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TRILOBITES AND STRATA OF THE LOWER AND MIDDLE CAMBRIAN PEYTO, MOUNT WHYTE AND NAISET FORMATIONS, ALBERTA AND BRITISH COLUMBIA

by

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TRILOBITES AND STRATA OF THE LOWER AND MIDDLE CAMBRIAN PEYTO, MOUNT WHYTE AND NAISET FORMATIONS, ALBERTA AND BRITISH COLUMBIA

ABSTRACT

The uppermost Lower Cambrian Peyto Formation consists mainly of bioclastic, oolitic, and oncolitic limestones and dolostones which contain locally abundant quartz sand; shales are a minor component. Four carbonate facies-associations record shallow subtidal deposition adjacent to shelf-edge oolitic sand shoals.

The uppermost Lower Cambrian to lowermost Middle Cambrian Mt. Whyte Formation conformably overlies the Peyto and consists of a lower bioturbated quartz siltstone and shale member, followed by oolitic and bioclastic limestones with locally abundant oncolites and thrombolites. Four facies associations, all of which include a silt- to mud-grade siliciclastic component, are indicative of shallow subtidal to intertidal shelf deposition.

The Naiset Formation is correlative with the Mt. Whyte and comprises mainly thinly laminated lime mudstones, quartz siltstones, and shales. Two primarily fine-grain siliciclastic facies-associations are characterized by slumps, slide scars, debris flows and turbidites that indicate continental slope deposition.

Twenty-one collections yielded over 1,686 trilobites. Two Lower Cambrian, and four Middle Cambrian trilobite biofacies are defined from generic relative abundance data. Each biofacies is associated with a particular depositional environment on the Cambrian continental shelf and slope.

New, species-based trilobite zones, established in the context of biofacies, provide greater biostratigraphic resolution than the genus-based zones which they replace. In ascending order, the zones are: the *Olenellus gilberti* - *puertoblancoensis* Zone, the *Syspacephalus laticeps* Zone, the *Syspacephalus perola* Zone, and the *Alokistocare cleora* Zone.

Major revisions to the Corynexochida are made at the suprageneric level: Zacanthoididae Swinnerton, and Dolichometopidae Walcott, are both synonymized with the Corynexochidae Angelin, and the superfamily Oryctocephalacea Beecher is revised to include the Dinesidae Lermontova, Oryctocephalidae Beecher and Dorypygidae Kobayashi. Numerous genus-level revisions are made in the Corynexochida and the Ptychopariida, including the following synonymies: *Bonnia* Walcott with *Olenoides* Meek; *Stephenaspis* Rasetti with *Fieldaspis* Rasetti; *Poulsenia* Resser, *Onchocephalus* Resser, *Piaziella* Lochman, *Eoptychoparia* Rasetti, *Parapoulsenia* Rasetti, *Spencella* Rasetti, *Nyella* Palmer, and *Illtydaspis* Fritz with *Antagmus* Resser; and *Amecephalus* Walcott with *Alokistocare* Lorenz. A total of 32 species representing 16 genera are described and illustrated.

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There are many other faculty, staff, and students at McMaster University who have helped me during the course of my studies here, but I would especially like to thank J. Whorwood at the Department of Geology for his invaluable photographic advice.

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CHAPTER 1

INTRODUCTION

OUTLINE OF STUDY

In the eastern Main Ranges of the southern Canadian Rocky Mountains, Alberta and British Columbia, the Peyto Formation and the overlying Mt. Whyte and Naiset formations comprise a largely complete record of mixed carbonate-siliciclastic, shallow shelf to slope sedimentation across the Lower-Middle Cambrian boundary. The Peyto and, in places, the Naiset overlie Lower Cambrian Gog Group sandstones, while the Mt. Whyte and Naiset are succeeded by the Middle Cambrian Cathedral Formation. These formations are well exposed, and virtually undeformed, in thick, relatively flat thrust sheets (Oldow et al., 1989).

Whereas the stratigraphy and generalized sedimentology of the Peyto, Mt. Whyte, and Naiset formations have been studied recently by Hockley (1973) and Aitken (in press), the trilobite faunas of these formations are in need of a detailed, modern analysis. The trilobites of the Lower Cambrian Peyto Formation received only cursory treatments by Walcott (1917) and Rasetti (1951) and are in need of a modern systematic treatment. Although trilobites of the Mt. Whyte and Naiset formations were described and illustrated by Rasetti (1951, 1957), the stratigraphic framework for his study was poorly defined, and his collections lacked detailed location and relative abundance data. Moreover, several taxa are now in need of revision, and others have been poorly documented.

A significant erosional unconformity is said to occur at the top of Lower Cambrian strata in the study area (Rasetti 1951; Aitken 1989, in press; Fritz et al. 1991). Although an unconformity has been described at the top of the Lower Cambrian in other areas (Fritz 1972, 1991; Fritz et al. 1991), no convincing evidence for an unconformity exists in the study area. New evidence demonstrates that a virtually complete sedimentary record exists across the Lower-Middle Cambrian boundary in Banff and Yoho National Parks, providing a unique opportunity to study the accompanying faunal transition. An examination of the stratigraphic expression of the Lower-Middle Cambrian boundary, and an analysis of the transition faunas constitute significant components of this thesis.

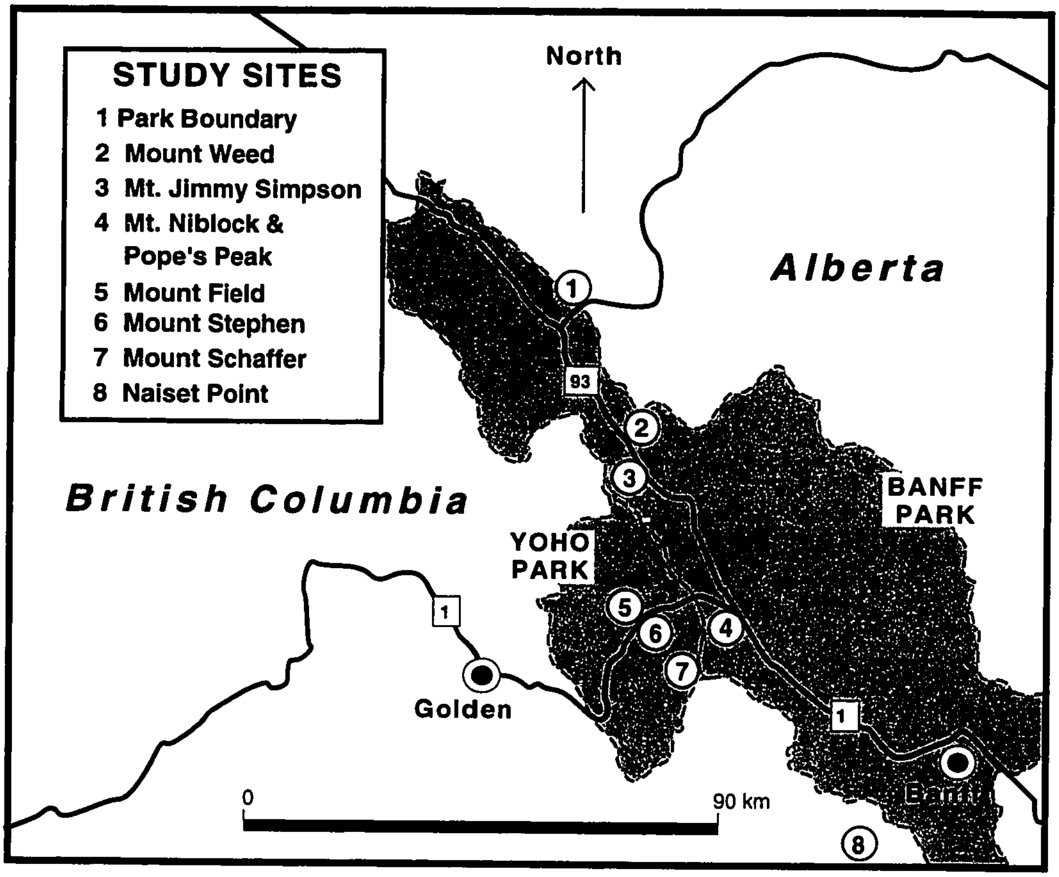
For the first time, quantitative biofacies analysis has been performed on Lower Cambrian and lowest Middle Cambrian trilobite faunas. Results for the lower Cambrian interval show that two distinct trilobite biofacies - the Periomma and Onchocephalites biofacies - can be distinguished for shallow carbonate shelf deposits of the Peyto Formation. In addition, a Syspacephalus dominated biofacies occurs in deeper-water slope deposits of the Naiset Formation. This biofacies is known from uppermost Lower Cambrian through lowest Middle Cambrian strata. In fact, at least six of the nine genera that occur in the Lower Cambrian portion of the study interval are also known from Middle Cambrian rocks. The Plagiura and Antagmus biofacies occur in lowest Middle Cambrian carbonate shelf facies of the Mt. Whyte Formation.

The uppermost Lower Cambrian interval in Laurentia has previously encompassed a single trilobite zone - the Bonnia-

Olenellus Zone - which, in some places, attains a thickness of over 800 metres and contains dozens of trilobite species (see Fritz, 1991). In his work on uppermost Lower Cambrian trilobites of the northern Cordillera, Fritz (1991) alluded to the possibility of further subdividing the Bonnia-Olenellus Zone, but was unable to recognize species-based zones that extended to widely separated regions of the Cordillera. Palmer and Repina (1993) noted that Bonnia was restricted geographically to carbonate shelf deposits, and occupied only the upper portion of the range of Olenellus. Consequently, as an alternative to the Bonnia-Olenellus Zone, they recognized an Olenellus Zone subdivided into three informal parts, the middle defined by the range of Wanneria, and the upper and lower parts undefined. With new data from the Peyto Formation, it is now possible to establish a species-based, uppermost Lower Cambrian zone for carbonate shelf sediments which correlates with the upper part of Palmer and Repina's (1993) Olenellus Zone. A second zone, which straddles the Lower-Middle Cambrian boundary, is proposed for deeper-water slope deposits.

Lowest Middle Cambrian strata in Laurentia have been assigned previously to the Plagiura-Poliella Zone. This study shows that the distributions of both of these genera are strongly facies-specific, with Plagiura occupying relatively nearshore, shallow carbonate facies, while Poliella is restricted to deeper outer shelf or slope shales and carbonates. Most of the strata previously assigned to the Plagiura-Poliella Zone in the study area contain neither genus. The Plagiura-Poliella Zone is herein replaced by the Syspacephalus

FIGURE 1. Map showing locations of measured sections and collection sites. Location 4 (Lake Louise) includes Pope's Peak and Mount Niblock sections; location 6 (Mount Stephen) includes Monarch Creek, Snow Shed, North Gully, Waterfall and Fossil Gully sites.


STUDY SITES
1 Park Boundary
2 Mount Weed
3 Mt. Jimmy Simpson
4 Mt. Niblock & Pope's Peak
5 Mount Field
6 Mount Stephen
7 Mount Schaffer
8 Naiset Point
North
Alberta
British Columbia
93
1
2
3
BANFF PARK
YOHO PARK
5
6
4
7
1
Golden
1
Banff
0
90 km
8

perola Zone in slope facies, and by the Alokistocare cleora Zone in carbonate shelf facies.

STUDY AREA

Field work for this thesis was conducted within Banff and Yoho National Parks and Mount Assiniboine Provincial Park. Stratigraphic sections were measured at twelve locations (see Figure 1) in the Simpson Pass and Pipestone Pass thrust sheets of the Main Ranges (Monger and Price, 1979). These locations provided hundreds of metres of uninterrupted vertical and lateral exposure of structurally uncomplicated, nearly flat-lying beds. The superb exposure allowed detailed recording of lithic and stratal data, and closely-spaced collecting. Twenty-four bulk fossiliferous samples were collected and yielded 1,686 trilobites representing thirty-nine species. In addition to trilobites, hyolithids are common elements of the Peyto fauna, whereas inarticulate brachiopods and molluscs are locally common in the Naiset Formation. Ichnofossils are particularly abundant in parts of the Mt. Whyte, but virtually absent from the Naiset and Peyto formations. Only trilobites are considered in the remainder of this thesis.

PREVIOUS WORK

Pioneering work on Cambrian stratigraphy and paleontology of the Rocky Mountains was conducted by Walcott around the turn of the century. Walcott (1908) described the Saint Piran and Mt. Whyte formations, and placed them in the Lower Cambrian, while the base of his Middle Cambrian coincided with the Cathedral Formation.

Later, Burling (1916) placed the Lower-Middle Cambrian boundary directly above the Olenellus Zone in the basal part of the Mt. Whyte Formation. Walcott (1917) described 60 species of fossils which he had collected from his Mt. Whyte Formation (which included what are now considered to be the Peyto, Naiset, and Cathedral formations). However, detailed collection locations were not provided. The definitions of the St. Piran, Mt. Whyte, and Cathedral formations were later summarized by Walcott (1928).

The next study of the Cambrian of the area was carried out by Deiss in the late 1930's. Deiss' (1939, 1940) work was primarily stratigraphic, and although he did not describe or illustrate fossils, he published incomplete faunal lists. Deiss (1939) was the first to propose a biostratigraphic zonation for Cambrian strata of the region: the Early Cambrian Olenellus-Bonnia Zone succeeded by the latest Early Cambrian Plagiura Zone. As defined by Deiss (1939, 1940), the Mt. Whyte Formation was entirely Early Cambrian in age. Deiss' (1940) earliest Middle Cambrian biostratigraphic unit was the Kochaspis Zone, which he recognized in the now-obsolete Ptarmigan Formation, and the Cathedral Formation. The stratal interval in which this fauna occurs is now included in the Mt. Whyte Formation. Deiss' Kochaspis Zone was followed by the Albertella Zone of the Cathedral Formation.

Two new formations were also established by Deiss (1940). He assigned the Lower Cambrian siliciclastic strata in the Mount Assiniboine area to the Gog Formation. In addition, the Naiset Formation was defined at Naiset Point near Mount Assiniboine to include the shale and limestone between the Gog and the Cathedral formations. The Gog Formation was later raised to group status by Mountjoy (1962).

In the late 1940's, Rasetti revisited many of Walcott's original locations, where he measured sections and made extensive fossil collections. Rasetti (1951) recognized the Bonnia-Olenellus Zone as the youngest Early Cambrian biostratigraphic unit, and designated Olenellus-bearing limestone beds at the base of the Mt. Whyte Formation as the Peyto Limestone Member of the Saint Piran Formation. Accordingly, the Mt. Whyte Formation was entirely Middle Cambrian in age, and thus Walcott's and Deiss' concepts of the Mt. Whyte Formation were amended. In the Mt. Whyte and Naiset formations, Rasetti (1951) established the earliest Middle Cambrian Wenkchemnia-Stephenaspis and Plagiura-Kochaspis zones, but these have not been adopted by subsequent workers. They are succeeded by the Albertella Zone, which, in the study area, occurs in the Cathedral Formation. Today, the age designations of the Peyto, Mt. Whyte, and Naiset formations remain little changed from Rasetti's work.

Lochman-Balk and Wilson (1958) established the lowest Middle Cambrian Plagiura-Poliella Zone, and it has been widely used for this stratigraphic interval in North America.

Since the 1960's, Aitken has worked extensively with Cambrian stratigraphy in the Canadian Rockies. He (Aitken, 1968) demonstrated that the Mt. Whyte-Cathedral transition becomes younger to the east, so that at Ghost River (east of the area studied in this thesis), the Mt. Whyte is within the Albertella Zone (Aitken, 1968).

Recently, Aitken (1989b, and in press), following the recommendations of Hockley (1973), proposed formal division of the Mt. Whyte into two members. At the base of the Mt. Whyte, the Weed Member comprises mainly quartz siltstone and minor very fine sandstone that are locally calcareous, and extensively bioturbated in places. The upper portion of the Mt. Whyte, comprising varied limestones alternating with shale and siltstone, is assigned to the Chephren Member. Aitken also revised the lower and upper contacts of the Mt. Whyte. Accordingly, the base of the Mount Whyte coincides with the base of the Weed Member, "or similar and equivalent siltstones and sandstones" (Aitken, in press). Where both the top of the Peyto and the base of the Mt. Whyte contain abundant sand, silt, and shale (Popes Peak section for example), Aitken (in press) placed the base of the Mt. Whyte at the first major shale bed. He placed the upper contact with the Cathedral at the top of the highest bed of shale or siltstone, followed by cliff-forming carbonates. Finally, Aitken (in press) elevated the Peyto Member of the Gog Group to formational status.

Hockley (1973) completed an M.Sc. thesis which dealt with the stratigraphy and paleoenvironmental patterns of the Peyto and Mt. Whyte sediments. Hockley contributed no new biostratigraphic or paleontologic information, although Hockley's work comprised the only facies analysis of these formations until now.

FIGURE 2. Diagram showing approximate stratigraphic relationships between the Gog Group, Peyto, Mt. Whyte, Naiset and Cathedral formations in Banff and Yoho National Parks.

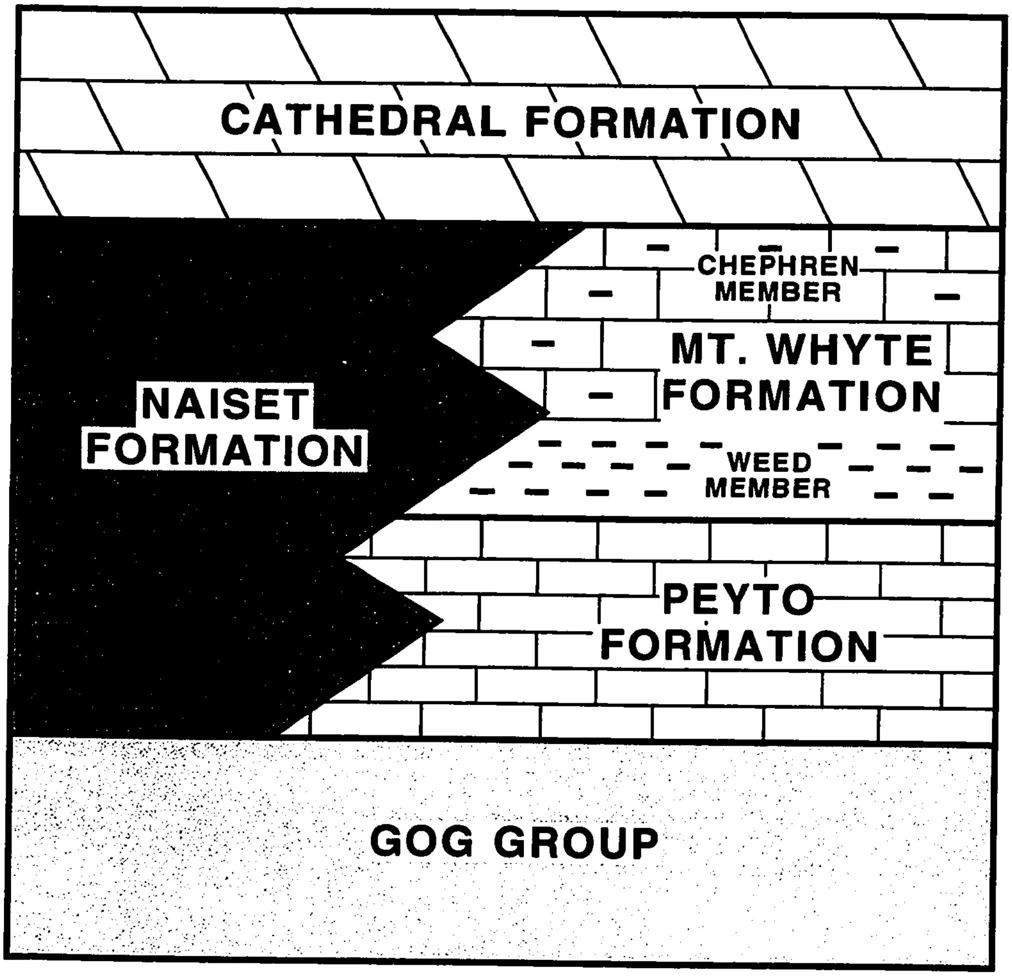
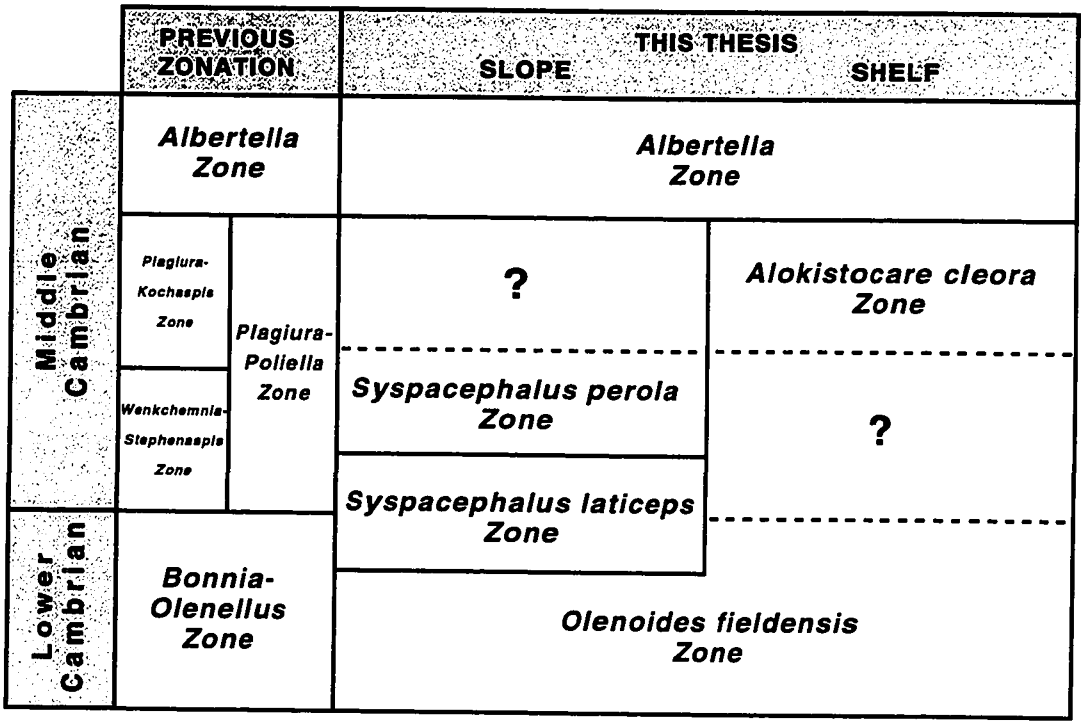

CATHEDRAL FORMATION
CHEPHREN MEMBER
MT. WHYTE FORMATION
NAISET FORMATION
WEED MEMBER
PEYTO FORMATION
GOG GROUP

FIGURE 3. Proposed trilobite zonation for the study interval compared with previous zonation.



