
12. *Bolbolenellus* sp. 1. GSC location 68964, 64-7C. Heavily compacted cephalon.
13. *Bolbolenellus* sp. 1. GSC location 68964, 64-12A. Compacted cephalon.

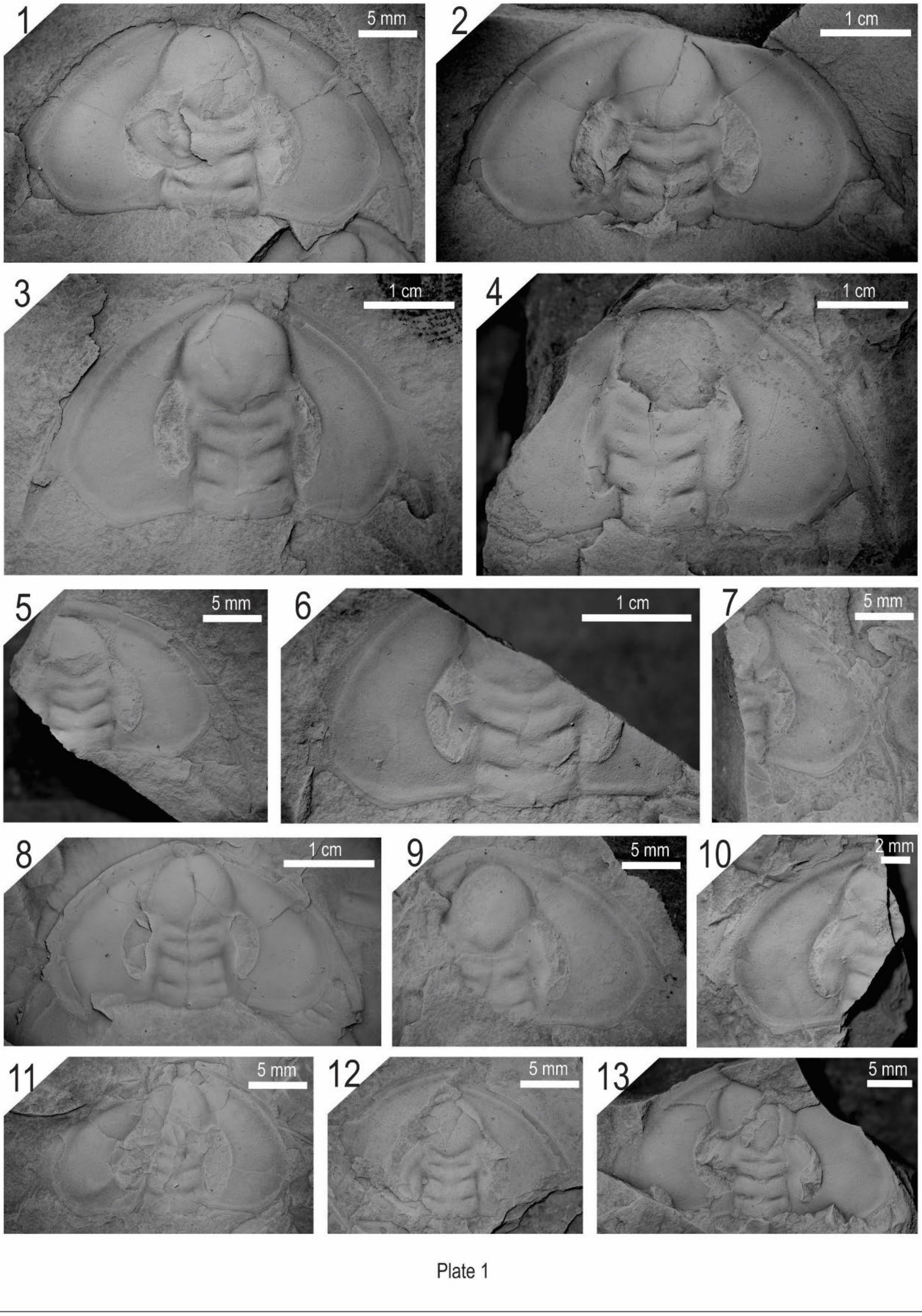
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Plate 1

Plate 3A -2. Representative olenellids from the *Bonnia-Olenellus* Zone.

1. *Bolbolenellus* sp. 1. GSC location 68964, 64-22B. Glabella and partial gena.
2. *Bolbolenellus* sp. 1. GSC location 68964, 64-22C. Compacted cephalon.
3. *Bolbolenellus* sp. 1. GSC location 68964, 64-33A. Compacted cephalon.
4. *Bolbolenellus* sp. 1. GSC location 68964, 64-41A. Cephalon.
5. *Bolbolenellus* sp. 1. GSC location 68964, 64-41A. View of dorsal outline of cephalon.
6. *Bolbolenellus* sp. 1. GSC location 68964, 64-29A. Compacted cephalon.
7. *Bolbolenellus* sp. 1. GSC location 68964, 64-29A. View of dorsal outline of compacted cephalon.
8. *Bolbolenellus* sp. 1. GSC location 68964, 64-1A. Near-complete individual with pathology on left gena.
9. *Bolbolenellus* sp. 1. GSC location 68964, 64-1A. View of pathology on genae on specimen 1A.
10. *Bolbolenellus* sp. 2. GSC location 68964, 64-11A. Cephalon.
11. *Bolbolenellus* sp. 2. GSC location 68964, 64-34A. Cephalon and partial thorax.

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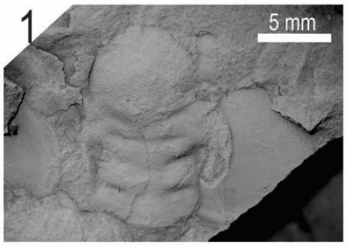

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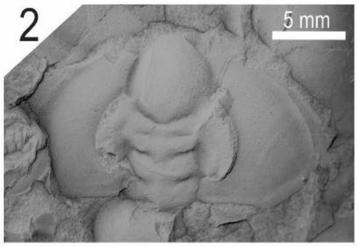

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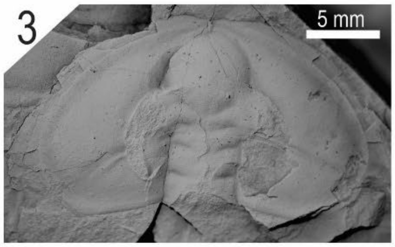

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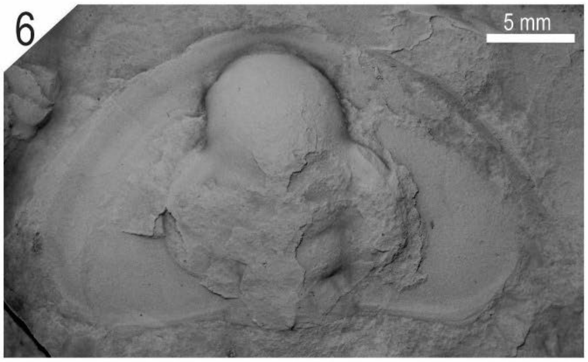

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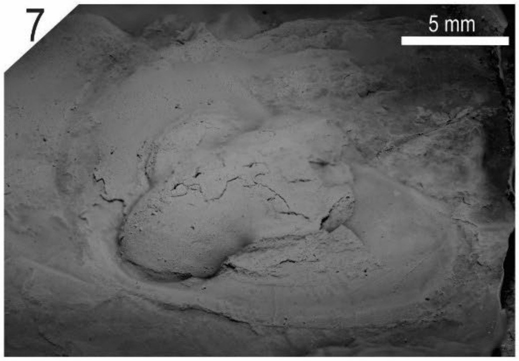