<table>
<tr><th></th><th colspan="2">PREVIOUS ZONATION</th><th colspan="2">THIS THESIS</th></tr>
<tr><th></th><th colspan="2"></th><th>SLOPE</th><th>SHELF</th></tr>
<tr><td rowspan="4">Middle Cambrian</td><td colspan="2">Albertella Zone</td><td colspan="2">Albertella Zone</td></tr>
<tr><td>Plagiura-Kochaspis Zone</td><td rowspan="3">Plagiura-Poliella Zone</td><td>?</td><td>Alokistocare cleora Zone</td></tr>
<tr><td rowspan="2">Wenkchemnia-Stephenaspis Zone</td><td>Syspacephalus perola Zone</td><td rowspan="2">?</td></tr>
<tr><td>Syspacephalus laticeps Zone</td></tr>
<tr><td>Lower Cambrian</td><td colspan="2">Bonnia-Olenellus Zone</td><td colspan="2">Olenoides fieldensis Zone</td></tr>
</table>

CHAPTER 2

STRATIGRAPHY AND BASIN HISTORY

INTRODUCTION

This chapter examines the large-scale spatial and temporal setting of the strata in the study interval. The correlation of the Peyto, Mt. Whyte and Naiset formations with other formations of the early Paleozoic western passive margin is outlined, followed by a discussion of the plate tectonic setting in which they were deposited.

REGIONAL STRATIGRAPHY

In the eastern Main Ranges of the southern Canadian Rocky Mountains, Alberta and British Columbia, the Peyto Formation (Aitken, in press) comprises mainly carbonate sediments of latest Early Cambrian age, and is overlain, conformably in the study area, by the lowest Middle Cambrian Mt. Whyte (Walcott, 1908) and Naiset (Deiss, 1940) formations (Figure 2). The Peyto overlies Lower Cambrian Gog Group sandstones, and the Mt. Whyte and Naiset formations are succeeded by the Middle Cambrian Cathedral Formation. The Mt. Whyte/Naiset-Cathedral contact has traditionally been placed at the first occurrence of massive Cathedral dolostone without siltstone interbeds (Aitken, in press).

Near its type section at Mount Jimmy Simpson (Figure 1), the Peyto Formation comprises about 46 m of thick, cross-bedded, oolitic grainstone, and sandy, bioclastic grainstone, with an eleven-metre interval dominated by green-gray quartz shale near the base of the section. The principal reference section, located 10 km to the north at Mount Weed, exposes about 34.6 m of strata similar to that of the type section, but lacks thick units of oolitic grainstone. The Peyto contains trilobites that are characteristic of the Olenoides fieldensis Zone (Figure 3).

In the vicinity of Mount Robson, the Hota Formation comprises limestones that are coeval with the Peyto (Fritz and Mountjoy, 1975). Northward, in the Mackenzie Mountains, the upper portions of the Sekwi and Illtyd formations (Fritz 1972 and 1991 respectively) are coeval with the Peyto. Farther west and to the south, in the Columbia Basin, uppermost Lower Cambrian strata of the Donald Formation consist of fine-grained siliciclastics (Fritz et al. 1991). Eastward, the Peyto interfingers with sandstones of the Gog Group (Aitken 1989b).

The stratotype of the Mt. Whyte Formation is located at Popes Peak (Rasetti, 1951), near Lake Louise (Figure 1). Here, the basal portion of the 58.8 m section consists of grey-green shale, minor calcareous sandstone, and gray nodular limestone. The shale unit lacks trace fossils or bioturbation, and contains complete trilobites characteristic of the Naiset Formation on Mount Stephen. It is interpreted as a tongue of Naiset Formation. This is followed by thick units of thinly interbedded limestone and siltstone, and the upper portion of the Mt. Whyte Formation at Pope's Peak is characterized by gray, micritic, bio-oolitic and oncolitic limestone. Thrombolites occur rarely near the top of the formation. A thicker (126.6 m) reference section (see Hockley, 1973; Aitken, in press) is exposed at Mount Weed (Figure 1). The diverse trilobite fauna of the Mt. Whyte Formation has, in the past, characterized the earliest Middle Cambrian Plagiura-Poliella Zone (Figure 3), although Olenellus, an uppermost Lower Cambrian trilobite, occurs in coquinas previously assigned to the lowest beds of the formation. Other common fossils include hyolithids, the mollusc Scenella, and inarticulate brachiopods. In places, the siltstone unit contains abundant trace fossils.

The Mt. Whyte Formation grades northwestward along strike, into the correlative Snake Indian Formation (Mountjoy and Aitken, 1978). Basinward of the shelf edge, the Naiset Formation is the deeper-water (outer shelf to slope) equivalent of the Mt. Whyte (Aitken, 1989b). The location of the Mt. Whyte's eastward depositional pinch-out is unknown (Aitken, 1989b).

The stratotype of the Naiset Formation is located at Naiset Point, near Mount Assiniboine (Deiss, 1940) (Figure 1). The formation consists mainly of dark gray to green-gray shale and mudstone, with minor siltstone, sandstone and limestone, attaining a thickness of 143.9 m at the stratotype (Aitken, in press). Naiset trilobites appear to be virtually restricted to outer shelf or upper slope biofacies, and most species do not occur in the coeval Mt. Whyte Formation. For example, Ogygopsis klotzi is widely distributed in North America. It occurs in black lime mudstone and shale of the Naiset on Mount Stephen, but nowhere in the Mt. Whyte Formation. Ogygopsis klotzi is associated with deep-shelf lithofacies and biofacies of the Middle Cambrian Carrara Formation in Nevada and California (Palmer and Halley, 1979), and its occurrence in the Naiset records a similar deep-shelf to upper slope biofacies. The lowest portion of the Naiset is Early Cambrian in age, as shown by the occurrence of Olenellus at Mount Jimmy Simpson and Mount Stephen. Above this, the Naiset contains trilobites of early Middle Cambrian age.

The Cathedral Formation (Walcott, 1908; Rasetti, 1951) comprises mainly massive, cliff-forming, dolostone or dolomite-mottled limestone. The formation contains trilobites of the Albertella and Glossopleura zones (Figure 3).

LOWER - MIDDLE CAMBRIAN PASSIVE MARGIN SEDIMENTATION

Strata of the Peyto, Mt. Whyte, and Naiset formations were deposited on the proto-Pacific passive continental margin of North America. Passive margin sedimentation continued in the study area through the Lower Paleozoic until as late as the Middle or Late Devonian, when the tectonic regime changed to that of a convergent plate boundary (Monger and Price, 1979; Oldow et al., 1989). The timing of initial continental rifting, the subsequent onset of rapid thermal subsidence and passive margin sedimentation, and the relationship between these events and an overall trend towards rising sea level in the Cambrian are relevant to interpretations of sedimentary cycles and discussions of sequence stratigraphy in the study interval.

In the past, a number of authors suggested that stratigraphic sequences of Middle Proterozoic age in the Cordillera (Belt/Purcell Supergroup and equivalents) may be related to a passive margin at this time (Price, 1964; Monger et al., 1972; Burke and Dewey, 1973;

Dickinson, 1977; McMechan, 1981). However, more recent opinion is that at least some of these packages were deposited in intracratonic basins (Stewart, 1972, 1976; Winston, 1986; Struik, 1987), or a back-arc basin (Hoffman, 1989).

Evidence supporting a latest Proterozoic (Bowring et al. 1993) age for rifting was provided by Bond and Kominz (1984) and Armin and Mayer (1983), working in the Canadian and American Rocky Mountains respectively. Comparing the one-dimensional stretching model of McKenzie (1978) with tectonic subsidence curves calculated to remove subsidence due to sediment loading, compaction, and water depth changes, Bond and Kominz (1984) used data from eleven Lower Paleozoic stratigraphic sections in British Columbia and Alberta to estimate the time when thermal subsidence began. By tracing each of these subsidence curves back to zero water depth, they arrived at a 555-600 Ma age for the initiation of thermal contraction. Applying similar techniques to four stratigraphic sections from the southern Rocky Mountains in Utah, Nevada, and California, Armin and Mayer (1983) predicted a 590 Ma age for the beginning of thermal contraction. Work in the Cordillera was augmented with tectonic subsidence analyses of miogeoclines in eastern North America, northwestern Argentina, the Middle East and northwestern Australia, which imply the breakup of a supercontinent between 625 and 555 Ma (Bond et al., 1984). Thus, it is now generally accepted that the continental rifting event which directly preceded passive margin sedimentation in the study area occurred in the Late Proterozoic.

The generalized stratal sequence for the westward thickening Cambrian miogeoclinal wedge throughout the Cordillera comprises essentially two parts: a Lower Cambrian siliciclastic sequence, which consists of the Gog Group in the study area, and a mainly carbonate, Middle to Upper Cambrian sequence, the lower part of which includes the Peyto, Mt. Whyte, and Naiset formations. The siliciclastic sequence rests, unconformably in places, on Upper and Middle Proterozoic rocks. The Gog consists mainly of quartz sandstone and siltstone with minor conglomerate, shale, and limestone (Aitken, 1989a; Stewart and Suczec, 1987). Thin mafic lava flows occur locally in Nevada and Utah (Stewart and Suczec, 1977) and in southeastern British Columbia (Devlin and Bond, 1988). In the northern Rocky Mountains of Canada, there is evidence for Lower Cambrian syndepositional block faulting (Aitken, 1989a). In the southern Rocky Mountains north of Jasper Park, the Lower Cambrian interval represents deposition in shallow marine, and non-marine environments (Young, 1979), while south towards Lake Louise and in the United States, mainly shallow marine sedimentation occurred (Aitken, 1989a; Hein, 1987; Stewart and Suczec, 1987).

The thick, shallow-water deposits of the Lower Cambrian sequence have been interpreted as the transition between rifting and drifting phases of the proto-Pacific passive margin. Stewart and Suczec (1977) related the terrigenous detrital sequence (including Upper Proterozoic strata) to erosion of an initial rift bulge created by thermal expansion at the time of continental rifting about 650 Ma. This theory is supported by the work of Devlin and Bond (1988) on the uppermost Proterozoic to Lower Cambrian Hamill Group in southeastern British Columbia, which suggests that this interval represents the rift-drift transition of the passive margin. Here, a number of lines of evidence including the occurrence of thick sequences of mafic metavolcanics, rapid vertical facies changes, unconformities that underlie both the lower and upper Hamill Group in places, and the coarse grain size and feldspar content of lower Hamill Group sediments suggest that extensional tectonism and widespread uplift took place around earliest Cambrian time (Devlin and Bond, 1988).

In the study area, detailed sedimentological analysis of the Upper Proterozoic Miette Group (Arnott and Hein, 1986) and the Lower Cambrian Gog Group (Hein, 1987), led to the interpretation that the Miette Group consists of deep-water syn-rift deposits, which are unconformably overlain by shallow marine clastic drift deposits of the Gog Group (Arnott and Hein, 1986).

Thus, the studied interval, including the Gog Group, represents deposition on a young passive margin. Thermal subsidence on the relatively young passive margin would have been very rapid (Bond and Kominz, 1984), accounting for the tremendous thickness of shallow-water siliciclastic deposits of the Gog Group. Later in this chapter, potential depositional models presented in a sequence stratigraphy framework will rely upon this point as a key premise.

CHAPTER 3

SEDIMENTARY ENVIRONMENTS

INTRODUCTION

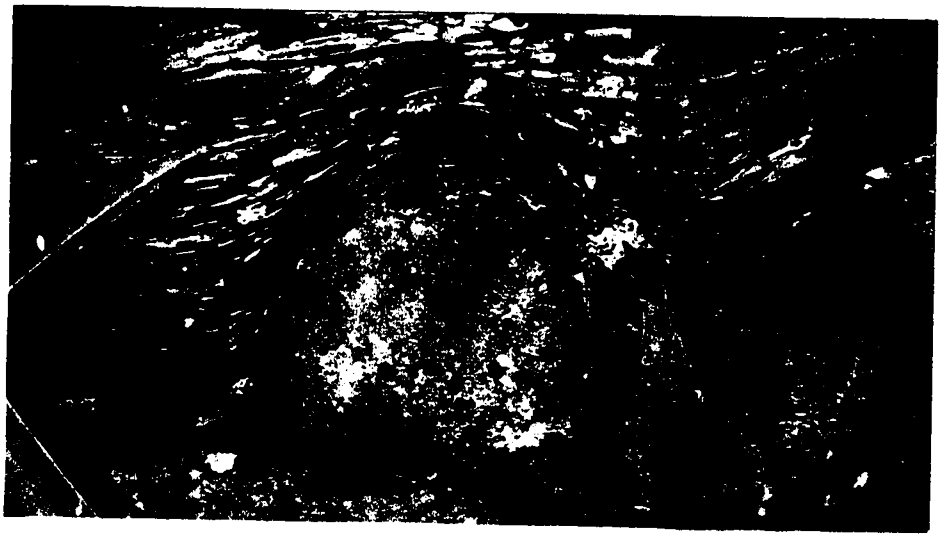
Chapter three begins with the description and interpretation of individual lithofacies and lithofacies associations of the Peyto, Mt. Whyte and Naiset formations. This is done in order to provide a framework in which the distribution of trilobite biofacies can be discussed in Chapter 4, and to support an hypothesis of depositional history. Next, a critical evaluation of the sedimentary record across the Lower-Middle Cambrian boundary in the study area, which has been interpreted widely as a regional unconformity (Rasetti, 1951; Aitken, 1989a, 1989b, in press; Fritz et al., 1991), is presented, followed by an examination of the grand cycles and the sequence stratigraphy of the study interval. Concluding this chapter is an hypothesis for the depositional history of the Peyto, Mt. Whyte and Naiset formations, and a correlation of measured sections (Figure 32).

The Peyto, Mt. Whyte, and Naiset formations have been subdivided into fifteen primary lithofacies. The observed occurrence of combinations of these lithofacies in different sections has resulted in the recognition of six lithofacies associations. Each of these associations is directly related to a specific depositional environment within the broad setting of the passive continental margin.

FIGURE 4. Lithofacies A: Thrombolitic/stromatolitic algal boundstone. a) Note overlying silty limestone or siltstone in this and subsequent examples, 0.5 m scale, Mt. Whyte Formation, Mount Jimmy Simpson, 138 m. b) Mt. Whyte Formation, Mount Weed, 112 m. c) Mt. Whyte Formation, Park Boundary, 88 m. d) Approximately 3 m thick interval of thrombolites, Mt. Whyte Formation, Mount Weed, 95 m. e) Mt. Whyte Formation, Mount Jimmy Simpson, 188 m.

A

B



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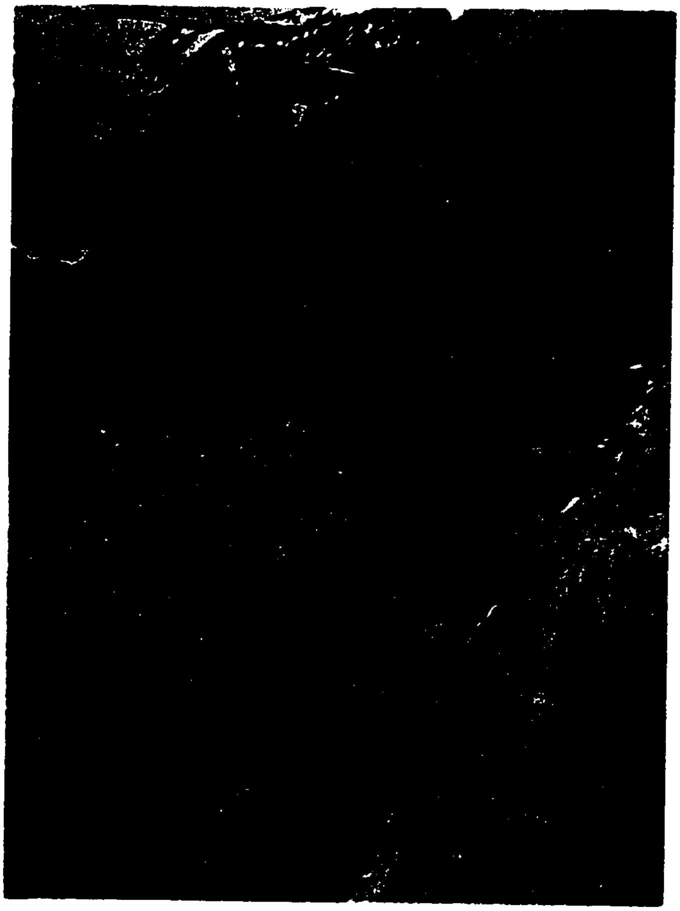

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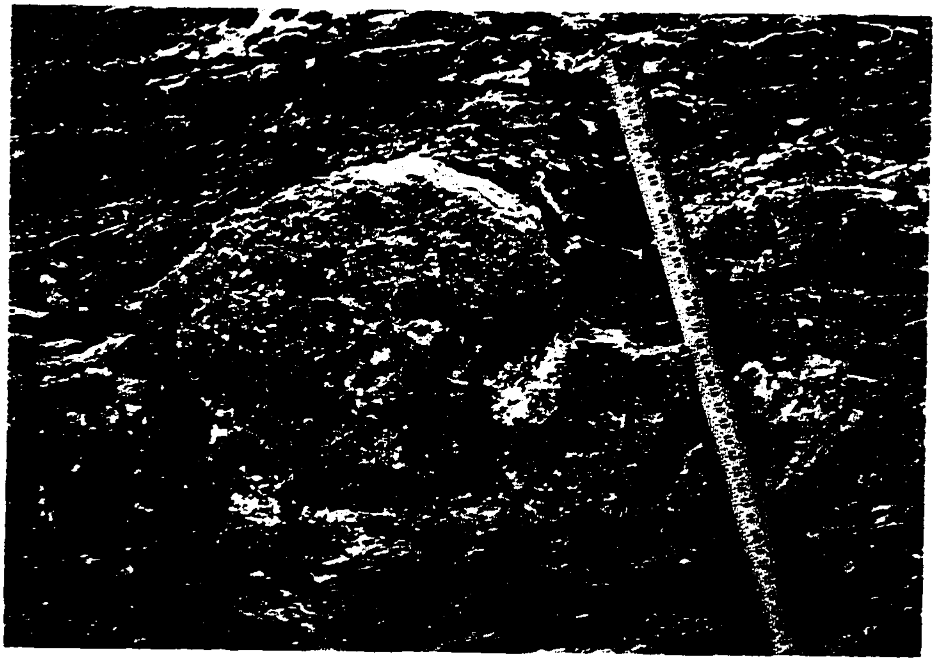
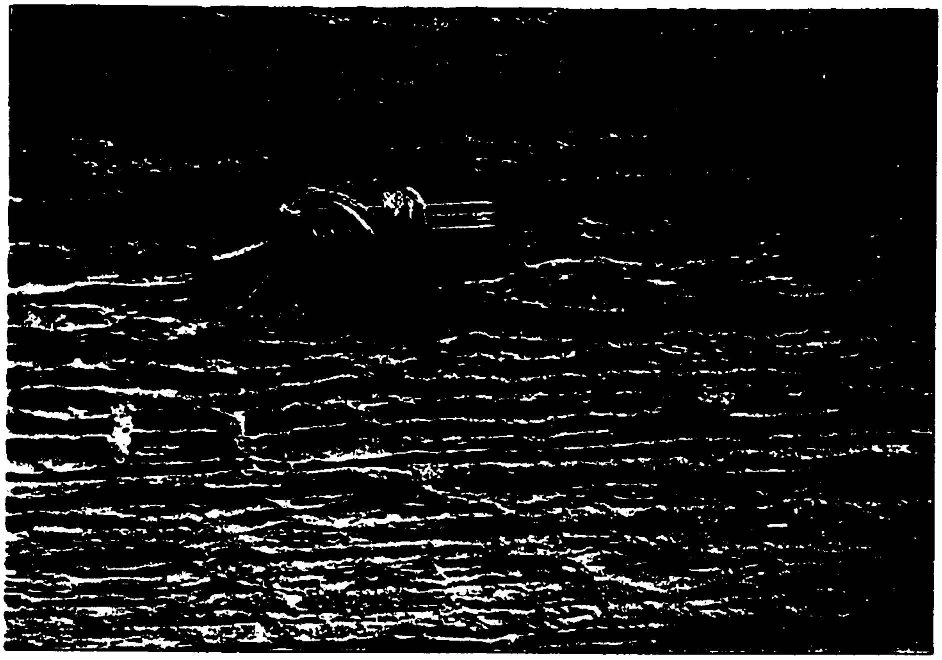


FIGURE 5. Lithofacies B: Interbedded bioturbated quartz siltstone and wackestone-mudstone. a) & b) Note prominent weathering siltstone, and vertical burrow tubes, Mt. Whyte Formation, Pope's Peak, 30-36 m.



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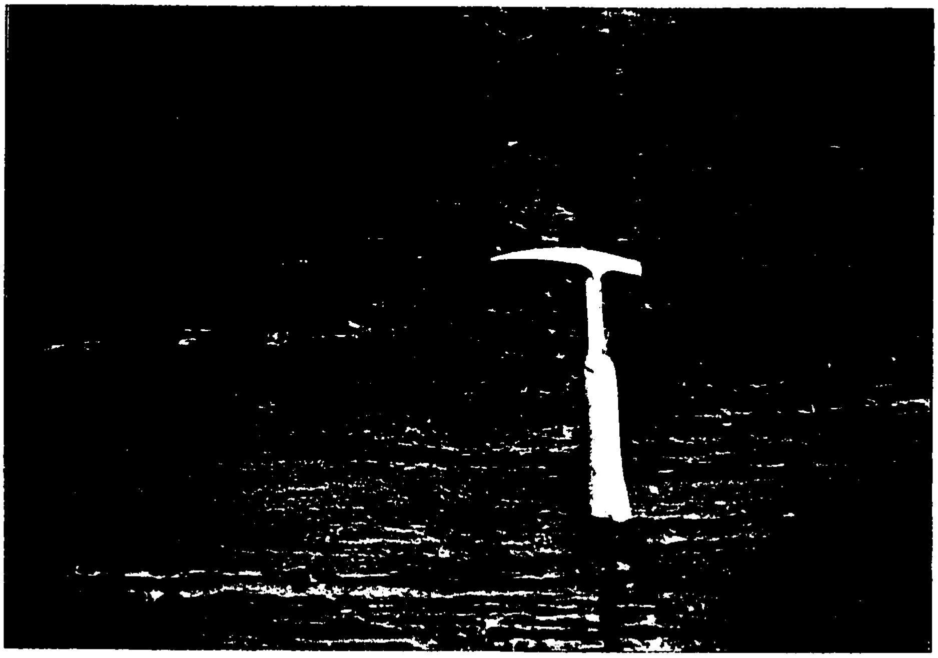
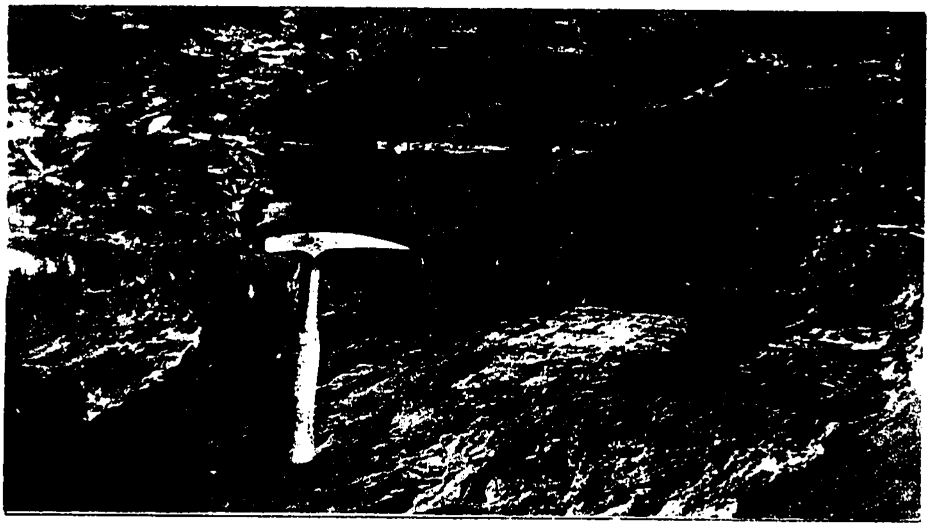


B

FIGURE 6. Lithofacies C: Bio-oolitic, wackestone/packstone. a) Note rusty-coloured silty partings, Mt. Whyte Formation, Mount Field, 95 m. b) Note wave ripple crests striking nearly E - W, Mt. Whyte Formation, Park Boundary, 73 m. c) Note bioclastic interbed with waveform top within thick interval of Lithofacies B, Mt. Whyte Formation, Mount Weed, 115 m.

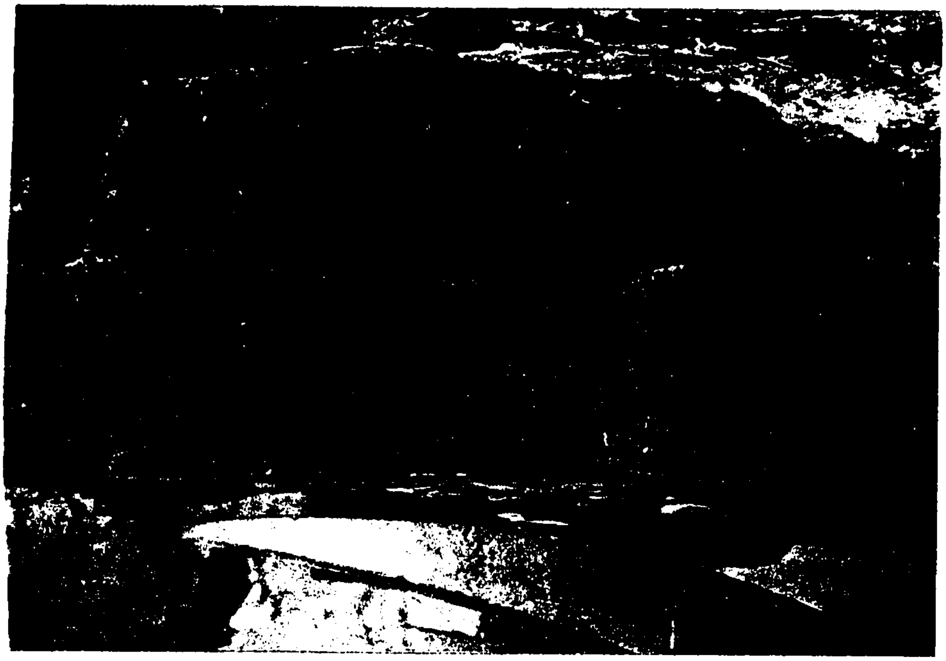
A

B



C

FIGURE 7. Lithofacies D: Oolitic grainstone. a) Thin oolitic grainstone bed resting on scoured surface of thinly laminated wackestone, Mt. Whyte Formation, Mount Weed, 108 m. b) & c) Thick, cross-bedded oolitic grainstone, Peyto Formation, Mount Jimmy Simpson, 16, 18 m. d) Thin, cross-bedded, oolitic grainstone, Peyto Formation, Mount Weed, 25 m. e) Mud-draped, rippled bedform in oolitic grainstone, Peyto Formation, Mount Weed, 22 m.



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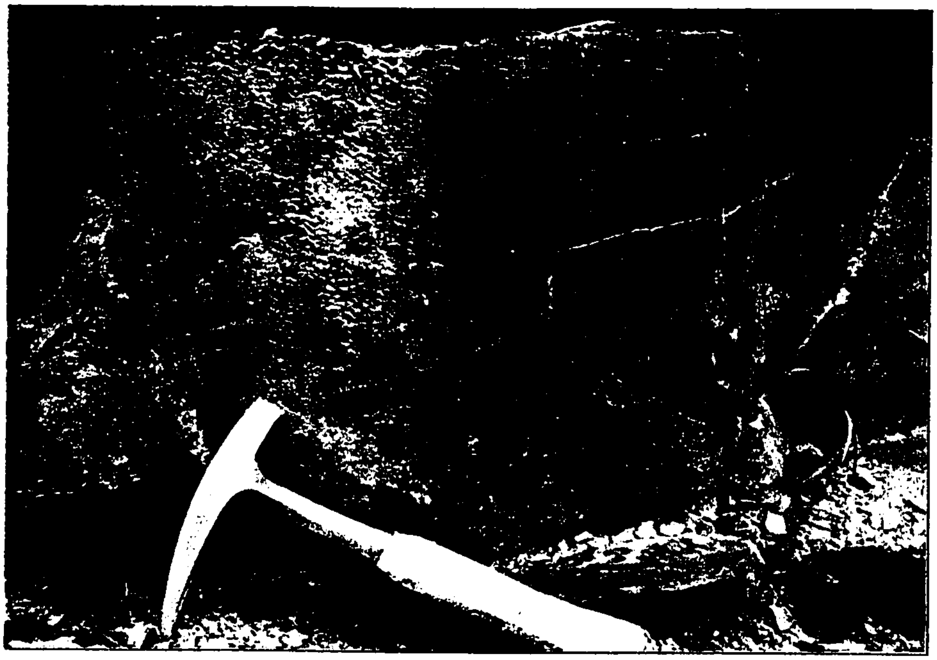

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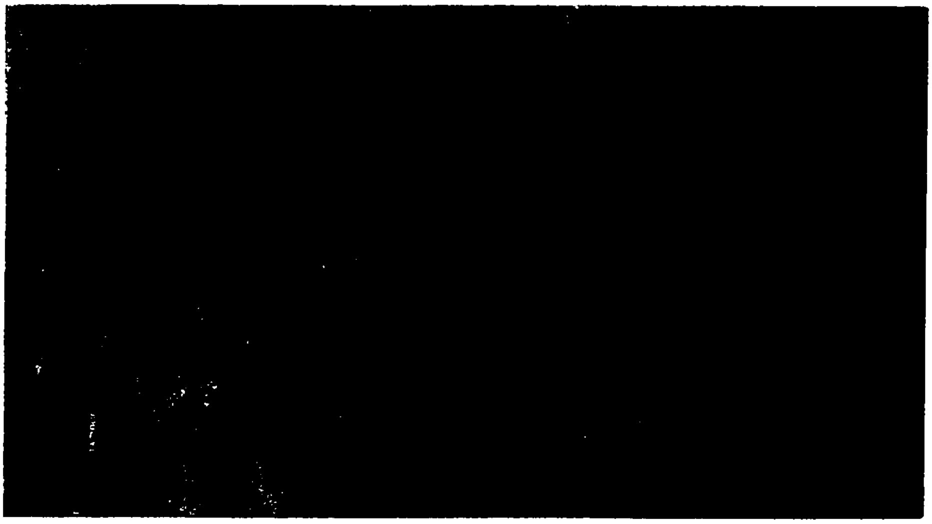

C

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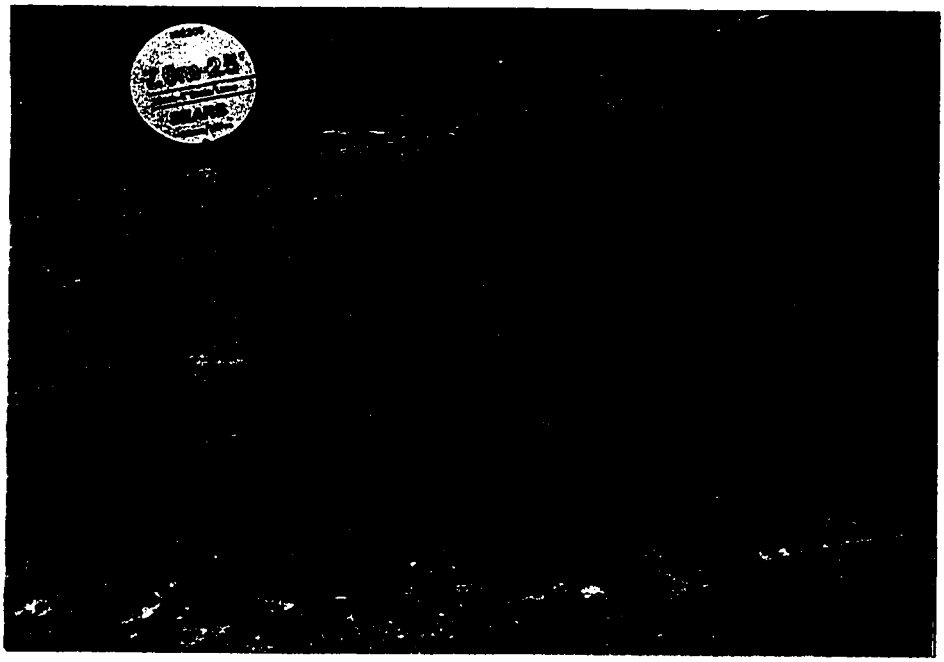
E

FIGURE 8. Lithofacies E: Bioclastic grainstone. Thin, cross-bedded bioclastic grainstone, Peyto Formation, Mount Jimmy Simpson, 43 m.



A

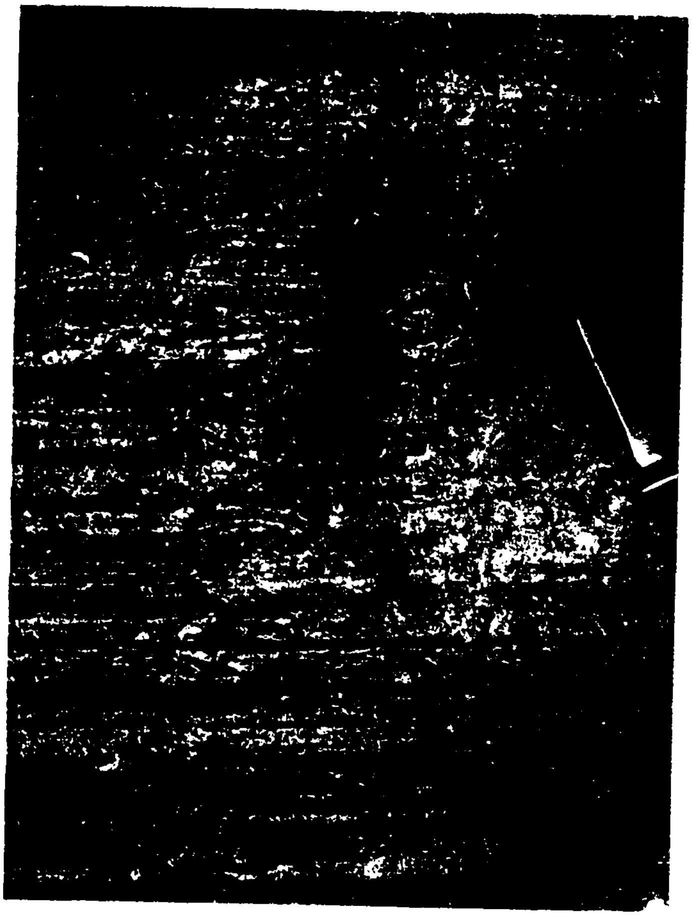
FIGURE 9. Lithofacies F: Oncolitic rudstone. a) 2-cm. diameter, spherical oncoids in sandy dolostone, Peyto Formation, Pope's Peak, 3m. b) Compressed, black oncoids in micritic limestone, Mt. Whyte Formation, Mount Weed, 152 m. c) Thin interbed of oncolitic-oolitic rudstone with gutter-cast at base, under- and overlying siltstone, Mt. Whyte Formation, Monarch Creek, 60 m.

A

B

C

FIGURE 10. Lithofacies G: Laminated, poorly fissile, grey, siltstone. a) Thin lamination and colour banding in this facies, Naiset Formation, Mount Field, 56 m. b) Pebble-size, fine sandstone clast, Naiset Formation, Mount Field, 35 m. c) Slump in this facies, Naiset Formation, North Gully, 8 m. d) Slump in float block, Mount Field. e) Intraformational truncation surface, assistant has hand at base, Waterfall site, Mount Stephen.



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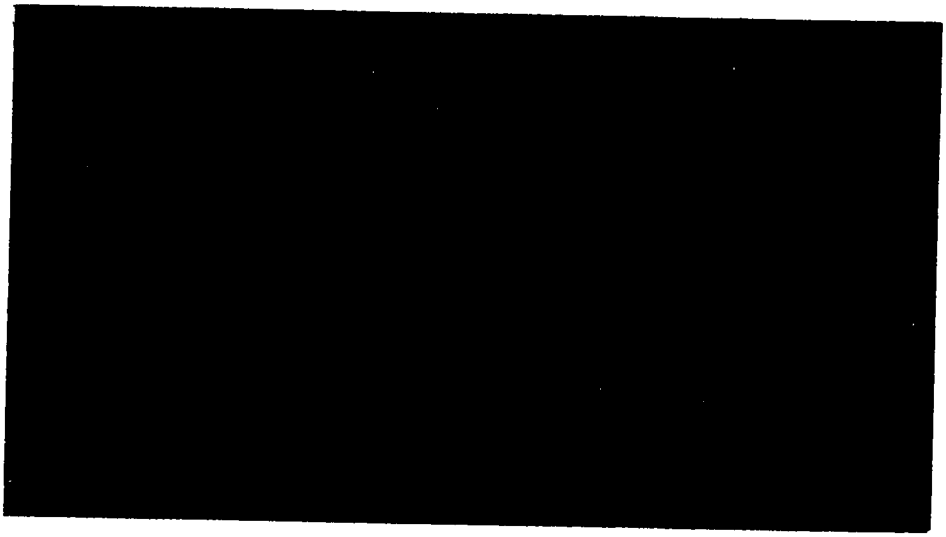
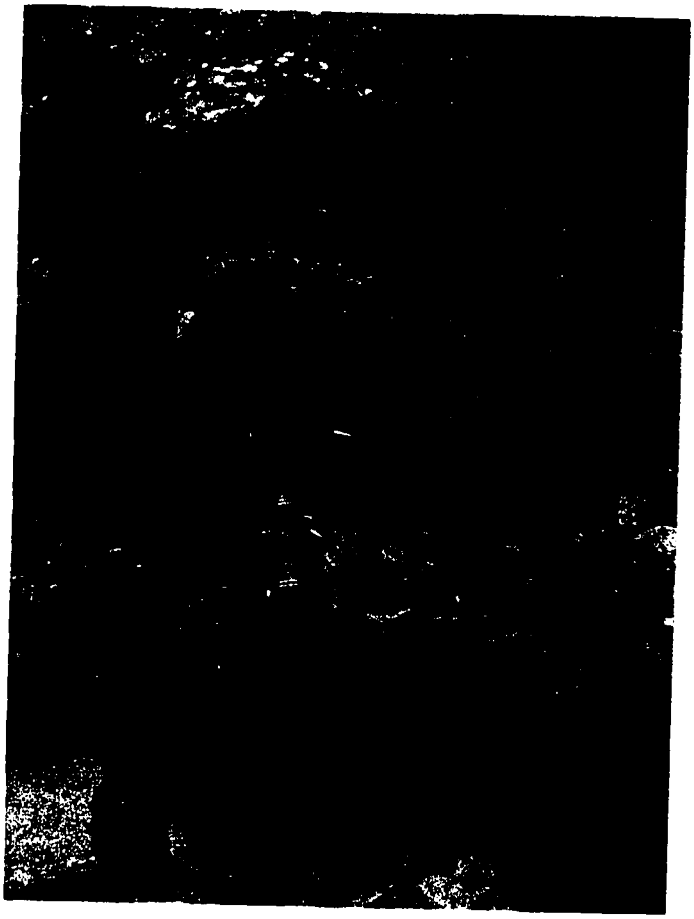


D

E

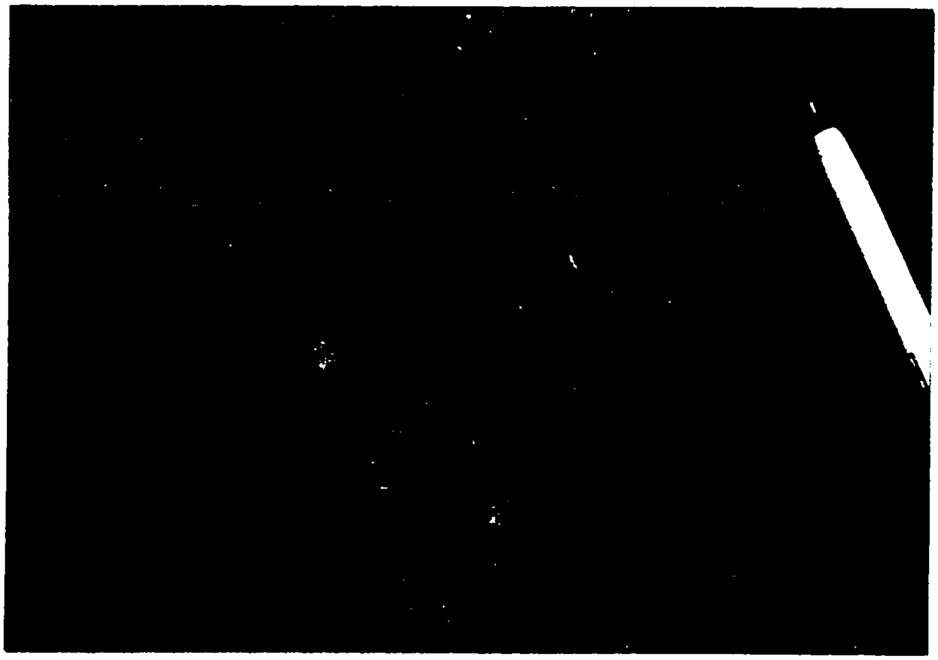
FIGURE 11. Lithofacies H: Matrix-supported boulder conglomerate. a) View showing inverse grading of boulders from decimetre-size clasts below hammer to 1 m diameter clast at top of photo, Waterfall site, Mount Stephen. b) Wide-angle view of north end of deposit showing channel-like form; assistant is standing on base of deposit.