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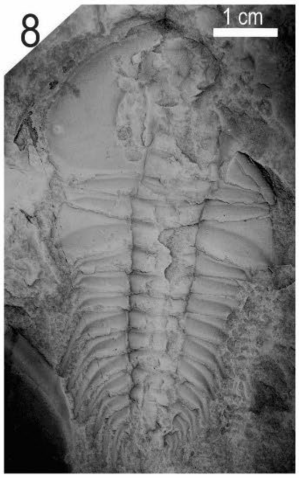

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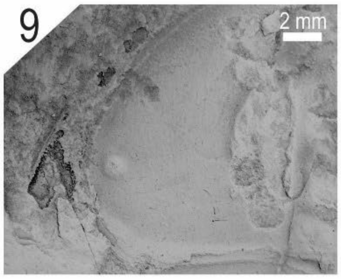

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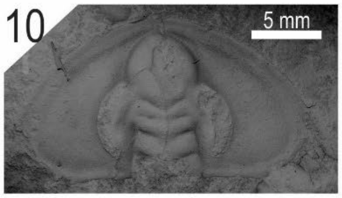

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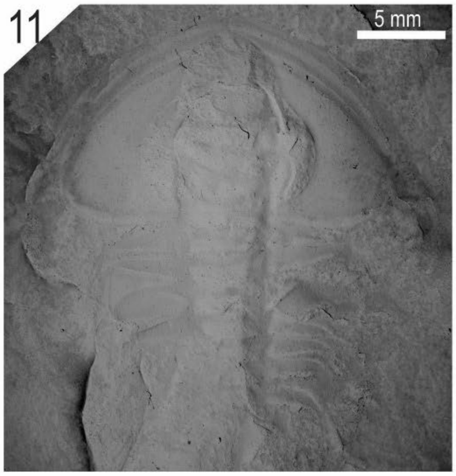

Plate 2

Plate 3A -3. Representative olenellids from the *Bonnia-Olenellus* Zone.

1. *Bolbolenellus* sp. 1. GSC location 98964, 64-1B. Compacted cephalon preserving outline of hypostome.

2. *Bolbolenellus* sp. 1. GSC location 98964, 64-24B. Tentatively assigned partial cephalon and thorax of juvenile individual.

3. *Bolbolenellus* sp. 1. GSC location 98964, 64-3C. Tentatively assigned intermediate-sized cephalon.

4. *Bolbolenellus* sp. 1. GSC location 98964, 64-3D. Tentatively assigned intermediate-sized cephalon.

5. *Bolbolenellus* sp. 1. GSC location 98964, 64-3E. Tentatively assigned intermediate-sized cephalon.

6. *Olenellus* sp. GSC location 98964, 64-2A. Latex cast of moderately compacted cephalon and partial thorax.

7. *Olenellus* sp. GSC location 98964, 64-3F. Relatively pristine, non-compacted cephalon exhibiting a well-defined intergenal ridge and slight genal ridge.

8. *Olenellus* sp. GSC location 98964, 64-9A. Cephalon.

9. *Olenellus* sp. GSC location 98964, 64-10A. Poorly preserved cephalon.

10. *Olenellus* sp. GSC location 98964, 64-18A. Gena.

11. *Olenellus* sp. GSC location 98964, 64-18B. Gena bearing well-preserved genal caeca and intergenal ridge.

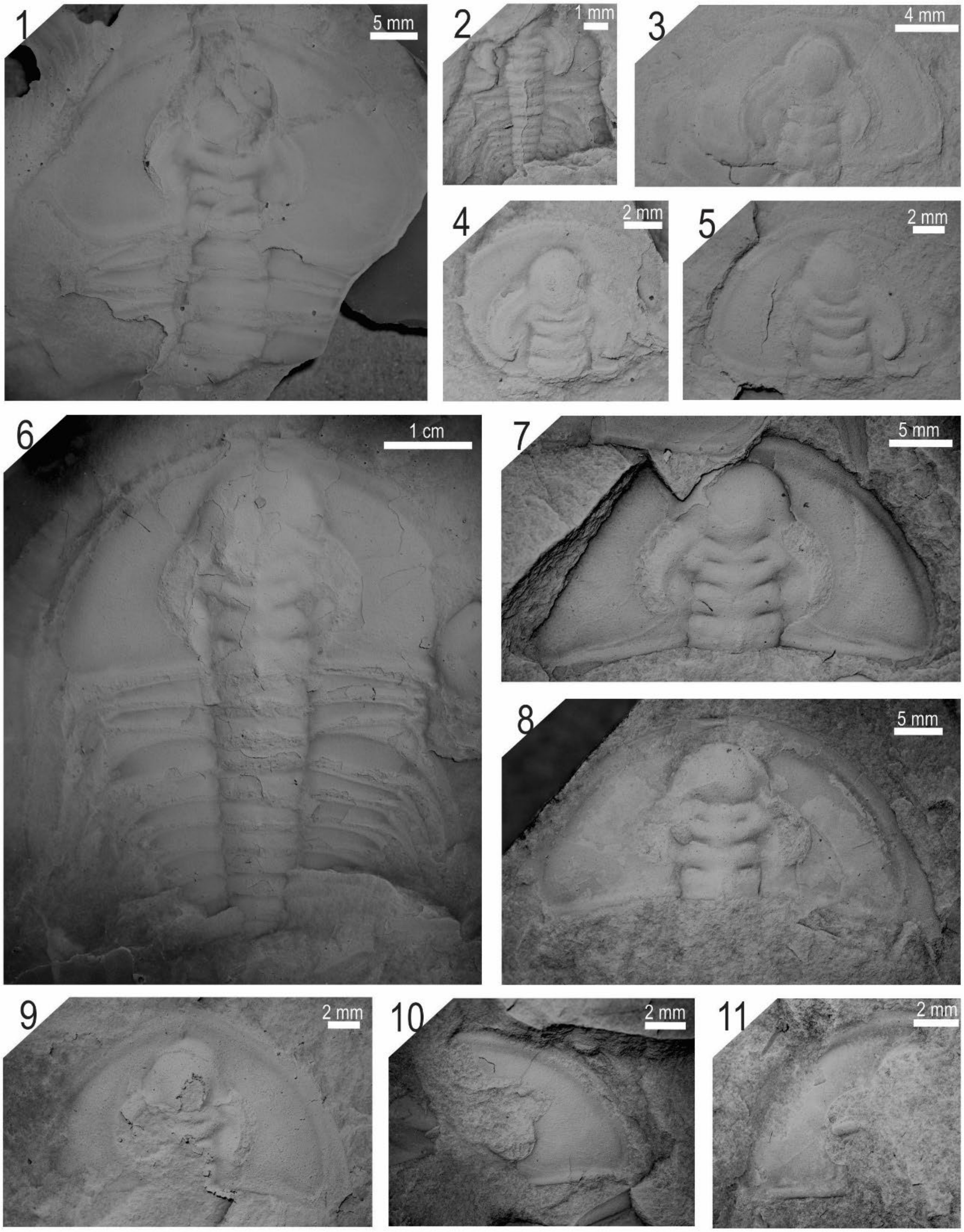

Plate 3

Plate 3A -4. Representative olenellids from the *Bonnia-Olenellus* Zone.

1. *Olenellus* sp. GSC location 98964, 64-8A. Partial cephalon and thorax. Gena bears an anastomosing genal ridge that bifurcates and merges with genal caeca at its termination.