A

B

FIGURE 12. Lithofacies I: Bioturbated, green-grey, quartz siltstone/fine sandstone. a) Close-up showing bedding interrupted by bioturbation, and current ripples, Mt. Whyte Formation, Mount Field, 88 m. b) Float block with view of bedding surface showing wave ripples crossed by burrow traces, Mt. Whyte Formation, Mount Niblock, 35-60 m.



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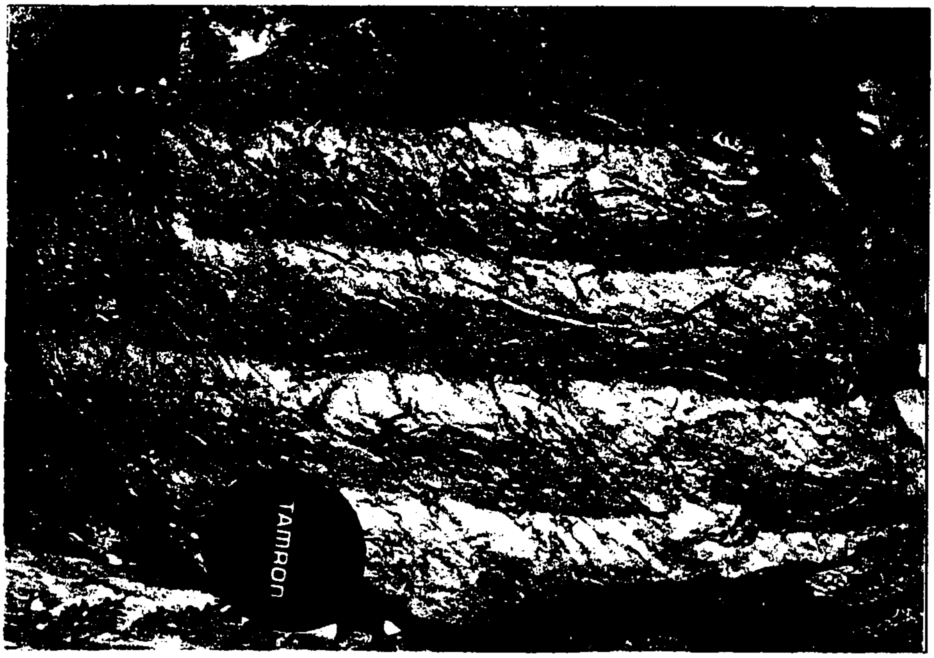
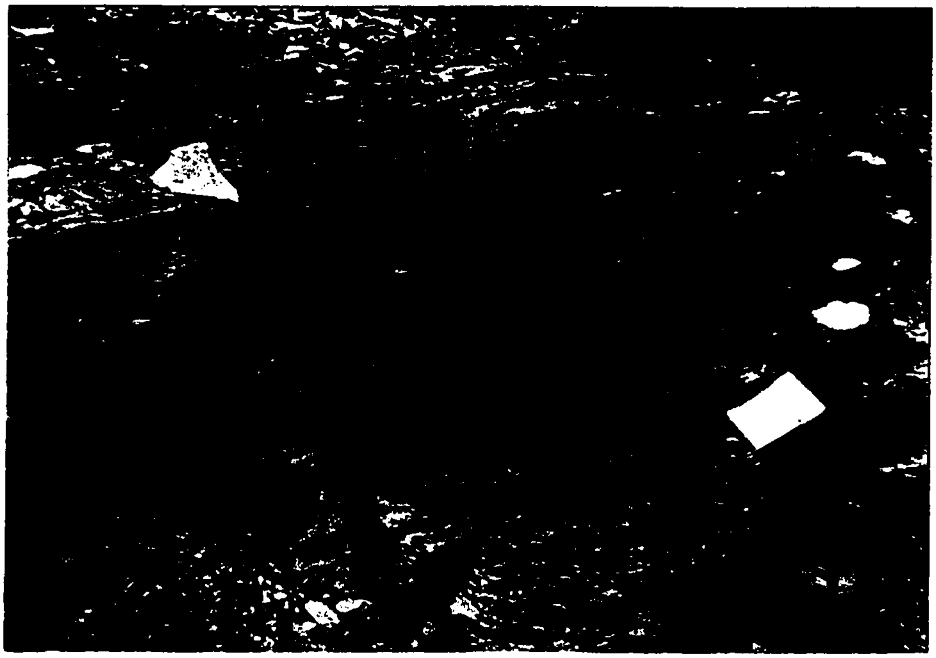


B

FIGURE 13. Lithofacies J: Silty, dolomitic, "parted limestone". Typical example of this lithofacies showing buff-coloured silty dolostone and grey packstone, Mt. Whyte Formation, Mount Weed, 107 m.

A

FIGURE 14. Lithofacies K: Thinly laminated, green-grey, shale. a) Typical exposure of this lithofacies, yellow notebook for scale, Naiset Formation, Mount Niblock, 26 m. b) Close-up showing small-scale intraformational truncation surface, Naiset Formation, Naiset Point, 17 m.



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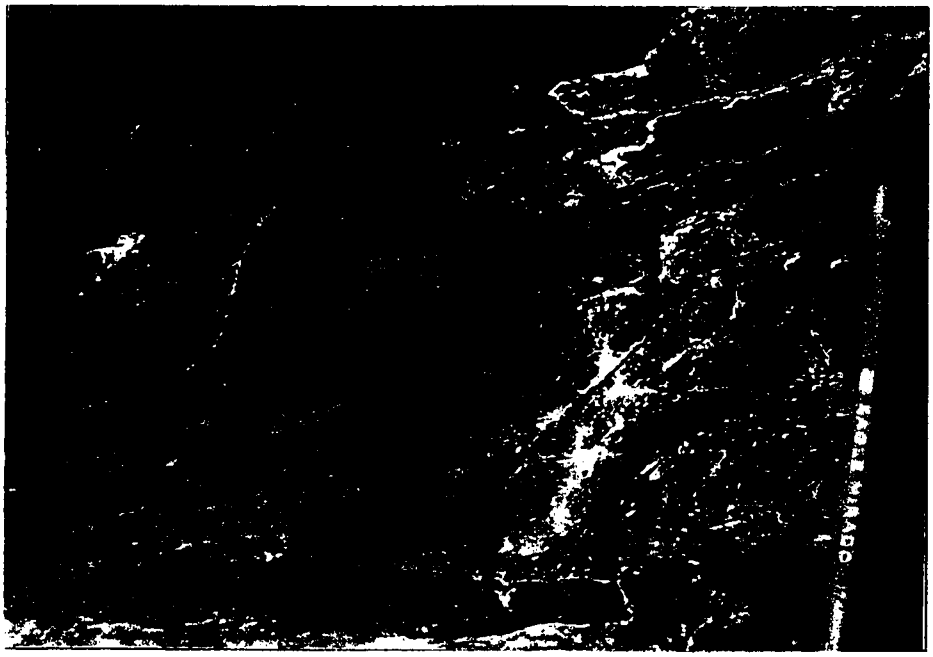

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FIGURE 15. Lithofacies L: Black shale. Exposure of this lithofacies showing prominent cleavage, Naiset Formation, Mount Field, 1 m.

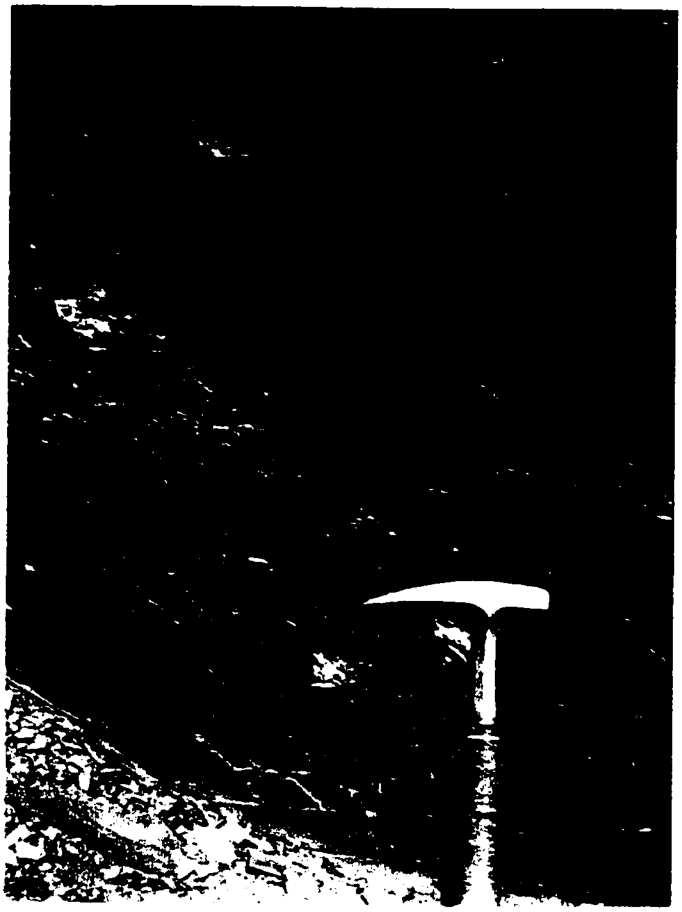
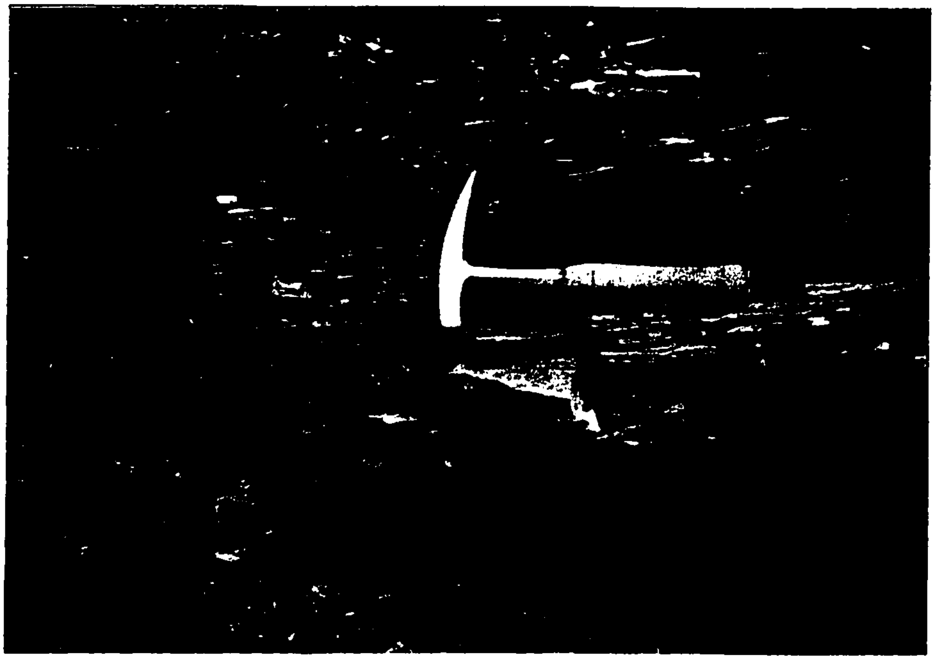

A

FIGURE 16. Lithofacies M: Thinly laminated, black, lime mudstone. a) Typical exposure showing flat bedding surfaces, Naiset Formation, North Gully, 55 m. b) Wavy bedding, Mt. Whyte Formation, Mount Field, 125 m.



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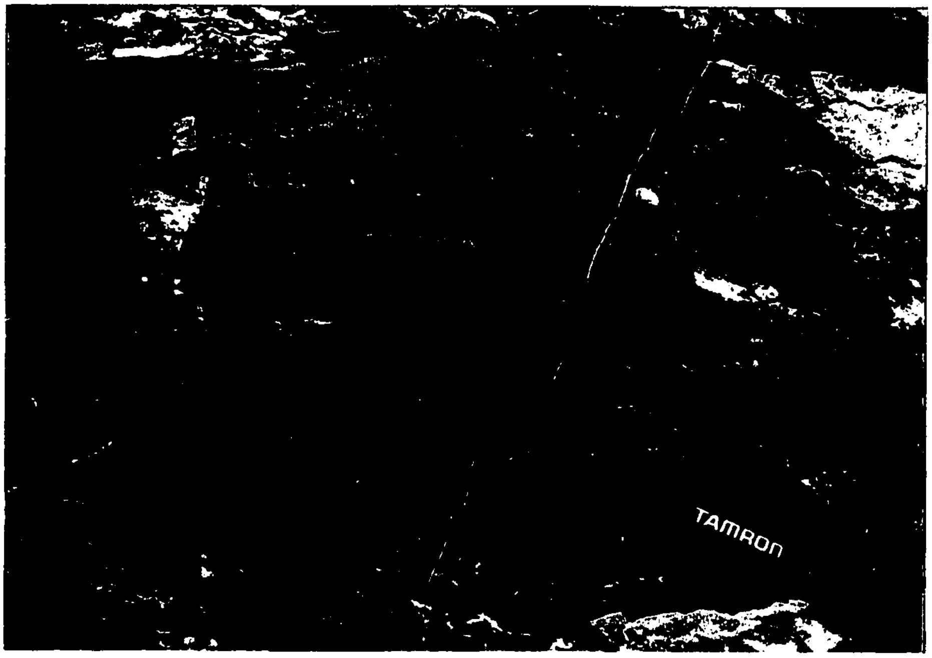
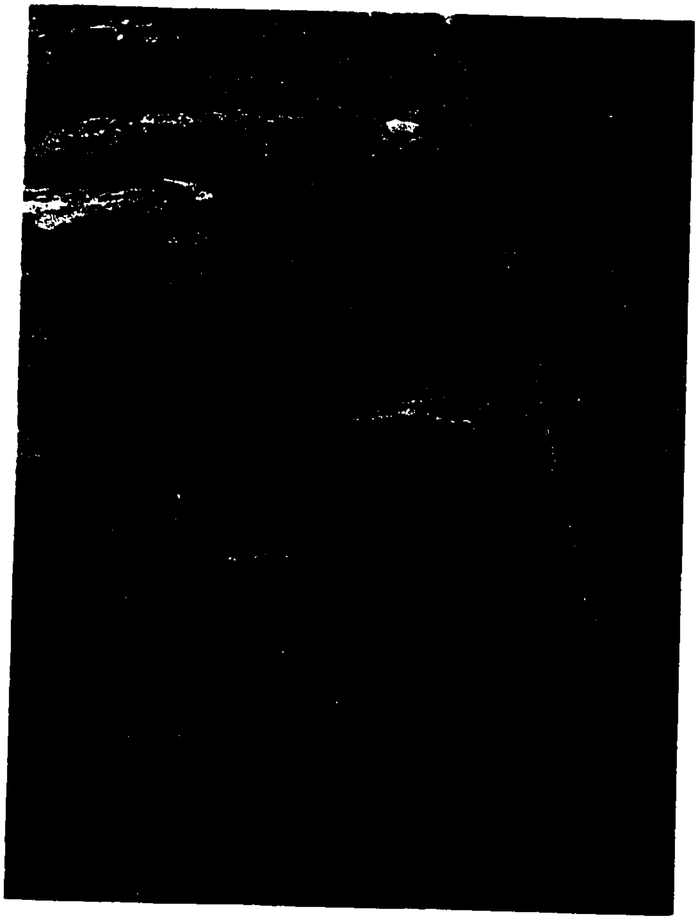


B

FIGURE 17. Lithofacies N: Thin-bedded to massive dolostone. a) Massive to thick-bedded dolostone, Cathedral Formation, Mount Jimmy Simpson, 200 m. b) Thin bedded, oolitic dolostone, yellow hat for scale, Cathedral Formation, Monarch Creek, 90 m.



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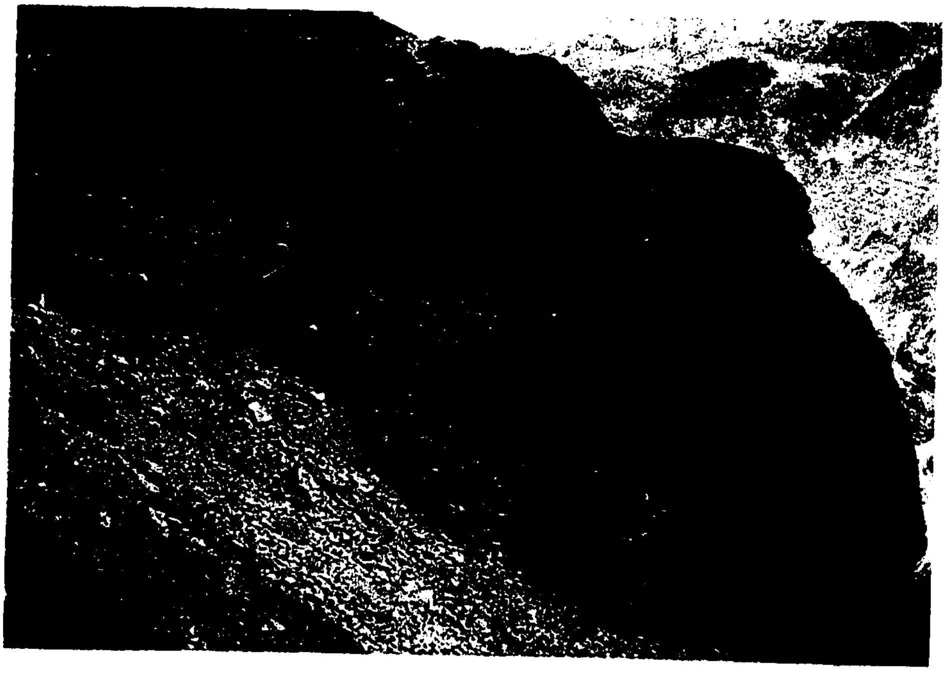


B

FIGURE 18. Lithofacies O: Quartz sandstone. a) Cross-bedded, coarse quartz sandstone, Peyto Formation, Mount Niblock, 7 m. b) Bi-modal cross-bedding in coarse quartz sandstone, Gog Group, Pope's Peak.

A

B

MAJOR LITHOFACIES

Lithofacies A: Thrombolitic/stromatolitic algal boundstone

Thrombolites (Aitken 1967; Kennard and James 1986), ranging in size from 10 cm-scale domes to metre-scale irregular masses (Figure 4), occur in the Mt. Whyte Formation at Popes Peak, Mount Jimmy Simpson, Mount Weed and Park Boundary, and in the Peyto Formation at Park Boundary. They consist of light-medium grey lime mudstone which exhibits a clotted texture, and lacks obvious laminations. At Mount Weed and Mount Jimmy Simpson, where thrombolites are most common, some domes have irregular, millimetre-scale laminations, and are thus considered to be stromatolites.

Thrombolites and stromatolites in the Peyto and Mt. Whyte formations are commonly associated with oolitic packstone at their bases. This style of growth is similar to that reported for Middle and Upper Cambrian shallow subtidal to intertidal carbonate platform rocks in Alberta by Aitken (1967) and Westrop (1989), and in southwest Virginia by Markello and Read (1981). Sediment fill between algal heads in the Peyto and Mt. Whyte formations ranges from mudstone to oolitic packstone, and in the Mt. Whyte Formation, thrombolites are frequently capped with quartz siltstone (see Figure 4a-e).

In the Peyto and Mt. Whyte formations, thrombolites or stromatolites are interpreted to have grown in shallow, subtidal environments. The lack of any evidence for subaerial exposure (such as desiccation polygons or fenestral fabric) associated with the buildups argues against intertidal conditions. No thrombolites or stromatolites were observed at Mount Stephen, Mount Field, or Naiset Point where siliciclastic slope facies (Lithofacies G, K, L, and H) pass upward into shelf carbonate facies (Lithofacies C). Therefore thrombolites and stromatolites in the Peyto and Mt. Whyte formations are interpreted to have been formed in a middle to inner shelf location. A similar depositional site for thrombolites in southwest Virginia was proposed by Markello and Read (1981).

Lithofacies B: Interbedded bioturbated quartz siltstone and wackestone-mudstone

This buff-weathering facies consists of medium grey, bioclastic wackestone-mudstone in 1-3 cm thick beds, with up to 3 cm thick interbeds of micaceous grey-green quartz siltstone (Figure 5). This alternation results in a differential weathering pattern in some places. The siltstone is commonly extensively bioturbated, especially on bedding surfaces, but also vertically (see Figure 5a). Wave-ripple marks are also common. In places, bedding is indistinct and the limestone has a nodular appearance. This may be due to homogenization of the quartz silt and carbonate through bioturbation, or it may be due to differential compaction and solution. In this process, the silt compacts readily, but the lithified carbonate resists compaction, and layers are further disrupted by disolution (Wilson and Jordan 1983). Most of the trilobite fragments in the carbonate are too small to identify, although Rasetti (1951) recognized fragments of Alokistocare from this facies at Pope's Peak. This lithofacies occurs in units one to over ten metres thick in the Mt. Whyte Formation at Pope's Peak, Mount Niblock, Mount

Weed, Park Boundary and at the Monarch Creek section on Mount Stephen.

This facies is associated with a transition from sandy, coarse, bioclastic grainstone (Lithofacies E) to overlying green-grey quartz shale (Lithofacies K) at Pope's Peak and Mount Niblock. At Pope's Peak, green quartz shale overlying Lithofacies B yields complete trilobite exoskeletons indicating relatively deep subtidal deposition compared to the underlying bioclastic grainstone which contains only abundant fragments of trilobites. "Parted limestone" or "ribbon rock" like that of Lithofacies B has been associated with shallow subtidal, shelf depositional environments (Cook and Taylor 1977; Aitken 1978; Wilson and Jordan 1983; Westrop 1989; Cowan and James 1993). This interpretation is followed here, although, at Monarch Creek, its proximity to slope facies (Lithofacies G and H) on Mount Stephen indicates an outer shelf setting for this location.

Lithofacies C: Bio-oolitic wackestone/packstone

Lithofacies C (Figure 6) occurs at all sections of the Peyto, Naiset, and upper Mt. Whyte formations, with bedding thickness ranging from two to tens of centimetres. Colours range from light to medium grey in the Peyto and Mt. Whyte, to black in the Naiset. Bioclasts include trilobites, hyolithids, and brachiopods.

In the Peyto and Mt. Whyte formations, this facies is dominated by thin to medium beds in thick units of light to medium grey wackestone/packstone in which ooids are common constituents. Cross-bedding (Figure 6a), megaripples (Figures 6b, 6c), and vertical burrows are common in packstone. Bioclasts are abraded, and trilobites are disarticulated. In these settings, this lithofacies is interpreted as having been deposited in shallow subtidal environments above storm wave base, in close proximity to oolitic sand shoals. The mud and bioclast content, bioturbation and wide distribution are features this lithofacies in the Peyto and Mt. Whyte formations shares with modern platform interior sand blankets in the Bahamas (Ball 1967). In the Bahamas, these extensive sand blankets are located between shelf-edge oolitic sand bodies and nearshore environments. Such a setting is reasonable for most of the Peyto and Mt. Whyte bio-oolitic wackestone/packstones. Palmer and Halley (1979) made a similar interpretation for oolitic lithofacies of the Carrara Formation in the southern Great Basin.

In the Naiset Formation, Lithofacies C occurs in two forms: (1) Thinly laminated, black bio-wackestones, completely devoid of ooids and bioturbation, and, in some places, containing complete trilobite exoskeletons, are interbedded with similar lime mudstones in thick units. These are interpreted as autochthonous, deep subtidal, slope deposits. (2) At other locations in the Naiset, thin to thick, and, in places, irregular beds of medium to dark grey, bioclastic and/or oolitic packstones occur as isolated beds within thick units of quartz siltstone or shale (Lithofacies G, K) (Figures 6b, 6c). Cross-bedding (Figure 6a) occurs rarely. In every case, these units occur a few metres below a major shallow subtidal (above normal wave base) carbonate unit. The isolated nature of the beds, the occurrence with interbedded shales, and the association with prograding shelf carbonates suggests that these units were deposited below normal wave base and were transported from the edge of nearby prograding carbonate banks during major storms. A similar depositional site was interpreted for ooid packstones in the Nolichucky Formation of southwest Virginia (Markello and Read 1981), and the Bison Creek Formation of southern Alberta (Westrop 1989).

Lithofacies D: Oolitic grainstone

Thin to thick-bedded, light to dark grey, oolitic grainstones (Figure 7) are common in both the Peyto and upper Mt. Whyte formations. In most places, including all occurrences in the Mt. Whyte Formation, this facies occurs as thin to medium beds, often cross-bedded, that are interbedded with Lithofacies C. However, at Mount Jimmy Simpson, a 30 metre thick unit of medium to thick-bedded, commonly planar-tabular cross-bedded, wave rippled, light to medium grey oolitic grainstone occurs at the top of the Peyto Formation (Figure 32). Here, the occurrence of the oolite unit directly above an 11 metre thick interval of thinly laminated, green-grey quartz shale (Lithofacies K) suggests that this oolite was deposited at a site close to the shelf margin. Thick, cross-bedded, oolitic grainstone also occurs as a 10 metre thick unit in the Peyto Formation at Park Boundary, near the base of the section.

These thick oolitic grainstone units at Mount Jimmy Simpson and Park Boundary are interpreted as having been deposited as part of either a tidal-bar belt or sand belt, both at the shelf edge (Ball 1967; Hine 1977; Halley et al. 1983). The thickness, sedimentary structures, and spatial isolation of these units supports this conclusion. Within modern tidal-bar belts, such as that of Schooner

Cay in the Bahamas (Ball 1967), individual sand bars are long and narrow, oriented perpendicular to the shelf margin and separated by tidal channels. By comparison, sand belts such as the oolitic belt at Cat Cay in the Bahamas (Ball 1967), run parallel to the shelf edge. Although exposure of this lithofacies at Mount Jimmy Simpson and Park Boundary is inadequate to discern the geometry of the sand bodies, no evidence for tidal channels (muddy, bioturbated channel bottom sediments cf. Ball 1967) was observed, and bimodal cross-bedding is very uncommon, thus decreasing the likelihood that this facies represents tidal bar belt deposits. Since there is no evidence of subaerial exposure or other evidence for the existence of islands anywhere in the Peyto or Mt. Whyte formations, and bimodal cross-bedding is rare in Lithofacies D, it is unlikely that this lithofacies was deposited in tidal deltas.

In its most common occurrence as thin units, Lithofacies D is interpreted to represent shallow subtidal sand blanket deposition (Ball 1967) similar to that of Lithofacies C in the Peyto and Mt. Whyte formations. This conclusion is supported by the thinness of the oolitic grainstone beds, the association with Lithofacies C, and the wide distribution of this facies throughout the study area. Palmer and Halley (1979) interpreted similar oolitic facies in the Carrara Formation as representing platform-interior blanket sands. Although platform-interior deposition is possible for most occurrences of Lithofacies D in the Peyto and Mt. Whyte formations, at Mount Field and Mount Stephen the close association of this facies with slope sediments suggests outer shelf deposition.

Chow and James (1987) interpreted thin to medium-bedded oolites from the Upper Cambrian of western Newfoundland as representing the subtidal mobile fringe of intertidal oolitic sand shoals. Major oolitic sand shoals have been recognized at only two locations in the study interval (see above). If an interpretation similar to that of Chow and James' (1987) is held here then the widespread nature of Lithofacies D in the Peyto and Mt. Whyte formations implies that more major oolitic sand shoals were deposited but were either not preserved or have not been discovered.

Lithofacies E: Bioclastic grainstone

Bioclastic grainstones (Figure 8) are relatively common in the Peyto and Mt. Whyte formations, but are absent from the Naiset Formation. In most cases, the rock is light to medium grey and, in places, also contains ooids and quartz sand. Bed thickness is typically a few to tens of centimetres, occurring as isolated beds or in thin units, often associated with Lithofacies C and D. Cross-bedding is common. Bioclasts are dominated by disarticulated and broken trilobites, although hyolithids are locally important constituents near the top of the Peyto at Mount Jimmy Simpson.

The occurrence of ooids and cross-bedding in this facies, the association with oolite units and Lithofacies C, and the thin bedding point to shallow subtidal deposition in platform-interior sand blankets (Ball 1967). Currents responsible for the cross-bedding could have been storm or tide induced although, because bi-modal cross-bedding was not observed in this facies, the latter is less likely.

Lithofacies F: Oncolitic rudstone

Lithofacies F (Figure 9) is common in the Peyto and upper Mt. Whyte formations. This lithofacies has a light to medium grey micritic matrix containing darker grey to black oncoids, which range in size from 1cm to about 6cm. Oncoids within individual beds are very well size-sorted. In many cases, nuclei, which are commonly trilobite fragments, can be seen in the oncoids. Concentric layers in the oncolites are less obvious. Although some oncoids are nearly spherical in shape, most are ovoid, and some are flattened.

In the Peyto Formation (at Popes Peak, Mount Niblock, and Monarch Creek), this lithofacies is commonly dolomitized. In these locations, the matrix consists of coarsely crystalline, buff dolomite, which weathers dark-buff to rusty. The oncoids also consist of crystalline dolomite, but are dark-grey to black. Most of the texture within the oncoids is lost, so that concentric layers and nuclei are obliterated.

In other ancient environments, oncolites are associated with intertidal to shallow subtidal deposition (Aitken 1967; Markello and Read 1981; Westrop 1989). In the study area, this lithofacies almost always occurs in association with other lithofacies (Lithofacies C and O) interpreted to have been deposited in a shallow-subtidal shelf setting, thus indicating a similar depositional environment for Lithofacies F. The only exception to this is the occurrence of oncolitic and oolitic packstone in the Mt. Whyte Formation at Monarch Creek on Mount Stephen. This unit (Figure 9c) is overlain by shales of the Naiset Formation

(Lithofacies K). The oncolites in this case are interpreted to be part of a debris flow deposit or turbidite, which was transported to the upper slope from a shallow shelf origin. This interpretation is supported by the stratigraphic setting, and by the structure of the beds in which it occurs, including gutter casts at the base of packstones which overly and are overlain by siltstones.

Lithofacies G: Laminated, poorly fissile, grey quartz-siltstone

This lithofacies (Figure 10) forms units up to tens of metres in thickness, and occurs only in the Naiset Formation at Mount Field, Mount Stephen, Naiset Point and Park Boundary. It consists almost entirely of silt to very fine sand-grade sediment with little carbonate. Light to dark grey colour banding occurs on a scale of a few centimetres, and starved or fading climbing ripples and low-amplitude ripples are common, although wave ripples are absent. Isolated pebble-size intraclasts of similar rock type and nearly circular cross-section were observed in this facies at Mount Field and Naiset Point (Figure 10b). These intraclasts were probably transported into non-lithified, laminated sediment as illustrated by the deformation below and above the clasts. Slumps and intraformation truncation surfaces are relatively common in Lithofacies G at Mount Field and Mount Stephen (see Figures 10c-e). Trace fossils and body fossils are extremely rare in this facies.

Numerous features of this facies indicate that deposition took place in a deep shelf to upper continental slope environment. First, exposures of Lithofacies G are most extensive in the westernmost locations, farthest away from the Cambrian shoreline. Slumps and intraformational truncation surfaces are well-documented indicators of continental slope deposition (Cook and Mullins 1983). Slumps are a result of sediment failure accompanied by rotation (Stow 1986), whereas intraformational truncation surfaces (Davies 1977; Cook and Mullins 1983) are thought to represent cohesive sediment slides (Stow 1986). At Mount Stephen, a channelized boulder conglomerate (Lithofacies H) in Lithofacies G is interpreted as a slope-derived debris flow deposit. Finally, light to dark grey colour alternation of the sediment along with low-amplitude and starved or fading climbing ripples are indicative of low-density, fine-grained turbidity currents (see Stow 1986, p. 415; Piper and Stow 1990, p. 366-367).

Lithofacies H: Matrix-supported, boulder conglomerate

A matrix-supported boulder conglomerate (Figure 11) occurs as a channelized deposit within Lithofacies G, directly overlying Peyto dolostone at the Waterfall section on Mount Stephen. The exposed width of the channel is about 30 m, and the axis trends roughly east-west. While the southern flank of the channel is covered, the northern flank is cut into laminated siltstone of Lithofacies G. The central part of the channel directly overlies Peyto dolostone. Moderately well-rounded clasts are composed of siltstone and possibly dolostone, and range in size from about 10 cm to over 1 metre. Reverse grading is apparent (see Figure 11.2). The matrix consists of grey siltstone, similar in composition to Lithofacies G, but lacking lamination. Two intraformational truncation surfaces occur a few metres above and to the south of the channel (see Figure 10, and description under Lithofacies G). At the North Gully section on Mount Stephen, basal Naiset siltstone of Lithofacies G is slumped (see Figure 10).

All of the evidence points to an interpretation of this lithofacies as a channelized debris-flow deposit (Walker 1984; Stow 1986) in slope sediments. Numerous examples of debris flows consisting of large clasts suspended in a fine-grain matrix have been described for ancient slope and basin margin deposits (Enos and Moore 1983; Cook and Mullins 1983).

Lithofacies I: Bioturbated, green-grey siltstone/fine sandstone

This lithofacies (Figure 12) occurs as thick units in the Mt. Whyte Formation at every location except Mount Stephen. Lithofacies I is superficially similar in appearance to, and in some places (Mount Field for example) is gradational with Lithofacies G, but contains more abundant coarse silt and more fine quartz sand, especially in the east. Moreover, horizontal and vertical bioturbation is pervasive in this facies but occurs only rarely in Lithofacies G. In some places where bioturbation is limited to bedding surfaces, centimetre-scale lamination is well-preserved, while in other places, lamination is completely obliterated due to bioturbation. No body fossils were observed in this facies. Parallel and interference wave ripples are very common on bedding surfaces (Figure 12c), while current ripples are less common (Figure 12b).

The abundant bioturbation and wave ripples indicate that Lithofacies I was deposited under shallower water than Lithofacies G, but the absence of evidence for subaerial exposure, such as desiccation cracks or fenestral fabric, prevents an interpretation of intertidal deposition. Several metres below the bases of major prograding shallow-shelf carbonate units at Mount Field and Naiset Point, Lithofacies G passes upward into Lithofacies I as part of shallowing upward sequences. Lithofacies I is therefore interpreted as a shallow, subtidal, outer to middle shelf deposit.

Lithofacies J: Silty, dolomitic "parted limestone"

Silty, dolomitic, "parted limestone" (Aitken 1966; Westrop 1989; Cowan and James 1993) occurs in units generally less than 5 metres thick, and is characteristic of the Mt. Whyte Formation at every location. Lithofacies J (Figure 13) is thin-bedded, with buff-coloured silty dolostone and medium to dark grey lime-mudstone to packstone alternating on a vertical scale of a few centimetres. Weathered surfaces are rusty-buff. Vertical and horizontal burrows are common, and body fossils occur only as small fragments. This rock type differs from Lithofacies B in having less siltstone and more limestone, which is well-bedded.

As for Lithofacies B, this type of facies has been associated with shallow subtidal depositional environments (Cook and Taylor 1977; Aitken 1978; Wilson and Jordan 1983; Westrop 1989; Cowan and James 1993), and this interpretation is adopted for Lithofacies J.

Lithofacies K: Thinly laminated, green-grey shale

This rock type (Figure 14) is characteristic of the Naiset Formation at most sections, but is volumetrically most significant at Naiset Point where it comprises most of the 170 m section. The colour is light green-grey, weathering dark olive to brown. Fisility varies from very good to poor, and a cleavage may be present. An intraformational truncation surface is present in this facies at Naiset Point. Trace fossils do not occur in this facies, and the shale is usually poorly fossiliferous. However, at Popes Peak and, to a lesser extent, at Mount Niblock, abundant trilobites, in some cases completely articulated, occur in Lithofacies K. These intervals of green-grey shale at Pope's Peak and Mount Niblock were assigned previously to the Mt. Whyte Formation (Rasetti 1951; Aitken in press), but are designated herein as tongues of the Naiset Formation. Rasetti (1951) gave the name "Lake Agnes Shale Lentil" to these approximately 8 m thick units at Pope's Peak and Mount Niblock. There is, however, no evidence for these units having a lenticular geometry, and because these units cannot be correlated outside of the Lake Louise area, this name is abandoned.

Because of the absence of primary sedimentary structures other than planar lamination, and the complete lack of bioturbation, Lithofacies K is interpreted to have been deposited below normal wave base. Moreover, the presence of completely articulated trilobites is indicative of rapid burial, possibly under mud plumes generated by storms (Miller et al., 1988). This style of preservation is typically associated with deep water (below storm wave base), distal shelf or slope sedimentation (see Speyer, 1987). The close association of Lithofacies K with slope sediments at Mount Stephen and Naiset Point suggests continental slope deposition at these places, but mid to outer shelf depositional sites are interpreted for other occurrences.

Lithofacies L: Black shale

Black shale (Figure 15) occurs only in the Naiset Formation at Mount Field and Mount Stephen in units less than 5 metres thick. The shale is fissile and displays a strong cleavage in some places. Poorly preserved, compressed trilobites, inarticulate brachiopods, and the mollusc Scenella are common at Mount Stephen, while only trilobites occur rarely at Mount Field. At both locations, most of the trilobites are complete specimens of Syspacephalus, although disarticulated elements of Wenkchemnia sulcata occur rarely at North Gully. Pyrite occurs commonly at North Gully and rarely at Mount Field. These rocks are not bioturbated and millimetre-scale lamination is pervasive in this facies; other sedimentary structures such as ripple marks are absent. At both locations, the shale is overlain by black lime mudstone (Lithofacies M), and at North Gully, it, in turn, overlies a unit of black lime mudstone.

This lithofacies is interpreted to have been deposited below storm-wave base in an upper slope or outer shelf environment. This conclusion, based on lithologic criteria described above, is supported by the occurrence in the westernmost sections. Moreover, the black colour of the shale can be interpreted as evidence for relatively high levels of organic carbon and relatively low levels of dissolved oxygen in the benthic water at the time of deposition (Wignall and Myers, 1988). These conditions are consistent with a deep shelf to upper slope setting.