2. *Olenellus* sp. GSC location 98964, 64-14A. Partial cephalon and thorax.

3. *Olenellus* sp.GSC location 98964, 64-16A. Crushed cephalon and partial thorax.

4. *Olenellus* sp. GSC location 98964, 64-17A. Large, compacted cephalon.

5. *Olenellus* sp. GSC location 98964, 64-35A. Partial cephalon and thorax. Note the anastomosing genal ridge that is of similar character to that of Plate 4-A.

6. Olenellus sp. GSC location 98964, 64-19A. Partial thorax bearing an elongate posterior spine.

7. *Olenellus* sp. GSC location 98964, 64-44A. Partial cephalon.

8. *Olenellus* sp. GSC location 98964, 64-25A. Partial cephalon.

9. *Olenellus* sp. GSC location 98964, 64-22D. Tentatively assigned, poorly preserved juvenile cephalon.

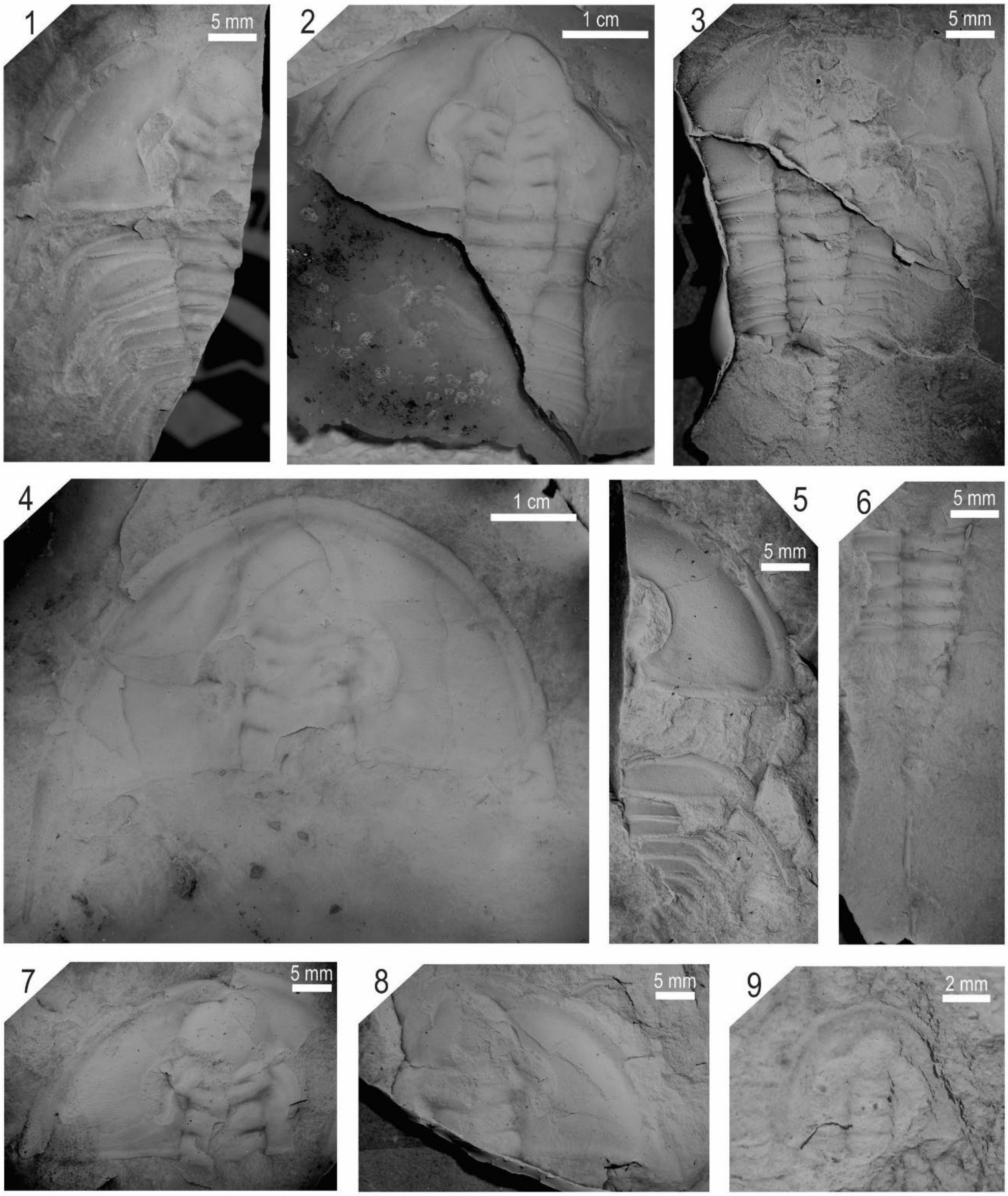

Plate 4

Plate 3A -5. Representative olenellids, ptychopariids, and corynexochids from the *Bonnia-Olenellus* and *Albertella* zones.

1. *Olenellus*? sp. 2. GSC location 98967, 67-1A. Partial cephalon.
2. *Olenellus*? sp. 2. GSC location 98967, 67-2A. Partial cephalon.
3. *Olenellus*? sp. 1. GSC location 98983, 83-1A. Partial juvenile cephalon.
4. *Olenellus*? sp. 1. GSC location 98983, 83-2A. Gena.
5. Indet. Biceratopsid. GSC location 98983, 83-3A. Partial cephalon.
6. Indet. Biceratopsid. GSC location 98983, 83-4A. Gena.
7. Indet. Biceratopsid. GSC location 98983, 83-5A. Gena.
8. "*Onchocephalus*" sp. GSC location 98983, 83-6A. Cranidium.
9. "*Onchocephalus*" sp. GSC location 98983, 83-7A. Cranidium.
10. "*Onchocephalus*" sp. GSC location 98983, 83-8A. Cranidium.
11. "*Onchocephalus*" sp. GSC location 98983, 83-9A. Cranidium.
12. "*Onchocephalus*" sp. GSC location 98983, 83-10A. Cranidium.
13. *Ogygopsis spinulosa*. GSC location 68992, 92-1B. Near complete individual with crushed cranidium.
14. *Ogygopsis spinulosa*. GSC location 68992, 92-1C. Pygidium.
15. *Ogygopsis spinulosa*. GSC location 68992, 92-1D. Pygidium.
16. *Ogygopsis spinulosa*. GSC location 68992, 92-1E. Crushed cranidium.
17. *Ogygopsis spinulosa*. GSC location 68992, 92-1F. Crushed partial pygidium.