Lithofacies M: Thinly laminated, black, lime mudstone

Lithofacies M (Figure 16) occurs in the Naiset Formation at Mount Field and Mount Stephen, and in the basal Cathedral Formation at Mount Field. The rock is thinly bedded black micrite. Millimetre-scale parallel lamination, and wavy bedding are the only primary sedimentary structures present. Fossils are locally abundant, particularly at North Gully, and consist almost entirely of trilobites, many of which are complete exoskeletons. Shaly partings occur in some intervals of this lithofacies at Mount Stephen. Trace fossils are absent and pyrite is locally common.

As for Lithofacies L, with which it occurs, both the lithologic evidence and its geographic location indicate that Lithofacies M was deposited in a deep shelf to upper slope environment.

Lithofacies N: Thin-bedded to massive dolostone

Thin-bedded to massive dolostone (Figure 17) is characteristic of the Cathedral Formation at all locations in the study area, and also occurs locally in the upper Mt. Whyte Formation. The colour of the dolostone ranges from buff to nearly black, and bedding thickness is commonly massive, but may be thin to medium bedded locally. In most places, dolostone is coarsely crystalline and featureless, but at the Monarch Creek section, relict oolitic texture is apparent in the basal Cathedral dolostone. Massive oncolitic dolostone occurs locally in the Peyto Formation (see Lithofacies F).

Rasetti (1951) used the occurrence of massive dolostone to define the base of the Cathedral Formation, even though he recognized that the stratigraphic occurrence of dolostone was highly variable laterally in many sections. Aitken (in press) defined the base of the Cathedral Formation with the occurrence of cliff-forming carbonates above the highest bed of shale or siltstone in the Mt. Whyte, thus including dolostone in the Mt. Whyte where it is interbedded with shale or siltstone.

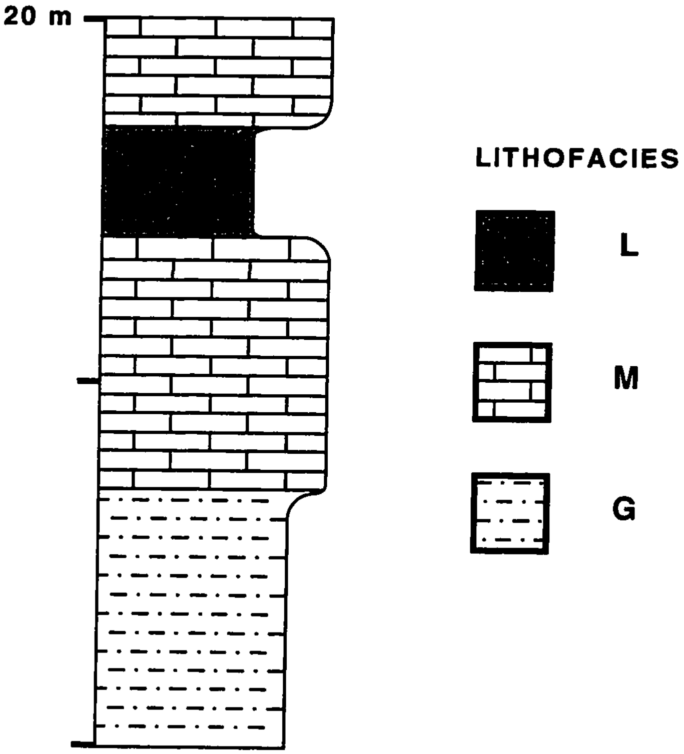
Lithofacies O: Quartz sandstone (calcareous)

Throughout the study area, quartz sandstone (Figure 18) is common in the Peyto Formation, where it is interbedded with limestones (Lithofacies C and D), and in the underlying Gog Group, where it is the dominant rock type. Bedding thickness is thin to medium, and cross-bedding is common. In some places, especially in the upper Gog, cross-bedding is bi-polar (Figure 18a), indicating a tidal influence. Quartz grains are subangular to rounded, and range in size from fine sand to medium pebbles. Colours range from nearly white to brown. In most cases, Peyto carbonates contain significant amounts of quartz sand, especially in the lower portion of the formation overlying Gog sandstones.

The coarse grain size, abundant cross-bedding, and stratigraphic relationships support an interpretation of shallow subtidal, high-energy shelf deposition for Lithofacies O.

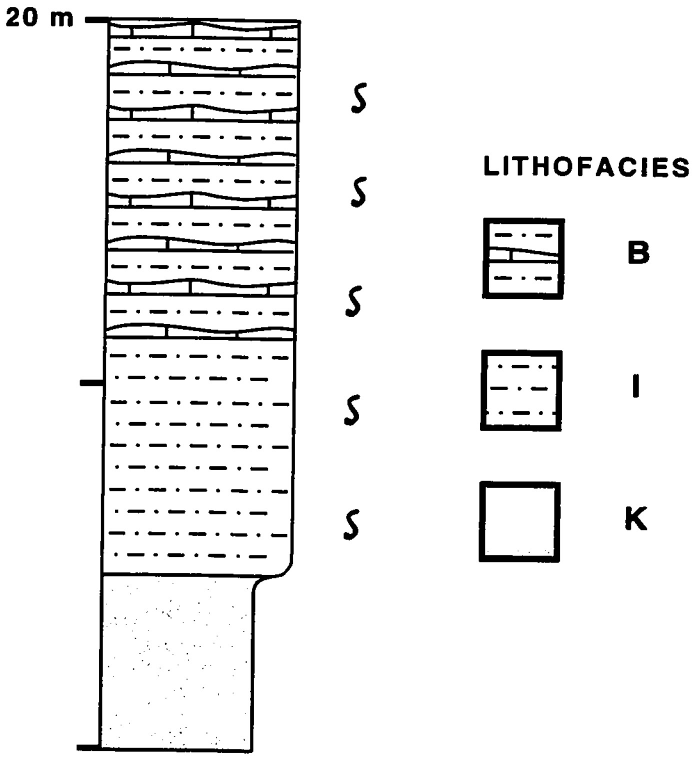
LITHOFACIES ASSOCIATIONS

FIGURE 19. Representative interval of Lithofacies Association 1. From lithologic log of Naiset Formation, North Gully.



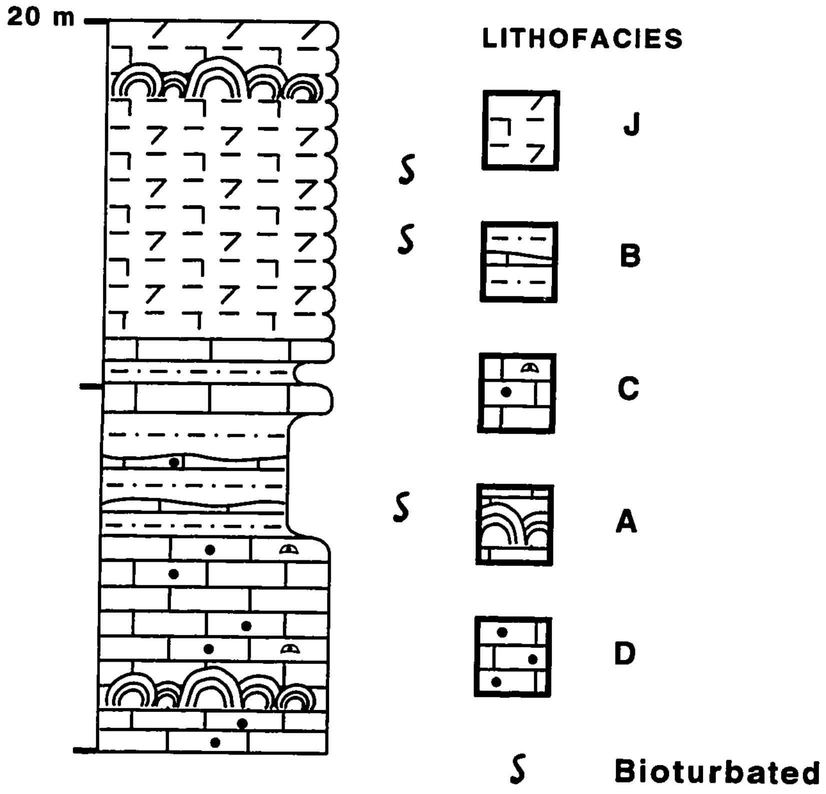
Lithofacies association 1

FIGURE 20. Representative interval of Lithofacies Association 2. From lithologic log of Naiset (shale) and Mt. Whyte formations, Mount Niblock.



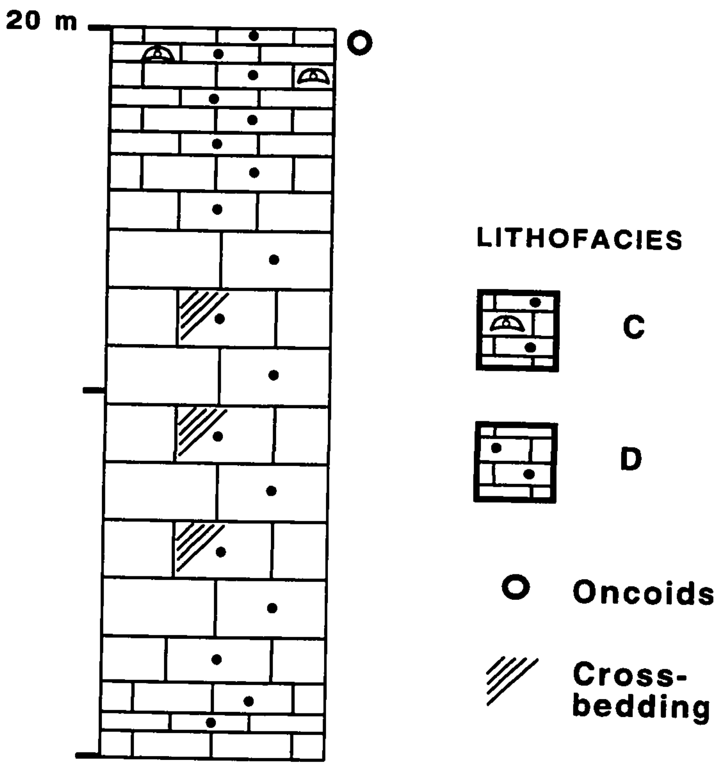
Lithofacies association 2

FIGURE 21. Representative interval of Lithofacies Association 3. From lithologic log of Mt. Whyte Formation, Mount Weed.



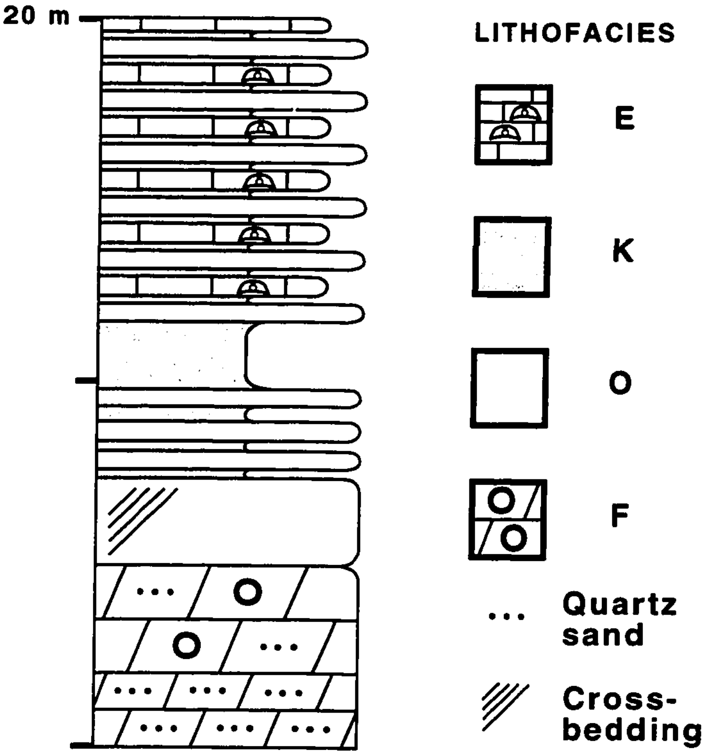
Lithofacies association 3

FIGURE 22. Representative interval of Lithofacies Association 4. From lithologic log of Peyto Formation, Mount Jimmy Simpson.



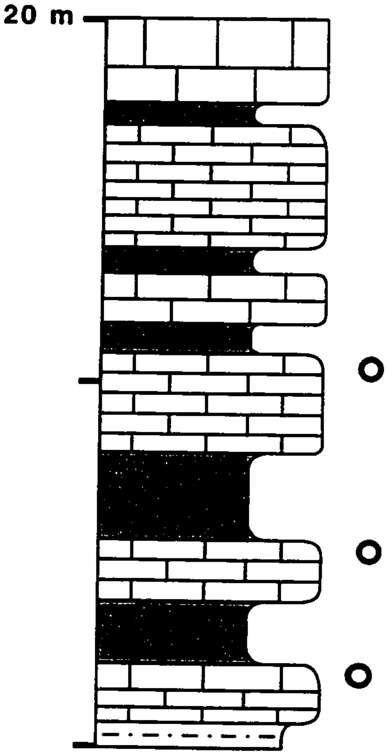
Lithofacies association 4

FIGURE 23. Representative interval of Lithofacies Association 5. From lithologic log of Peyto Formation, Mount Niblock.



Lithofacies association 5

FIGURE 24. Representative interval of Lithofacies Association 6. From lithologic log of Mt. Whyte Formation, Mount Weed.



Lithofacies association 6

Lithofacies Association 1

This association (Figure 19) consists of thick intervals of grey quartz siltstone (Lithofacies G), with thinner units of black limestone (M) and black shale (L). Lithofacies H is included in this association at the Waterfall section at Mount Stephen. At Park Boundary and Mount Field, a thick interval of Lithofacies G sharply overlies Lithofacies M, while at North Gully, G is overlain by M. Lithofacies L does not occur at Park Boundary, nor was it encountered in the minimally exposed, short Waterfall section.

Sedimentary structures within Lithofacies G, including undisturbed thin lamination, slumps and intraformation truncation structures (submarine slides), deep-water features of Lithofacies L, and a channelized debris-flow deposit (Lithofacies H) are strong evidence for deposition of this association in a continental slope environment. At Mount Stephen, McIlreath (1977) recognized similar features in the Middle Cambrian (Glossopleura Zone) Boundary Limestone, which he interpreted as a deep-water debris apron. Other examples of slope deposits which share at least some of these features include the Upper Cambrian - Lower Ordovician Hales Limestone of central Nevada (Cook and Taylor 1977), the Middle Pennsylvanian - Lower Permian Hare Fiord Formation of the Canadian Arctic (Davies 1977), and the Middle Cambrian - Lower Ordovician Cow Head Group of western Newfoundland (James et al. 1989). At Naiset Point, Park Boundary and Mount Field, Association 1 is followed by Association 2.

Lithofacies Association 2

This association (Figure 20) consists of bioturbated green-grey quartz siltstone (Lithofacies I), interbedded, bioturbated quartz siltstone and wackestone-mudstone (B), and green-grey quartz shale (K). It occurs in all exposures of the Mt. Whyte Formation, where it is characteristic of the Weed Member (Aitken, in press). Although sediment grade here is similar to that of the previous lithofacies association, Association 2 is distinguished by its abundant bioturbation, wave ripple marks, and lack of slumps and intraformation truncations surfaces. At Naiset Point, Park Boundary and Mount Field, Association 2 occurs directly above 1.

Lithofacies association 2 was deposited in shallower water and on a gentler slope than Association 1. Shallow subtidal deposition above normal wave base in Association 2 is indicated by abundant wave ripple marks. Furthermore, several studies (Rhoads and Morse 1971; Byers 1977; Myrow and Landing 1992) have shown that bioturbation in fine-grain siliciclastic sediments increases with decreasing subtidal water depth, and a similar pattern is apparent when comparing associations 1 and 2. Finally, there is no evidence in this association for slope deposition. Association 2 is herein interpreted as having been deposited in an outer shelf setting. Thus, the sequence of Lithofacies associations 1 to 2 represents a shallowing-upward cycle, and is associated with the progradation of shelf-edge carbonates (Association 3) on top of siliciclastics.

Lithofacies Association 3

This association (Figure 21) includes interbeds of bioclastic-oolitic wackestone/packstone (Lithofacies C), oolitic grainstone (D), parted limestone (J), interbedded bioturbated quartz siltstone and wackestone-mudstone (B), and in some places, thrombolitic algal boundstone (A) and oncolitic rudstone (F). This association occurs at all locations of the Mt. Whyte Formation, where it characterizes the Chephren Member.

All of the lithofacies in this association are indicative of shallow subtidal (above storm wave base) shelf sedimentation, and thin beds of oolite indicate deposition adjacent to oolitic shoals. Whether this facies association was deposited shoreward or basinward of oolitic shoals can only be estimated from the geographic position of each outcrop. Westrop (1989) suggested a similar depositional environment for a comparable facies association from the Upper Cambrian Bison Creek Formation of southern Alberta. Analogous depositional settings have been interpreted for similar facies in the Carrara Formation of the southern Great Basin (Palmer and Halley 1979).

The presence of thrombolites and stromatolites in the Peyto Formation at Park Boundary, and in the Mt. Whyte Formation at Pope's Peak, Mount Jimmy Simpson, Mount Weed and Park Boundary suggests periodically clearer water and possibly a shallower depositional environment than for Association 2. That these thrombolites did not thrive in silty conditions is made evident by the common "smothering" of thrombolites by siltstone at several locations (Figure 4). In the Mt. Whyte Formation, Association 3 always follows Association 2, and it is commonly overlain by carbonates of the Cathedral Formation.

It is worth noting that where shelf-edge carbonate deposits are seen to prograde over top of siliciclastics, (for example at Mount Stephen, Mount Field, or Naiset Point), a shallowing-upward sequence exists within the siliciclastics. At Mount Field, thinly laminated grey siltstone and black shale slope deposits (Lithofacies association 1) shallow upward into bioturbated, rippled, green-grey siltstone (Association 2), which becomes interbedded with carbonates (Association 3). Similarly, at Naiset Point, green-grey siltstone/shale lacking trace fossils, shallows upward into bioturbated, rippled, green-grey siltstone, which becomes interbedded with carbonates. A comparable progradational event at Mount Stephen (North Gully) is represented by slumped siltstones, black shales and limestones grading upwards into grey shales, and then carbonate. All three of the above cited examples are correlative (Syspacephalus laticeps Zone to Albertella Zone). Because these sequences display a shallowing trend within the siliciclastics prior to carbonate progradation, they indicate that the carbonate progradation is not due purely to carbonate production outpacing steady-state subsidence and sedimentation. There must be a component of either decreased subsidence, increased vertical aggradation of siliciclastics, eustatic sea-level fall, or a combination of factors.

Lithofacies Association 4

This association (Figure 22) consists almost entirely of thin to thick beds of oolitic grainstone (Lithofacies D), many of which are planar tabular cross-bedded, with minor interbeds of bioclastic-oolitic wackestone/packstone (C). It occurs only in the Peyto Formation. At Mount Jimmy Simpson, a prominent, 30 metre thick unit occurs at the top of the Peyto, and at Park Boundary, a 10 metre thick unit is exposed near the base of the formation.

The abundance of thick, planar-tabular cross-bedded oolite points to deposition on a major oolitic sand shoal (see discussion for Lithofacies D). The Pleistocene Miami Oolite of Florida (Halley et al. 1977) is an ancient oolitic sand body that compares in some ways with the Mount Jimmy Simpson example. Although the Miami Oolite shows more evidence of tidal influence than the Peyto oolites, thick cross-beds, and burrowed sands behind the oolite bars are comparable with the Peyto.

Both Rasetti (1951) and Hockley (1973) identified thick oolite units in the Peyto at outcrops to the north of Bow Lake, near the Mount Jimmy Simpson section. To a large degree, the thickness of the Peyto carbonate throughout the study area depends on the proximity to these thick oolitic sand bodies. In the vicinity of Mount Jimmy Simpson, the Peyto is over 45 m thick (see Figure 32). This is diminished to about 35 m with thin oolitic beds and some quartz sand content at nearby Mount Weed, but shrinks to less than 14 metres with abundant quartz sand but no oolite at Pope's Peak and Monarch Creek, Mount Stephen. Essentially, Peyto carbonates intertongue shoreward with Gog sandstones, as Aitken (in press) recognized, and basinward with the Naiset Formation. This depositional model (Figure 25) for the Peyto Formation does not require block faulting and subaerial erosion of carbonates, such as that proposed by Hockley (1973) and Aitken (in press), to explain thickness variations.

Lithofacies Association 5

This association (Figure 23) includes interbeds of bioclastic or oolitic packstone and grainstone (Lithofacies C, D, E), green-grey quartz shale or siltstone (K, I), calcareous quartz sandstone (O), and oncolitic rudstone (F). It occurs in the Peyto Formation at Pope's Peak, Mount Niblock and Mount Weed, and in the Mt. Whyte Formation without Lithofacies O and F at Park Boundary. Previously, some of these strata around Lake Louise have been assigned to the basal Mt. Whyte Formation (Aitken, in press; Rasetti, 1951) on the basis of their green-grey shale content, even though this lithology occurs widely in the Peyto Formation. Moreover, the sandstone and bioclastic grainstone are lithofacies more typical of the Peyto than the Mt. Whyte. Herein, these intervals are assigned to the Peyto Formation. It seems likely that oolite shoals, such as that at Mount Jimmy Simpson, were the source of oolite found in Association 5.

The coarse-grained bioclastic grainstone, the coarse quartz sandstone interbeds, and the oncoids suggest very shallow subtidal deposition. The alternation of coarse sediments with common wave-rippled surfaces and silt/shale on a scale of several centimetres (Figure 6b, c) suggests that this lithofacies association represents storm deposition, with packstone and grainstone beds representing high-energy winnowed lags, and the silts representing low-energy post-storm settling from suspension (see Kreisa 1981). Similar coarse-fine sediment facies associations described in the literature

(Kreisa 1981; Markello and Read 1981; Westrop 1989) have been interpreted as shallow subtidal storm deposits.

Lithofacies Association 6

In this association (Figure 24), thick units of green-grey quartz shale or siltstone (Lithofacies K, I) occur with relatively thin interbeds of oolitic and bioclastic grainstone (Lithofacies D, E). It occurs in the Peyto Formation at Mount Jimmy Simpson, in the Naiset Formation at Naiset Point, and in the upper Mt. Whyte Formation at Park Boundary.

This association represents deposition on the margins of carbonate banks. At Naiset Point and Mount Jimmy Simpson, the coarse carbonate grainstones of Lithofacies D and E have been transported and redeposited in outer shelf or upper slope shales in advance of prograding shelf-edge carbonate lithosomes. Comparable carbonates occur in shallow shelf quartz siltstones at Park Boundary. Storm-generated currents are a probable agent of sediment transport. Similar depositional sites were interpreted for ooid packstones in the Nolichucky Formation of southwest Virginia (Markello and Read 1981) and in the Sullivan Formation of the southern Canadian Rocky Mountains (Aitken 1978).

LOWER - MIDDLE CAMBRIAN BOUNDARY SEDIMENTATION

The discussion of sequence stratigraphy presented in the next section requires an understanding of the nature of disconformities in the study interval. To this end, an evaluation of the Lower - Middle Cambrian boundary is presented here, a boundary which reportedly contains "one of the larger, more significant unconformities in the Phanerozoic strata of North America" (Babcock, preface in Fritz, 1991).

Although Early to Middle Cambrian was a time of transgression on the North American continent, there is a general consensus that a major unconformity occurs in the study area at the base of the Middle Cambrian (Rasetti 1951; Aitken 1989a, 1989b, in press; Fritz et al. 1991). As defined in this thesis, the base of the Mt. Whyte Formation is earliest Middle Cambrian in age, and the unconformity reportedly occurs at the top of the Peyto Formation. Aitken (in press) also claimed that the unconformity is apparent at the base of the Naiset Formation on Mount Stephen.

Aitken (in press) cited several lines of evidence pointing to a sub-Middle Cambrian unconformity, including the apparent erosional beveling of the Peyto Formation across the axis of the Kicking Horse Rim at Mount Stephen. This hypothesis is appealing because if subaerial erosion was to have occurred anywhere on the Lower Cambrian shelf, then surely it would have been most significant at a major topographic-positive feature such as the Kicking Horse Rim. However, subaerial exposure of carbonate deposits would have left clear evidence. For example, the subaerial emergence of a Lower Cambrian shelf-edge carbonate rim in the Franklinian basin of the Canadian Arctic resulted in distinctive cave- and karst-fill of breccia-conglomerates (Long, 1989). In basal Peyto oolite at Mount Jimmy Simpson, evidence for local peritidal emergence by deposition is in the form of iron oxide staining and thick cement rims. However, there is no evidence whatsoever of extensive

FIGURE 25. Diagrammatic representation of Peyto carbonate lithosome showing thickness variations across depositional strike interpreted as a result of intertounging with Naiset shales and Gog sandstones.

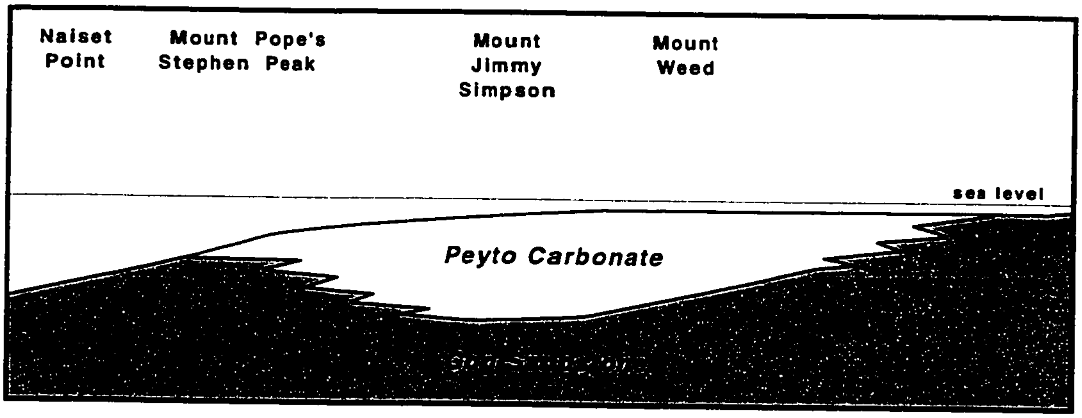
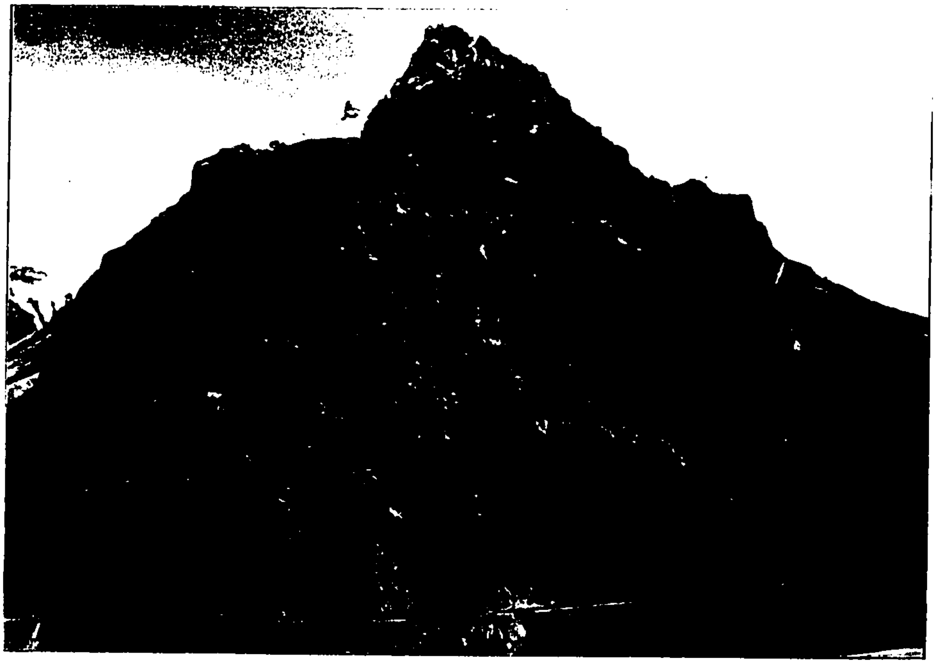

Naiset Point
Mount Stephen
Pope's Peak
Mount Jimmy Simpson
Mount Weed
sea level
Peyto Carbonate

FIGURE 26. Photograph and line drawing of the north face of Mount Stephen showing correlation of selected beds from Monarch Creek section to North Gully section. The beds that contain _Olenellus_ at Monarch Creek (collections B 26, B 28) are marked with an "X" and can be correlated along a dark-coloured layer above a light coloured layer (scree slope in places) to a point at North Gully marked with a "Y". This point is just above a clump of trees and overlies the beds that yielded collection C 47 which contains _Wenkchemnia walcotti_ and _Syspacephalus laticeps_.



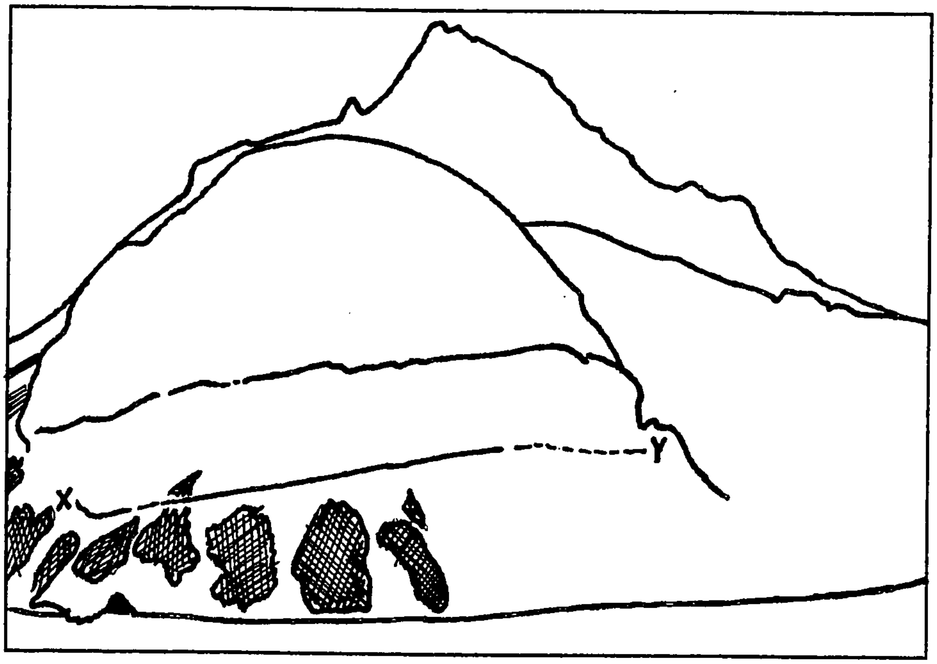
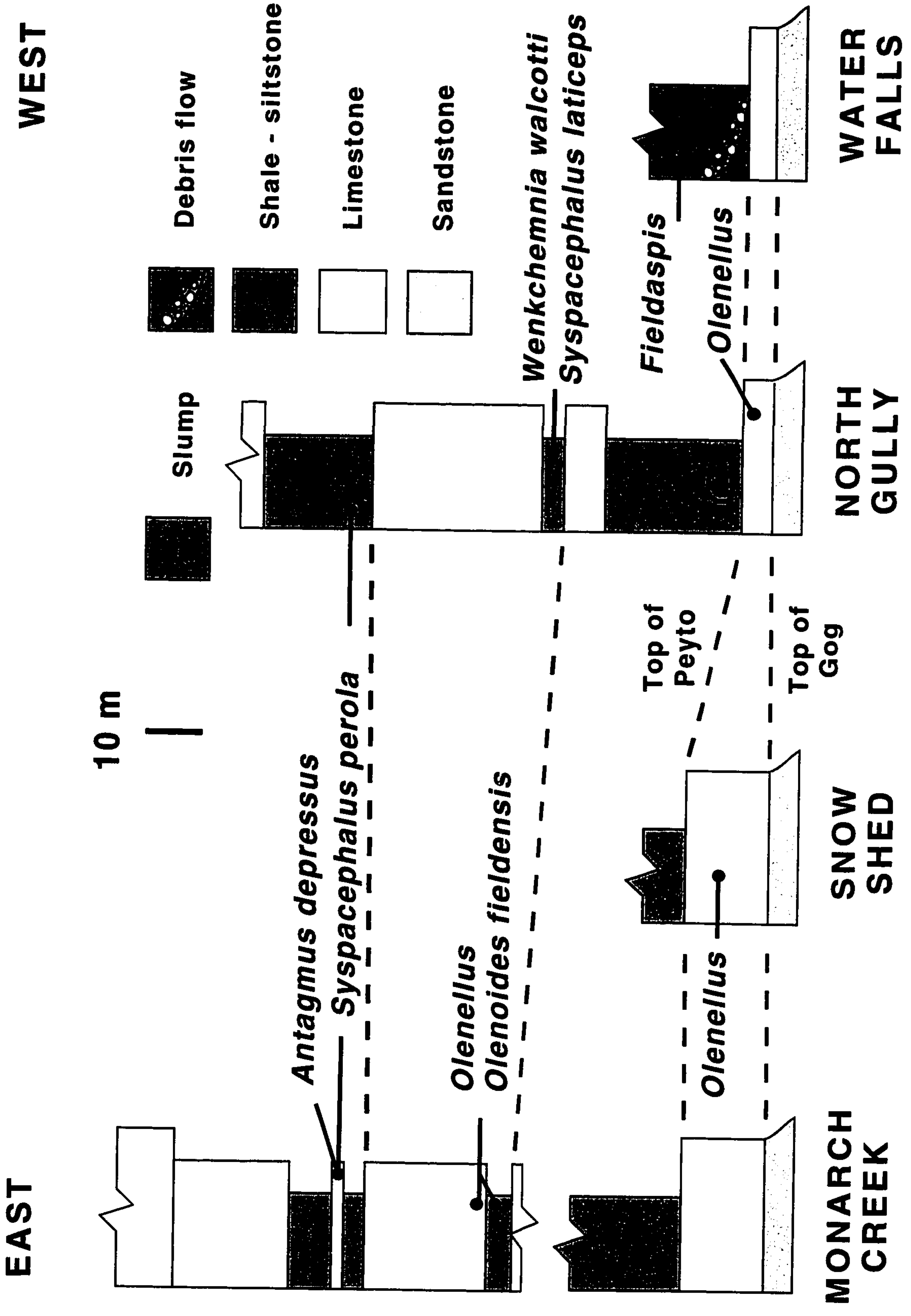

X
Y

FIGURE 27. Correlation of measured sections and collection sites on Mount Stephen.


EAST
WEST
10 m
Slump
Debris flow
Shale - siltstone
Limestone
Sandstone
Antagmus depressus
Syspacephalus perola
Olenellus
Olenoides fieldensis
Wenkchemnia walcotti
Syspacephalus laticeps
Fieldaspis
Olenellus
Olenellus
Top of Peyto
Top of Gog
MONARCH CREEK
SNOW SHED
NORTH GULLY
WATER FALLS

emergence due to sea-level fall in the Lower Cambrian strata at Mount Stephen, or in uppermost Lower Cambrian rocks anywhere in the study area. New evidence from four sections on Mount Stephen demonstrates that Lower Cambrian dolostone or trilobite-bearing limestone ranging in thickness from 3 to 14 metres occurs along an east-west transect (see Figures 26, 27). This work indicates that thickness changes in Lower Cambrian strata on Mount Stephen and elsewhere can be best explained with a depositional model that does not require erosional beveling (see Figure 25). The lack of an erosional unconformity at the Lower/Middle Cambrian boundary is by no means unique to Mount Stephen. Hockley (1973) could not find erosional features or karstification anywhere at the Peyto-Mt. Whyte contact, and suggested that the disconformity is due mainly to non-deposition rather than erosion.

Neither bio- nor lithostratigraphic evidence supports the hypothesis of a major sub-Middle Cambrian unconformity due to erosion or depositional hiatus in the study area:

1. Olenoides fieldensis, which has been recovered from the top of the thickest sections of the Peyto formation at Park Boundary (34.5 m), Mount Weed (34.6 m), and Mount Jimmy Simpson (46 m), also occurs in the thinnest sections at Mount Stephen. However, species recovered from the lowest part of Mount Weed do not occur in the thin sections. This indicates that differences in thickness between sections are not due to erosional removal of material from the top of the Peyto Formation, as suggested by Aitken (1989a, 1989b, in press), but rather are a result of facies changes within this interval (Figure 25). For example, the oolitic shoal facies at

Mount Jimmy Simpson has not been observed anywhere else. This interval may be coeval with unfossiliferous inner detrital-belt quartz-sandstones of the Gog Group at other sections.

2. Rasetti's (1951) observation that the faunal change across the Peyto-Mt. Whyte contact is sharp and that there is no transitional fauna, has been cited by Hockley (1973) and Aitken (in press) to support the hypothesis of a sub-Middle Cambrian unconformity. At Mount Stephen, Lower Cambrian trilobites (including Olenellus sp. and Olenoides fieldensis) occur within the lower portion of the Mt. Whyte Formation above previously-described "Middle Cambrian" trilobites (see Figures 26, 27). Furthermore, this study demonstrates that at least six of the nine genera that occur in the Peyto Formation also occur in Middle Cambrian strata. Even if Bonnia is viewed as a valid genus, the closely related genus, Olenoides, occurs in Middle Cambrian strata. The only significant extinction involves the olenellids. Thus, this study has revealed that the Lower / Middle Cambrian boundary is not as sharp as previously thought. It is now clear that some trilobites (Fieldaspis, Syspacephalus laticeps, Wenkchemnia) long viewed as Middle Cambrian taxa existed in deeper-water slope biofacies coeval with Olenellus in shallower-water shelf biofacies.

3. The erosional surface identified by Aitken (in press) overlying Peyto dolostone in a gully on Mount Stephen, 2 km northeast of Field, is best interpreted as the base of a debris-flow deposit which occurs in slope sediments (see discussion for Lithofacies H). Here, directly overlying 5 m of Peyto dolostone, a channelized, matrix-supported, boulder conglomerate occurs within

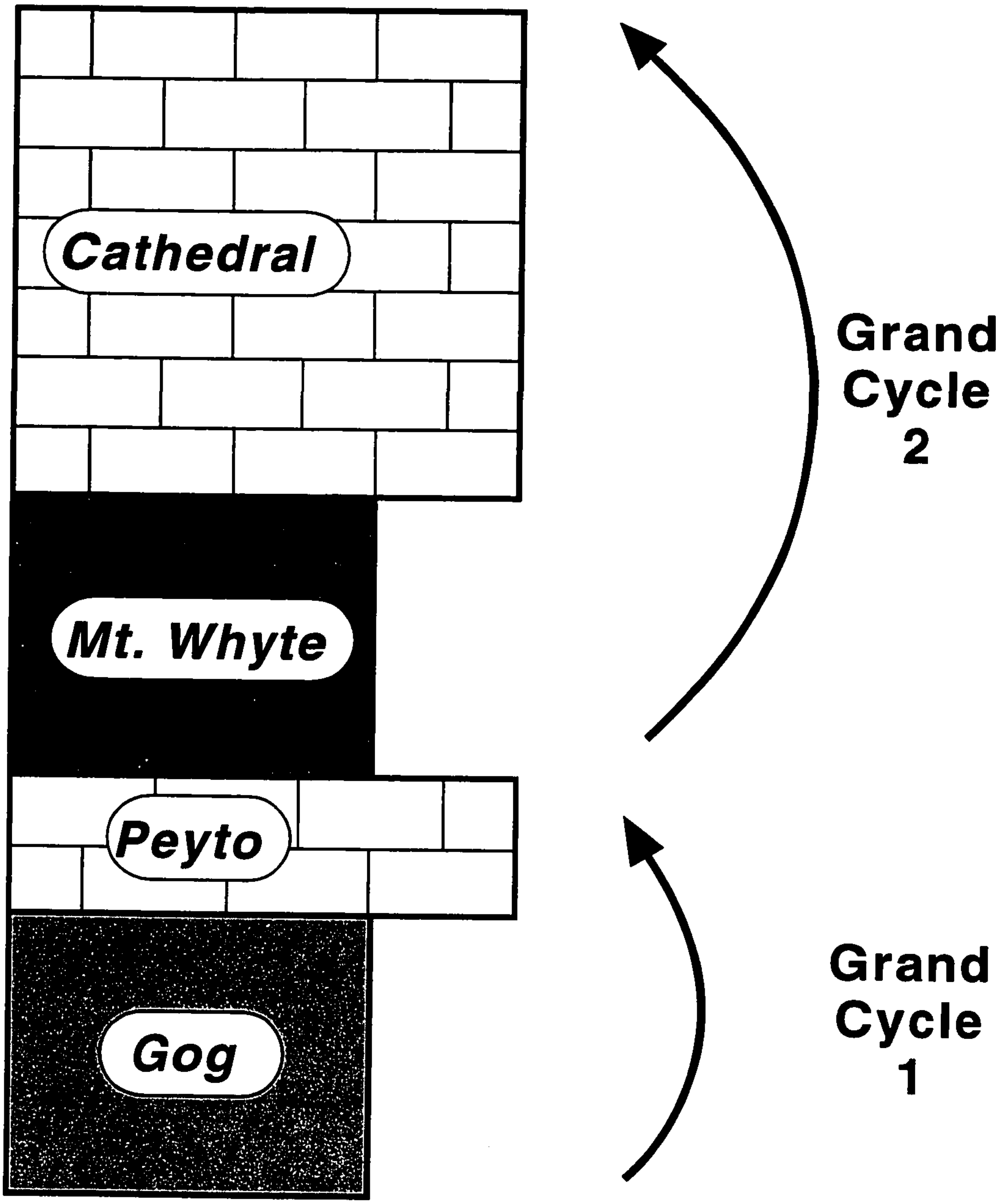
thinly laminated siltstone of the Naiset Formation (see Figure 11). Just a few metres above and to the south of this channel can be found intraformational truncation surfaces indicative of slides (Figure 10), and coeval siltstones a few hundred metres to the east on Mount Stephen clearly display severely distorted lamination attributed to slumping (see Figure 10). Moreover, the Peyto dolostone at this section is correlated with trilobite-bearing limestones in eastern sections on Mount Stephen. In these eastern locations, there is no conglomerate or "erosion surface" overlying the Peyto; rather, the limestone is directly overlain by Naiset siltstone.