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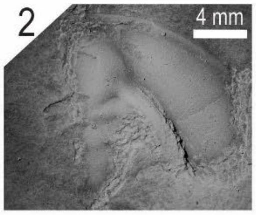

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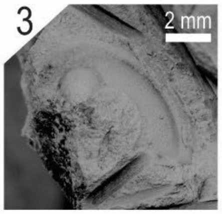

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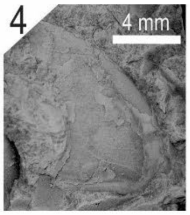

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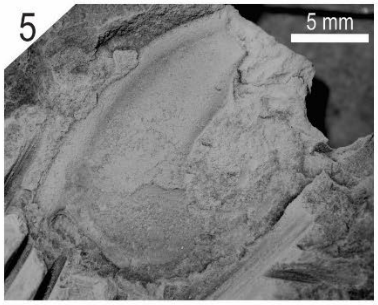

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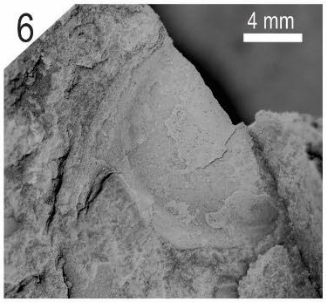

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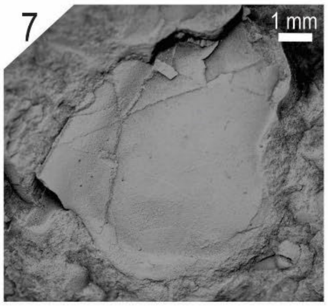

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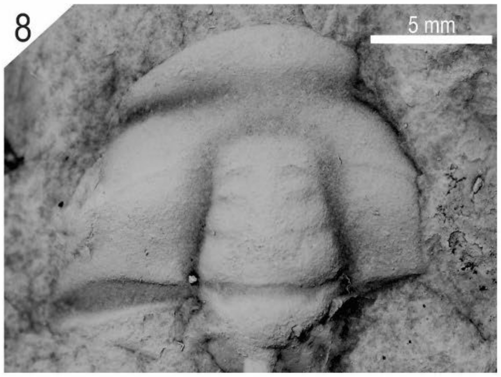

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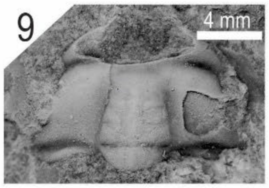

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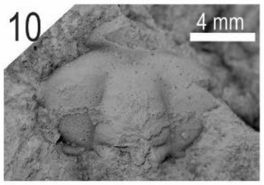

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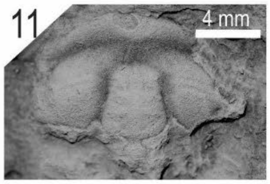

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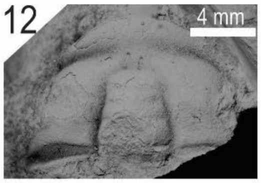

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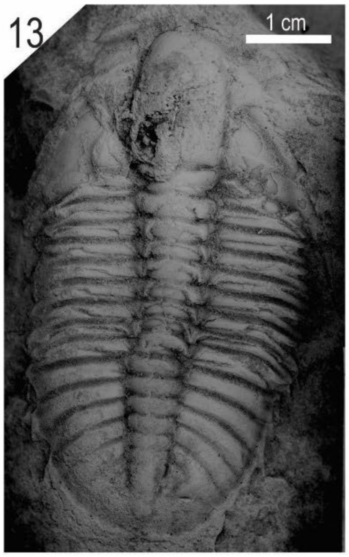

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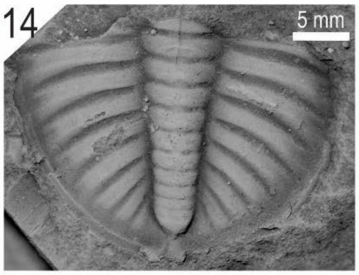

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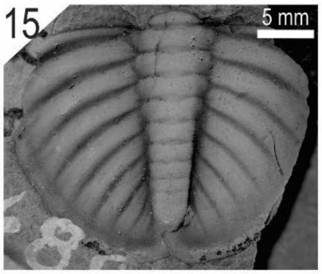

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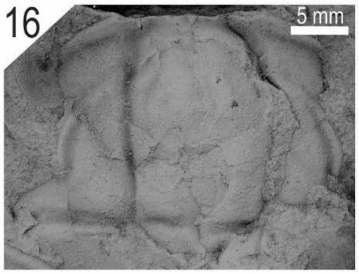

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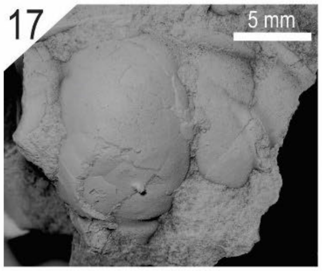

Plate 5

Plate 3A -6. Representative corynexochids and ptychopariids from the *Albertella* Zone.

1. *Ogygopsis spinulosa*. GSC location 68992, 92-1G. Crushed partial cranidium.
2. *Ogygopsis spinulosa*. GSC location 68992, 92-4A. Cranidium.
3. *Ogygopsis spinulosa*. GSC location 68992, 92-4B. Glabella.
4. *Ogygopsis spinulosa*. GSC location 68992, 92-5A. Worn pygidium.
5. *Ogygopsis spinulosa*. GSC location 68992, 92-11A. Pygidium.
6. *Ogygopsis spinulosa*. GSC location 68992, 92-11B. Pygidium.
7. *Ogygopsis spinulosa*. GSC location 68992, 92-7A. Partial cranidium.
8. *Ogygopsis spinulosa*. GSC location 68992, 92-14A. Non-compacted pygidium.
9. *Olenoides* sp. GSC location 68992, 92-1H. Tentatively assigned cranidium.
10. *Olenoides* sp. GSC location 68992, 92- 1I. Pygidium.
11. *Olenoides* sp. GSC location 68992, 92- 1J. Pygidium.
12. *Olenoides* sp. GSC location 68992, 92-7B. Pygidium.
13. *Olenoides* sp. GSC location 68992, 92-15A. Pygidium.
14. "*Syspacephalus*" *tardus*? GSC location 68992, 92-2A. Near-complete individual.
15. "*Syspacephalus*" *tardus*? GSC location 68992, 92-2B. Cranidium.
16. "*Syspacephalus*" *tardus*? GSC location 68992, 92-2C. Cranidium.
17. "*Syspacephalus*" *tardus*? GSC location 68992, 92-2D. Cranidium.
18. "*Syspacephalus*" *tardus*? GSC location 68992, 92-5B. Cranidium.
19. "*Syspacephalus*" *tardus*? GSC location 68992, 92-5C. Cranidium.
20. "*Syspacephalus*" *tardus*? GSC location 68992, 92-5D. Cranidium.

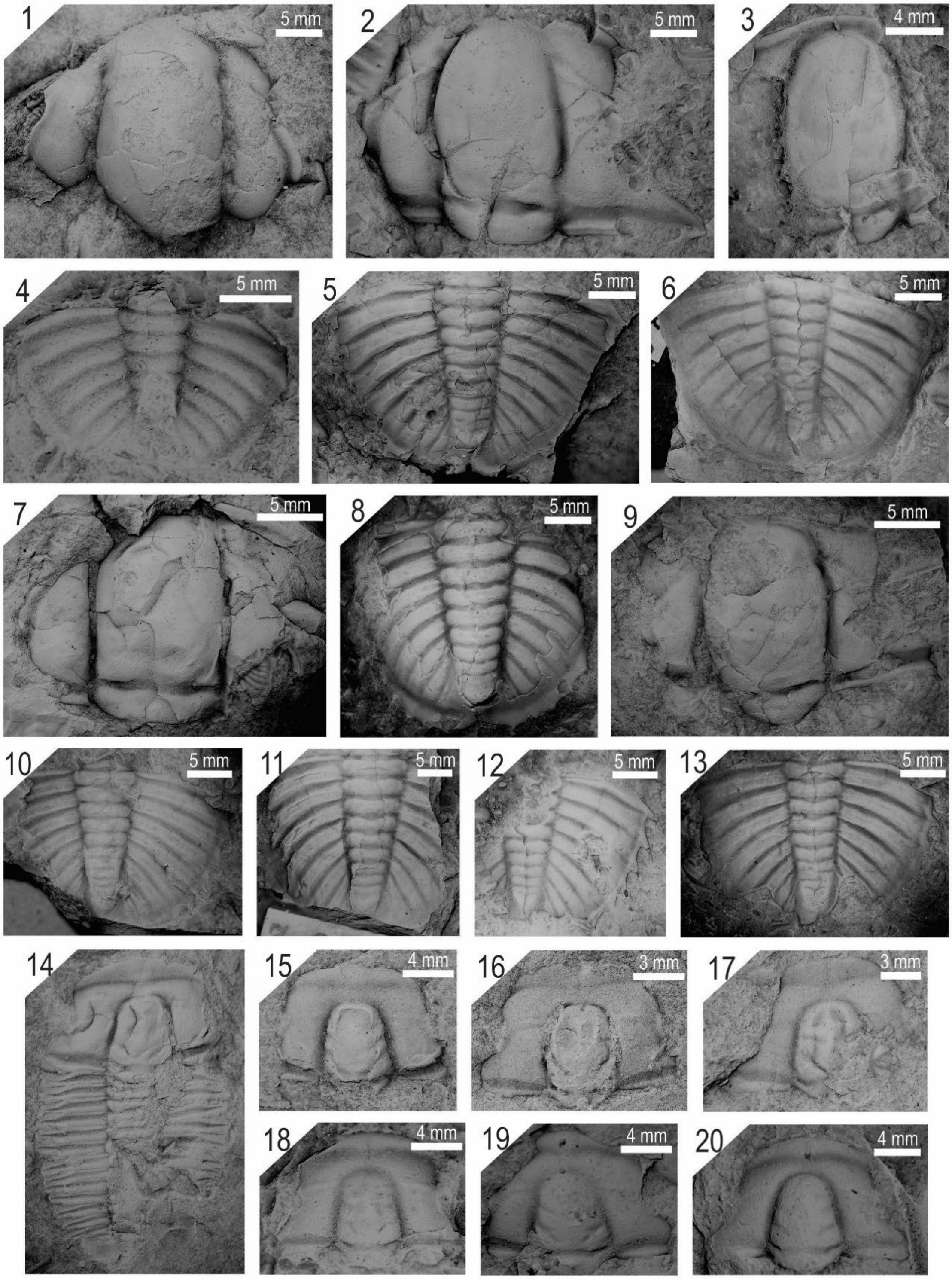
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Plate 6

Plate 3A -7. Representative ptychopariids from the *Albertella* Zone.

1. *Pachyaspis* sp. GSC location 68992, 92-2E. Cranidium.
2. *Pachyaspis* sp. GSC location 68992, 92-5E. Cranidium.
3. *Pachyaspis* sp. GSC location 68992, 92-10G. Cranidium.
4. *Pachyaspis* sp. GSC location 68992, 92-10H. Glabella.
5. *Nyella*? sp. GSC location 68992, 92-8A. Partial cranidium.
6. *Nyella*? sp. GSC location 68992, 92-8B. Partial cranidium.
7. *Yohoaspis* sp. GSC location 68992, 92-12A. Cranidium.
8. *Yohoaspis* sp. GSC location 68992, 92-12B. Cranidium.
9. *Yohoaspis* sp. GSC location 68992, 92-12C. Partial cranidium.
10. *Yohoaspis* sp. GSC location 68992, 92-12D. Cranidium.
11. *Yohoaspis* sp. GSC location 68992, 92-12E. Cranidium.
12. *Yohoaspis* sp. GSC location 68992, 92-B-B. Partial cranidium.
13. *Chancia* sp. GSC location 68992, 92-6A. Partial cranidium and thorax.
14. *Chancia* sp. GSC location 68992, 92-6B. Cranidium and partial thorax.
15. *Chancia* sp. GSC location 68992, 92-6C. Librigena adjacent to and exuviated from specimen 92-6B.

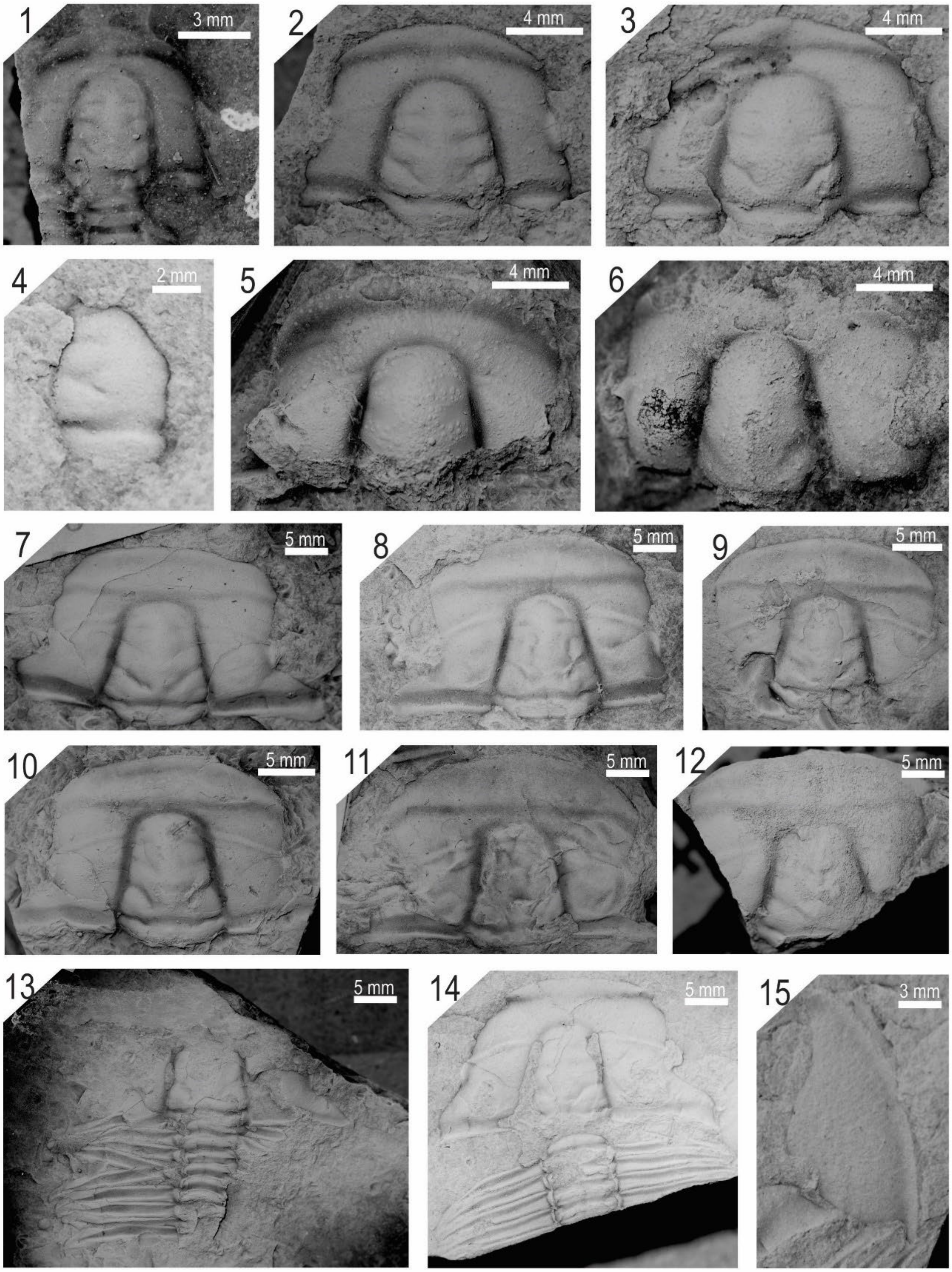
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Plate 7

Plate 3A -8. Representative ptychopriids, oryctocephalids, and eodiscines from the *Albertella* Zone.

1. *Kochiella* sp. GSC location 68992, 92-13A. Cranidium.
2. *Kochiella* sp. GSC location 68992, 92-13B. Cranidium.
3. *Chancia*sp. GSC location 68992, 92-13C. Associated pygidium.
4. *Chancia* sp. GSC location 68992, 92-13D. Associated pygidium.
5. *Zacanthoides* cf. *Z. sexdentatus* .GSC location 68992, 92-16C. Cranidium.
6. *Zacanthoides* cf. *Z. sexdentatus.* GSC location 68992, 92-16D. Cranidium.
7. *Zacanthoides* cf. *Z. sexdentatus.* GSC location 68992, 92-16E. Cranidium.
8. *Zacanthoides* cf. *Z. sexdentatus*. GSC location 68992, 92-4C. Cranidium.
9. *Zacanthoides* cf. *Z. sexdentatus*. GSC location 68992, 92-16F. Pygidium.
10. *Pagetia bootes*. GSC location 68992. 92-3C. Cranidium.
11. *Pagetia bootes*. GSC location 68992. 92-3D. Cranidium.
12. *Pagetia bootes*. GSC location 68992. 92-3F. Cranidium.
13. *Pagetia bootes*. GSC location 68992. 92-3E. Cranidium.
14. *Pagetia bootes*. GSC location 68992. 92-10E. Cranidium.
15. *Pagetia bootes*. GSC location 68992. 92-10F. Cranidium.
16. *Pagetia bootes*. GSC location 68992. 92-16A. Cranidium.
17. *Pagetia bootes.* GSC location 68992. 92-16B. Cranidium.
18. *Pagetia bootes*. GSC location 68992. 92-3A. Pygidium.
19. *Pagetia bootes.* GSC location 68992. 92-3B. Pygidium.
20. *Pagetia bootes.* GSC location 68992. 92-10C. Pygidium.
21. *Pagetia bootes.* GSC location 68992. 92-3G. Cranidium.
22. *Pagetia bootes.* GSC location 68992. 92-10D. Cranidium.
23. *Oryctocephalus indicus.* GSC location 68992. 92-1A. Cranidium.
24. *Oryctocephalus indicus.* GSC location 68992. 92-B-A. Cranidium.
25. *Oryctocephalus indicus.* GSC location 68992. 92-9A. Cranidium.
26. *Oryctocephalus indicus.* GSC location 68992, 92-9B. Partial thorax and pygidium.

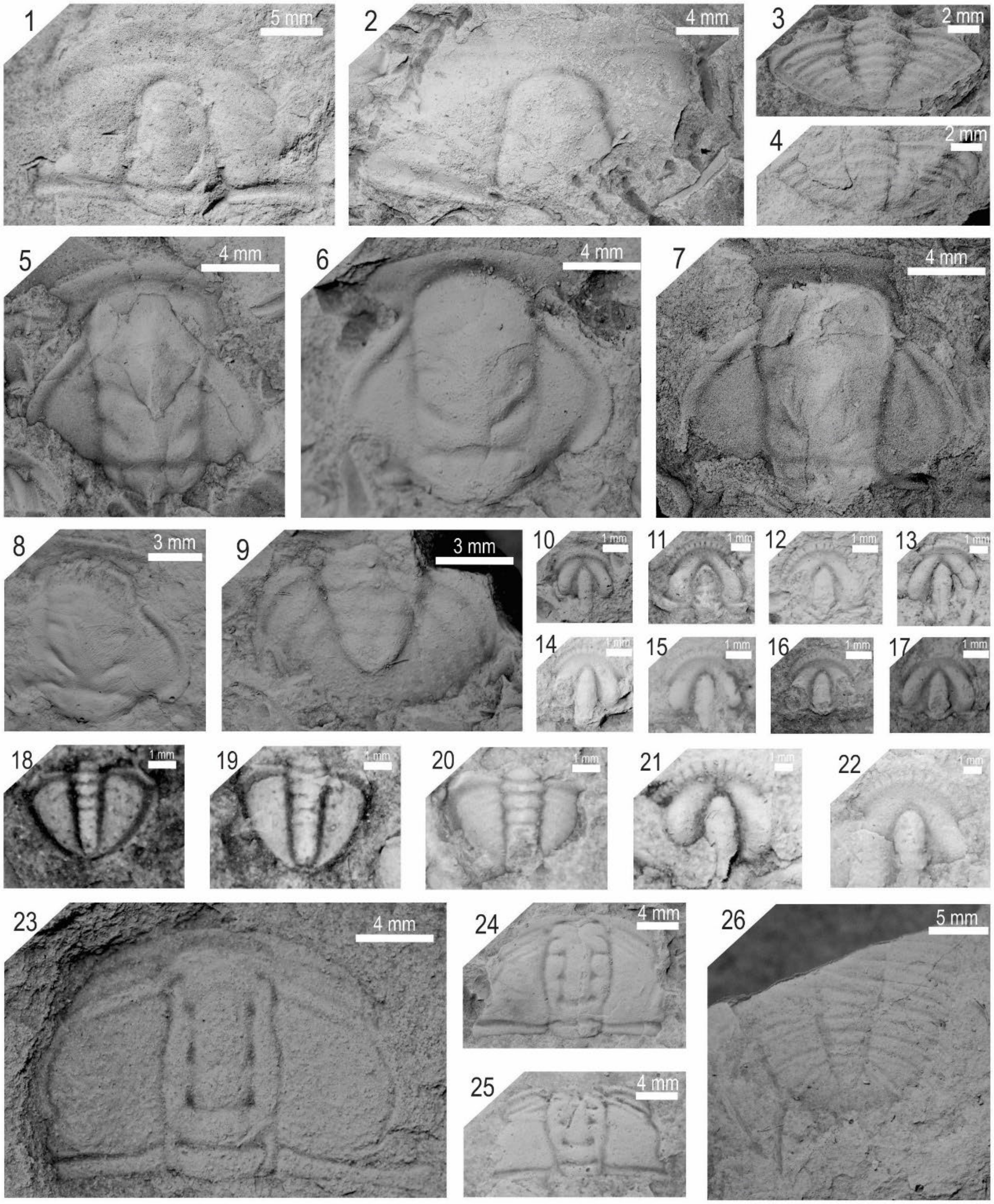
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Plate 8

Plate 3A -9. Representative ptychopariids and agnostines from the *Bolaspidella* Zone.

1. *Elrathia* sp. GSC location 69004, 04-1A. Partial cranidium.
2. *Utaspis*? sp. GSC location 68999, 99-1A. Cranidium.
3. *Utaspis*? sp. GSC location 69007, 07-1A. Cranidium.
4. *Utaspis*? sp. GSC location 69005, 05-1A. Near-complete individual.
5. *Utaspis*? sp. GSC location 69004, 04-2A. Weathered near-complete individual.
6. *Hemirhodon*? sp. GSC location 68999, 99-1A. Partial pygidium.
7. *Utaspis*? sp. GSC location 69007, 07-2A. Partial pygidium.
8. *Hypagnostus* cf. *H. parvifrons*.. GSC location 69004, 04-3A. Partial cranidium.
9. *Hypagnostus* cf. *H. parvifrons*. GSC location 69004, 04-4A. Partial cranidium.
10. *Hypagnostus* cf. *H. parvifrons*. GSC location 69005, 05-1B. Cranidium.
11. *Hypagnostus* cf. *H. parvifrons*. GSC location 69007, 07-3A. Cranidium.
12. *Hypagnostus* cf. *H. parvifrons*. GSC location 69005, 05-1C. Pygidium.
13. *Hypagnostus* cf. H. parvifrons. GSC location 69005, 05-1D. Worn, tentatively assigned, near-complete individual.
14. *Itagnostus*? sp. GSC location 69005, 05-1E. Negative of cranidium.
15. *Itagnostus*? sp. GSC location 69005, 05-1F. Compacted cranidium.
16. *Itagnostus*? sp. GSC location 69007, 07-4A. Cranidium.
17. *Baltagnostus*? sp. GSC location 69007, 07-5A. Cranidium.
18. *Baltagnostus*? sp. GSC location 69007, 07-6A. Pygidium.
19. *Homagnostus*? sp. GSC Location 68999, 99-2A. Pygidium.
20. *Eldoradia*? sp. GSC location 69005, 05-1G. Partial cranidium.

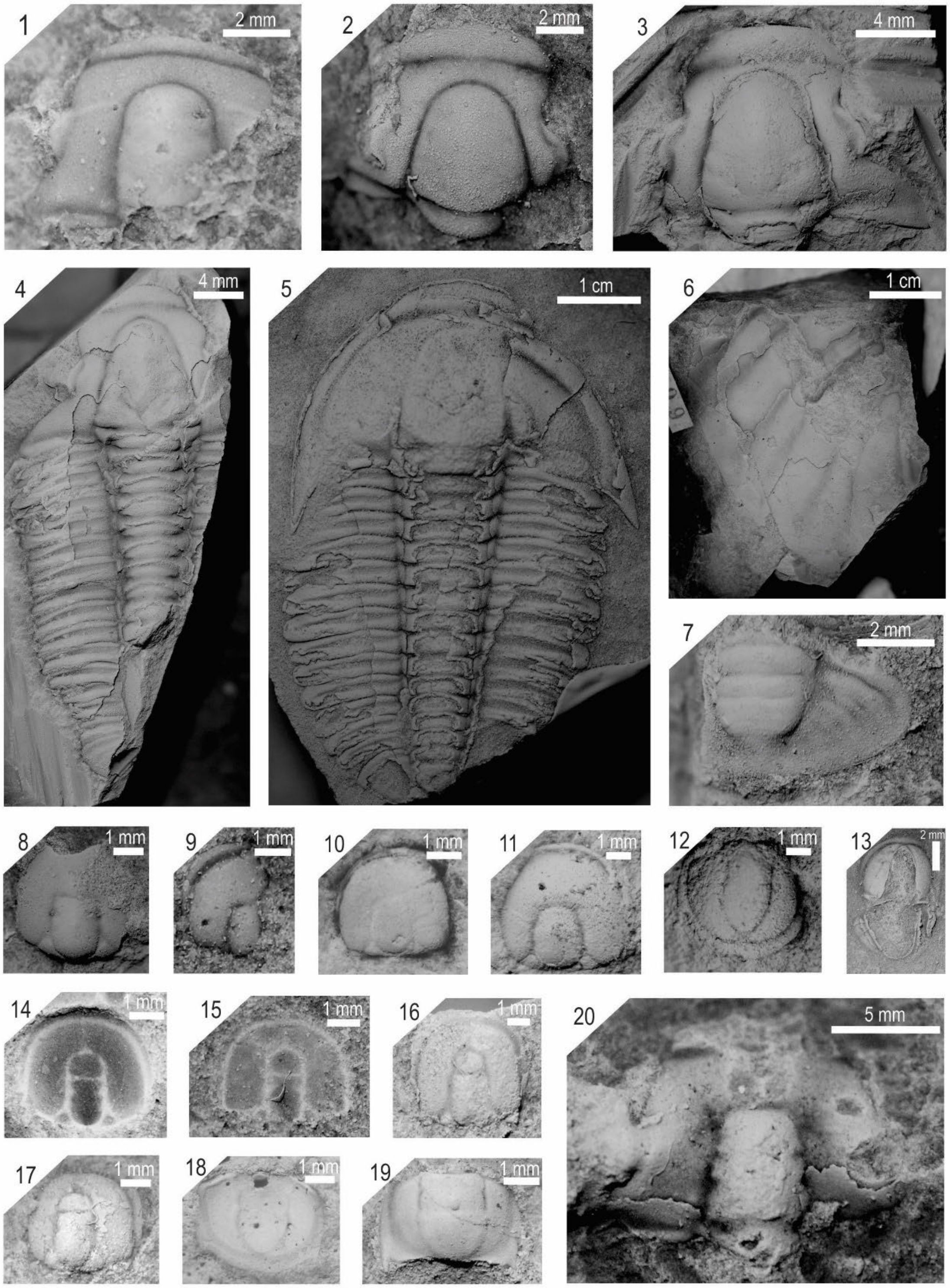
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Plate 9

APPENDIX 3B. Biostratigraphic data and metreage from Fritz (1979) used in Figs. 3-9, 3-10, and 3-12. Metreage is given as metres above the base of each stratigraphic unit.

Stratigraphic Unit	Section	GSC location	Meterage	Footage	Trilobite Taxa	Biostratigraphic assignment
Rabbitkettle Formation	Fritz 33	95529	76.2	250.0	*Acmarhachis* sp., *Crenuolimbus* ? sp., *Olenaspella* ? sp., *Pseudagnostus* sp.	Upper Cambrian
Rockslide Formation		95528	69.0	226.4	*Baltagnostus* sp., *Lejopyge calva* , *Modocia* sp.	Middle Cambrian
Rockslide Formation		95527	45.2	148.3	*Bonnia* sp., *Piaziella* sp., *Syspacephalus* sp.	Upper *Bonnia-Olenellus* Zone
Sekwi Formation		95526	476.0	1561.7	*Bonnia laterispina* , *Zacanthopsis* sp.	Upper *Bonnia-Olenellus* Zone
Sekwi Formation		95525	442.7	1452.4	*Olenellus* sp. 2 Fritz 1972, *Wanneria logani*	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		95524	407.0	1335.3	*Wanneria logani* , *Olenellus* sp.2 Fritz 1972	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		95523	371.3	1218.2	*Olenellus* sp., *Wanneria* sp.	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		95522	340.3	1116.5	*Olenellus* sp., *Variopelta* sp.	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		95521	237.1	777.9	*Laudonia* ? Sp.	Lower *Bonnia-Olenellus* Zone
Sekwi Formation		95520	107.1	351.4	*Kootenia* ? Sp.	*Nevadella* Zone
Sekwi Formation		95519	14.3	46.9	*Holmiella* ? Sp.	*Nevadella* Zone
Sekwi Formation		95518	11.9	39.0	*Holmiella* sp.	*Nevadella* Zone
Sekwi Formation		95517	11.9	39.0	*Parafallotaspis* sp.	*Fallotaspis* Zone
Rabbitkettle Formation	Fritz 35	94622	402.2	1319.6	Pagodia-like trilobite	Ordovician
Rabbitkettle Formation		94621	388.0	1273.0	indet. asaphid	Ordovician
Rabbitkettle Formation		94620	380.8	1249.3	indet. asaphid	Ordovician
Rabbitkettle Formation		94619	342.7	1124.3	indet. olenid?	Upper Cambrian
Rabbitkettle Formation		94618	340.3	1116.5	indet. olenid	Upper Cambrian
Rabbitkettle Formation		94617	266.6	874.7	*Charchagia* ? sp., *Agnostus* sp., *Boltagnostus* sp., *Cedaria* sp.	Upper Cambrian
Rabbitkettle Formation		94616	252.3	827.8	*Hedinaspis* sp.	Upper Cambrian
Rabbitkettle Formation		94615	152.3	499.7	*Eoorthis* sp., olenid trilobite, *Proceratopyge* sp., *Pseudagnostus* sp., *Taenicephalus* sp.	Upper Cambrian
Rabbitkettle Formation		94614	92.8	304.5	*Acmarhachis* sp., *Aphelaspis* sp., *Glyptagnostus reticulatus reticulatus* (Angelin)	Middle Cambrian
Rockslide Formation		94613	159.5	523.3	*Boltagnostus* sp., *Elrathina* ? sp., *Lejopyge* sp., *Ptychagnostus aculeatus* ? (Angelin)	Middle Cambrian
Rockslide Formation		94612	157.0	515.1	*Hypagnostus* sp., *Boltagnostus* sp.	Middle Cambrian
Rockslide Formation		94611	145.2	476.4	*Centropleura* sp.	Middle Cambrian
Rockslide Formation		94610	145.2	476.4	*Centropleura* sp.	Middle Cambrian
Rockslide Formation		94609	145.2	476.4	*Centropleura* sp.	Middle Cambrian
Rockslide Formation		94608	138.0	452.8	*Ptychagnostus richmondensis* (Walcott)	Middle Cambrian
Rockslide Formation		94607	26.2	86.0	*Bonnia* ? *fieldensis* , *Syspacephalus* sp., *Piaziella* ? sp.	Upper *Bonnia-Olenellus* Zone
Sekwi Formation		94606	540.3	1772.6	*Bonnia columbensis* ?, *Olenellus puertoblancoensis*, *Wanneria* ? sp.	Upper *Bonnia-Olenellus* Zone
Sekwi Formation		94605	528.4	1733.6	*Bonnia* sp.	*Bonnia-Olenellus* Zone
Sekwi Formation		94604	504.6	1655.5	*Olenellus paraoculus*	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		94603	449.8	1475.7	*Anabarella* ? sp., *Wanneria logani*	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		94602	442.7	1452.4	*Olenellus laxocules* , *Wanneria parvifrons*	Middle *Bonnia-Olenellus* Zone
Sekwi Formation		94601	100.0	328.1	*Holmiella* sp.	*Nevadella* Zone
Sekwi Formation		94600	83.3	273.3	*Nevadella bacculenta* ?, *Nevadella faceta* , *Holmiella preancora*	*Nevadella* Zone
Sekwi Formation		94599	23.8	78.1	*Parafallotaspis* ? sp.	*Fallotaspis* Zone
Sekwi Formation		94598	23.8	78.1	cf. *Parafallotaspis grata*	*Fallotaspis* Zone

Stratigraphic Unit	Section	GSC location	Meterage	Footage	Trilobite Taxa	
Rabbitkettle Formation	Fritz 36	94571	66.6	218.5	*Aphelaspis* sp., *Glyptgnostus* sp.	Upper Cambrian
Rabbitkettle Formation		94570	64.3	211.0	*Cedaria* sp., *Ptychagnostus* sp.	Upper Cambrian
Rabbitkettle Formation		94569	52.4	171.9	*Ankoura* sp., *Cedaria* sp.	Upper Cambrian
Rabbitkettle Formation		94568	0.0	0.0	*Agnostus* sp., *Baltagnostus* sp. *Cedaria* spp.	Upper Cambrian
Rockslide Formation		94567	119.0	390.4	*Baltagnostus* sp., *Cedaria* sp., *Hypagnostus* sp.	Middle Cambrian
Rockslide Formation		94566	116.6	382.5	*Agnostus* ? sp., *Baltagnostus* ? sp., *Cedaria* sp., *Hypagnostus* sp.	Middle Cambrian
Rockslide Formation		94565	100.0	328.1	*Baltagnostus* sp., *Diplagnostus* ? sp., *Elrathia* sp., *Hypagnostus* sp., *Lejopyge calva* Robison	Middle Cambrian
Rockslide Formation		94564	90.4	296.6	*Baltagnostus* ? sp., *Cedaria* sp., *Eldoradia* sp., *Hypagnostus* sp., *Ptychagnostus* (*Ptychagnostu* s) *aculeatus* (Angelin), indet gen. & sp. 1 Robis	Middle Cambrian
Rockslide Formation		94563	88.0	288.7	*Hypagnostus* sp., *Diplagnostus planicuda vestgothus* (Wallerius), *Lejopyge calva* (Robison)	Middle Cambrian
Rockslide Formation		94562	59.5	195.2	*Hypagnostus* sp., *Lejopyge calva* Robison	Middle Cambrian
Rockslide Formation		94561	52.4	171.9	*Bathyuriscus* ? sp., *Cedaria* sp., *Hypagnostus* sp., *Lejopyge calva* Robison, *Modocia* sp.	Middle Cambrian
Rockslide Formation		94560	21.4	70.2	*Ptychagnostus* (*Ptychagnostus*) *punctuosus* (Angelin), cf. *Ptychagnostus* (*Triplagnostus*) *lundgreni* (Tullberg)	Middle Cambrian
Rockslide Formation		94559	17.7	58.1	*Ptychagnostus* (*Ptychagnostus*) *punctuosus* (Angelin), cf. *Ptychagnostus* (*Triplagnostus*) *lundgreni* (Tullberg)	Middle Cambrian
Rockslide Formation		94558	7.1	23.3	*Lejopyge* sp., *Peronopsis* sp.	Middle Cambrian
Rockslide Formation		94557	0.0	0.0	*Cedaria* ? sp., *Hypagnostus* sp., *Peronopsis* sp.	Middle Cambrian
Sekwi Formation		94556	214.2	702.8	*Olenellus* sp.	*Bonnia-Olenellus* Zone
Sekwi Formation		94555	133.3	437.3	*Holmiella* sp., *Nevadella* sp., *Nevadia* sp.	*Nevadella* Zone
Sekwi Formation		94554	85.7	281.2	*Holmiella* sp., *Nevadia* sp.	*Nevadella* Zone
Sekwi Formation		94553	85.7	281.2	*Holmiella* sp.	*Nevadella* Zone
Sekwi Formation		94552	71.4	234.3	*Holmiella* ? sp.	*Nevadella* Zone
Sekwi Formation		94551	61.9	203.1	*Holmiella* sp., cf. *Holmiella* sp., *Nevadia* sp., *Nevadella* sp.	*Nevadella* Zone
Sekwi Formation		94550	47.6	156.2	*Holmiella* ? sp., *Nevadia* sp.	*Nevadella* Zone
Sekwi Formation		94549	40.5	132.9	*Holmiella* , *Keeleaspis* ? sp., *Nevadella* sp.	*Nevadella* Zone
Sekwi Formation		94548	4.8	15.7	*Parafallotaspis* sp.	*Fallotaspis* Zone

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[i] The Husky Lakes arch is referred to in the literature as the "Eskimo Lakes arch" (Cecile et. al. 1997). The location that this feature was named after has been renamed Husky Lakes. Hadlari et al. (2020) proposed that the Eskimo Lakes fault zone be renamed the Husky Lakes fault zone to avoid using pejorative nomenclature, and this paper follows suit with the arch of the same name.