In contrast to previously published reports of a sub-Middle Cambrian unconformity of regional extent, it is now clear that no such unconformity exists in the study area. Furthermore, some sites examined in this study appear to preserve a complete record of trilobite faunas across the Lower-Middle Cambrian boundary. These conclusions have major implications for sequence-stratigraphic models, the interpretation of the depositional history of the study area and for biostratigraphy.

GRAND CYCLES AND SEQUENCE STRATIGRAPHY

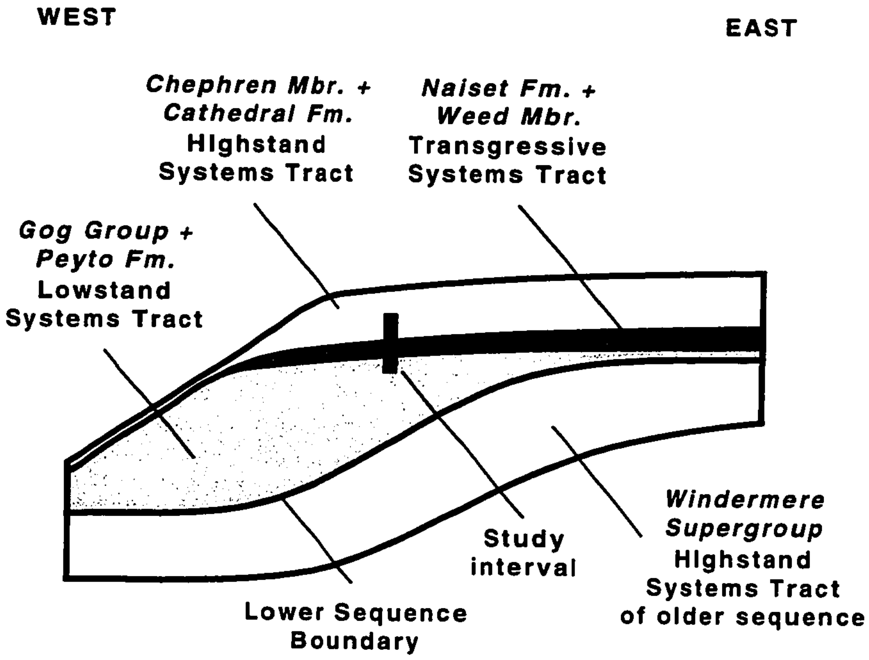
The generalized rock sequence for the westward thickening Cambrian miogeoclinal wedge throughout the Cordillera comprises essentially two parts: a Lower Cambrian siliciclastic sequence and a Middle to Upper Cambrian mixed carbonate-siliciclastic sequence. Strata in the study interval belong to two successive grand cycles

FIGURE 28. Grand Cycles of the study interval.



Grand cycles of the study interval.

FIGURE 29. Sequence stratigraphy of the study interval.



Sequence stratigraphy of the study interval

(Figure 28). The Peyto Formation represents the carbonate upper half of one cycle, while the Mt. Whyte Formation represents the mainly siliciclastic lower half of a second grand cycle. Uppermost Gog Group sandstones constitute the lower half of the Peyto cycle, and the Cathedral Formation represents the carbonate upper half of the Mt. Whyte cycle. Both of these grand cycles likely belong to a single, genetically related, stratigraphic sequence formed during one cycle of relative sea-level change. Nonetheless, each of these grand cycles differs from the other in several important aspects, including thickness, composition, and across-strike extent of the half-cycles, and each one is discussed individually below.

The grand cycle comprising uppermost Gog sandstone and Peyto limestone was identified by Fritz (1975) as being the youngest of three Lower Cambrian grand cycles, which he recognized throughout the cordillera. This view was supported by Palmer (1981) who correlated the tops of these grand cycles. Due to limited exposure in the sections examined for this thesis, only the uppermost Lower Cambrian cycle was observed. The lower half of the Gog-Peyto cycle is different from the Mt. Whyte half-cycle and most other siliciclastic half-cycles in that it consists almost exclusively of fine to coarse quartz-sandstone, rather than siltstone or shale. Hein (1987) interpreted the uppermost Gog Group sandstones in the study area as having been deposited by migrating sand waves in a shallow marine shelf setting. Northwest of the study area, Young (1979) interpreted sandstones of the lowermost Gog Group McNaughton Formation as representing shallow marine, piedmont, and fan-delta environments. Basinwards, the Gog passes laterally into outer detrital-belt shales. Early Cambrian subsidence was rapid, and contributed to the entire Gog Group attaining a western maximum thickness of about 2 km in the study area (Aitken, 1989a). To the north, in the upper Fraser River region, the Gog Group has a maximum thickness of about 3 km (Young, 1979).

The carbonates of the Peyto Formation rest conformably and, in a regional sense, gradationally on top of the Gog sandstone. In contrast to the more than 600 m of Gog sandstone exposed in the study area, the Peyto attains a maximum thickness of about 45m at Mount Jimmy Simpson. To the northeast of the study area at Mount Kerkeslin, Hockley (1973) reported a thickness of about 126 m for the Peyto. There, the bulk of the sequence consists of shallow subtidal to intertidal lime-mudstones, but a lack of fossils precludes an Early Cambrian age assignment for the complete package. The formation thins markedly westward, attaining only a few metres thickness at Kicking Horse Pass. It was not deposited in deeper-shelf and slope environments, which received only silt and mud of the Naiset Formation during latest Early Cambrian time. Eastward, the formation interfingers with sandstones of the Gog. Based on sedimentological analysis in this study, the Peyto is interpreted to represent shelf-edge oolitic sand shoals and very shallow, subtidal, inner shelf carbonate deposits.

In sequence-stratigraphic terms, the Peyto Formation, together with at least the uppermost Gog Group, likely represents the lowstand wedge portion (see Figure 29) of a lowstand-systems tract (Van Wagoner et al. 1988). This conclusion is suggested by the great thickness of coarse-grained, shallow marine and non-marine sediments, deposited on a subsiding continental shelf. The great thickness of the Gog lowstand wedge is to be expected because of its very early time of emplacement with respect to passive margin formation. Very rapid initial thermal subsidence associated with the early drift phase of the miogeocline (Bond and Kominz 1984) contributed to the tremendous thickness of the Gog sandstones. Although not observed during the course of field work for this thesis, the lower sequence boundary (type 1 of Van Wagoner et al. 1988) may occur at the base of the Gog Group, which unconformably overlies the Precambrian Miette Group (Windermere Supergroup). The transition from continental slope to shelf sedimentation is recorded across this unconformity (Hein 1987).

Towards the end of lowstand-wedge deposition in the study area, Peyto carbonates were deposited as a result of temporarily increased shoaling of the shallow shelf, diminished coarse-clastic input, or a combination of these factors. The occurrence of a tongue of relatively thick, non-bioturbated, quartz-shales assignable to the Naiset Formation, a few metres above the base of the Peyto Formation at Mount Jimmy Simpson, indicates deepening conditions during early Peyto time. Furthermore, the occurrence of the Naiset Formation directly above Gog sandstones in the Naiset type section near Mount Assiniboine, in combination with the absence both of Peyto carbonates and of evidence for erosional removal, indicates that shales of the Naiset Formation were deposited in this basinward location at about the same time as Peyto carbonates were deposited on the shallow shelf at other locations in this study. In order to account for varying thickness of the Peyto Formation from

FIGURE 30. Photograph showing typically sharp contact (at arrow) between Peyto Formation (Gog-Peyto grand cycle) and overlying Mt. Whyte Formation (Mt. Whyte-Cathedral grand cycle). Park Boundary section, 34.6 m.

one location to another, Aitken (in press) and Hockley (1973) invoked block faulting during late Peyto time as a mechanism to explain uplift and subsequent erosional removal of Peyto limestone. However, this study shows that differences in thickness of the Peyto Formation can be explained by facies changes, and by pinching-out basinward with the Naiset and shoreward with the Gog (see Figure 25 and discussion under Lithofacies association 4).

The contact with the base of the overlying Mt. Whyte-Cathedral grand cycle is sharp (Figure 30), and is marked at every location by the appearance of fine-grained siliciclastic sediments over top of coarse quartz sands or carbonates. In the Naiset Formation, green-grey to nearly black, non-bioturbated silts and shales overlie Gog sandstone or very thin Peyto carbonate. It is at Mount Stephen where the increase in water depth across this contact is most obvious. Here, the basal Naiset consists of turbiditic, siliciclastic, slope sediments with slumps, slide scars and a debris flow deposit, and contrasts sharply with the cross-bedded, coarse, quartz sand and pebbles of the underlying Gog. In the vicinity of Mount Stephen, the Gog was interpreted by Hein (1987) as having a shallow marine shelf origin. At Mount Field, the Naiset is similar to that of Mount Stephen, but the Gog is covered, and at its type section, nearly featureless, dark grey Naiset shales overlie typical Gog. In the Mt. Whyte Formation, green-grey coloured, bioturbated quartz siltstones and fine sandstones mark the base of the Mt. Whyte-Cathedral grand cycle.

In sequence-stratigraphic models, the top of a lowstand wedge is marked by a major marine-flooding surface, which is followed by a transgressive systems tract (Van Wagoner et al. 1988). In this case, the bases of the Naiset Formation and the Weed Member of the Mt. Whyte Formation represent the marine-flooding surface, with these two formations comprising the transgressive systems tract (Figure 29). The maximum flooding surface (MFS, Walker 1990) which, in allostratigraphic models, marks the change from a landward-onlapping and upbuilding unit to a basinward-prograding wedge, is represented in this study by the base of the Chephren Member of the Mt. Whyte Formation. In this case, the limestones of the Chephren Member, which constitute the base of the Cathedral Lithosome (Aitken, 1989), prograde both basinward and shoreward, over top of siltstones and shales of the Mt. Whyte and Naiset formations respectively, and constitute the highstand systems tract (Van Wagoner et al. 1988). With diminishing shale and silt content, the Mt. Whyte and Naiset formations grade upwards into the massive carbonate of the Cathedral Formation, which likely formed a submarine escarpment with relief as high as 300 m at its basinward edge (Aitken 1989b, Aitken and McIlreath 1990, Fritz 1990; but see Ludvigsen 1989 for an alternate interpretation). As such, the Cathedral Formation represents an example of a keep-up carbonate highstand platform (Sarg 1988), as opposed to a more slowly accumulating, ramp-like, catch-up carbonate highstand platform (Sarg 1988). The early phase of the Cathedral Lithosome represented by the Chephren Member of the Mt. Whyte Formation constitutes such a catch-up platform.

The sequence top, by definition marked by an unconformity (Van Wagoner et al. 1988), possibly occurs at the top of the

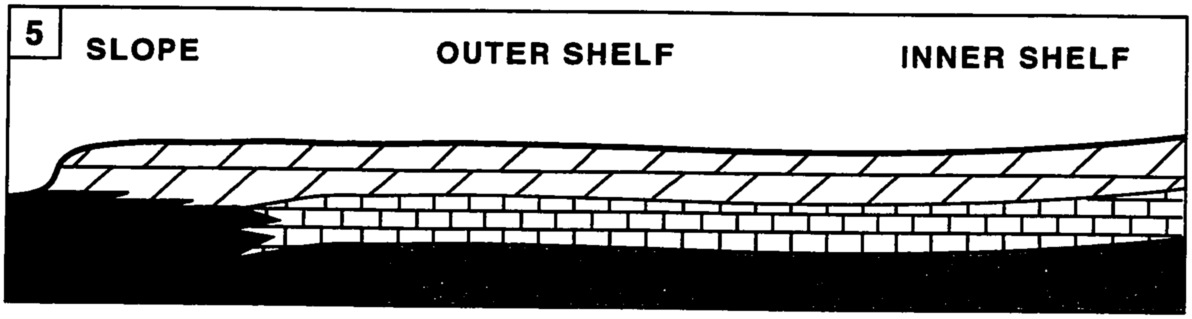
Cathedral Formation, where a disconformable relationship exists with the overlying Stephen Formation (Fritz et al. 1991, in Gabrielse and Yorath eds.). Although this sequence contains both siliciclastic and carbonate sediments (which are mixed in places), it displays most of the fundamental characteristics of the model for a type 1 sequence deposited in a basin with a shelf break (Van Wagoner et al. 1988). Such a model predicts the possibility of minor submarine erosion and nondeposition at the boundary between the lowstand systems tract and the transgressive systems tract (base of Naiset and Mt. Whyte formations in this study), but does not predict subaerial erosion or basinward shift in facies at that systems tracts boundary. The results of this study fully support the model in this regard (see section on Lower-Middle Cambrian boundary sedimentation).

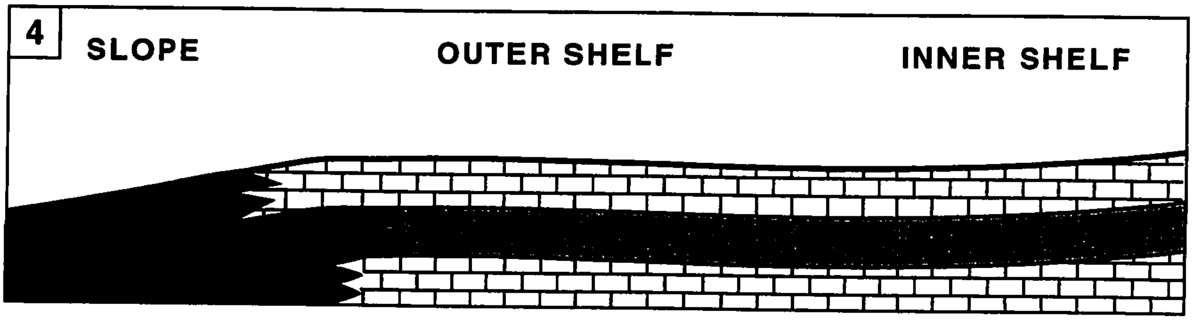
DEPOSITIONAL HISTORY

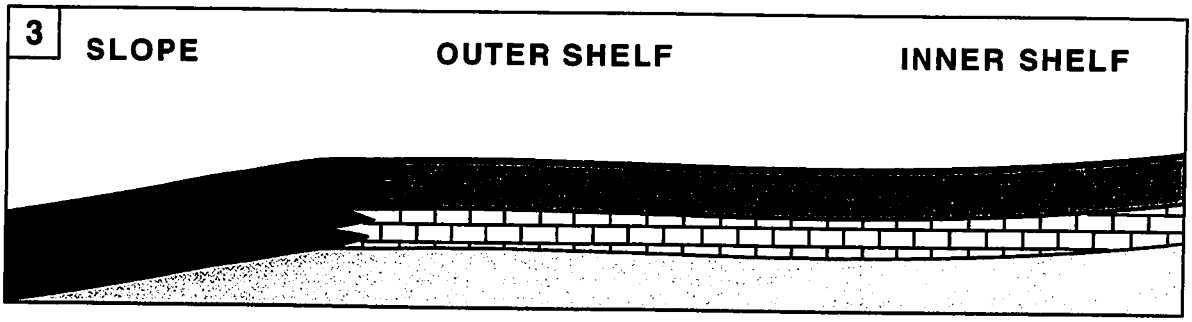
The depositional history of the study area can be summarized in five stages:

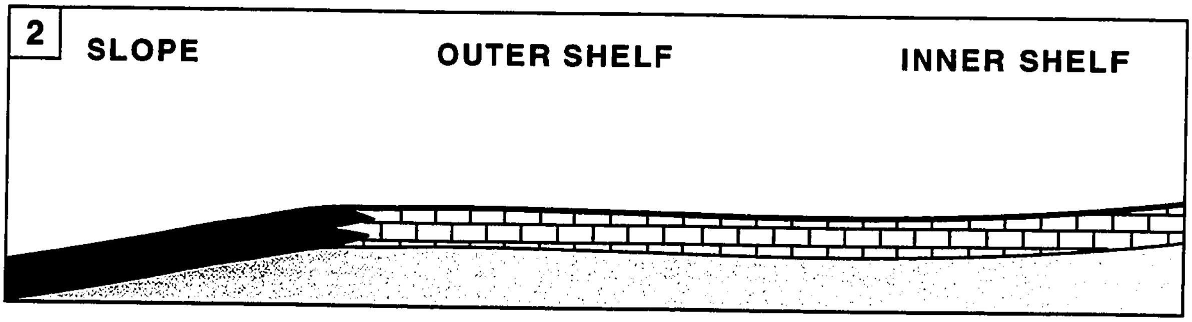
1. Just prior to deposition of the Peyto Formation, shallow marine quartz-sandstones of the Gog Group were deposited throughout the study area, including places that would later receive slope sediments of the Naiset Formation (Figure 31a).
2. During latest Early Cambrian time, shales of slope origin belonging to the Naiset Formation were deposited over top of Gog sandstone in basinward locations, while shoreward Peyto limestones were deposited over top of Gog sandstone in shallow shelf

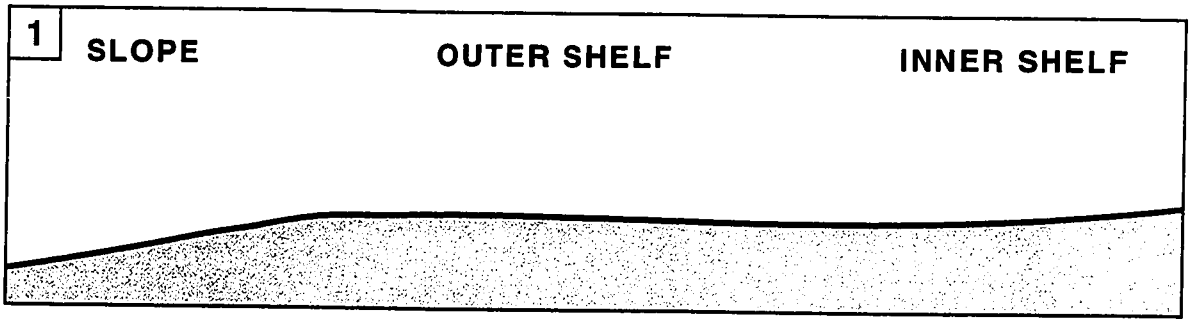
FIGURE 31. Depositional history of the Peyto, Mt. Whyte and Naiset formations in Banff and Yoho parks. 1) Early Cambrian deposition of Gog Group sandstone throughout the region. 2) Latest Early Cambrian (*Olenellus gilberti* - *puertoblancoensis* Zone) deposition of Peyto carbonate across the continental shelf, and deposition of Naiset shale and silt on the continental slope. 3) Earliest Middle Cambrian (*Syspacephalus laticeps* Zone - *Syspacephalus perola* Zone) deposition of Mt. Whyte silt (Weed Member) across the shelf, while Naiset shale and silt deposition continues on slope. 4) Middle Cambrian (*Alokistocare cleora* Zone) deposition of Mt. Whyte carbonate (Chephren Member) across shelf and initial progradation on to slope, while Naiset shale and silt deposition continues on slope. 5) Middle Cambrian (*Albertella* Zone) progradation of Cathedral lithosome across shelf and upper slope.


5
SLOPE
OUTER SHELF
INNER SHELF


4
SLOPE
OUTER SHELF
INNER SHELF


3
SLOPE
OUTER SHELF
INNER SHELF


2
SLOPE
OUTER SHELF
INNER SHELF


1
SLOPE
OUTER SHELF
INNER SHELF

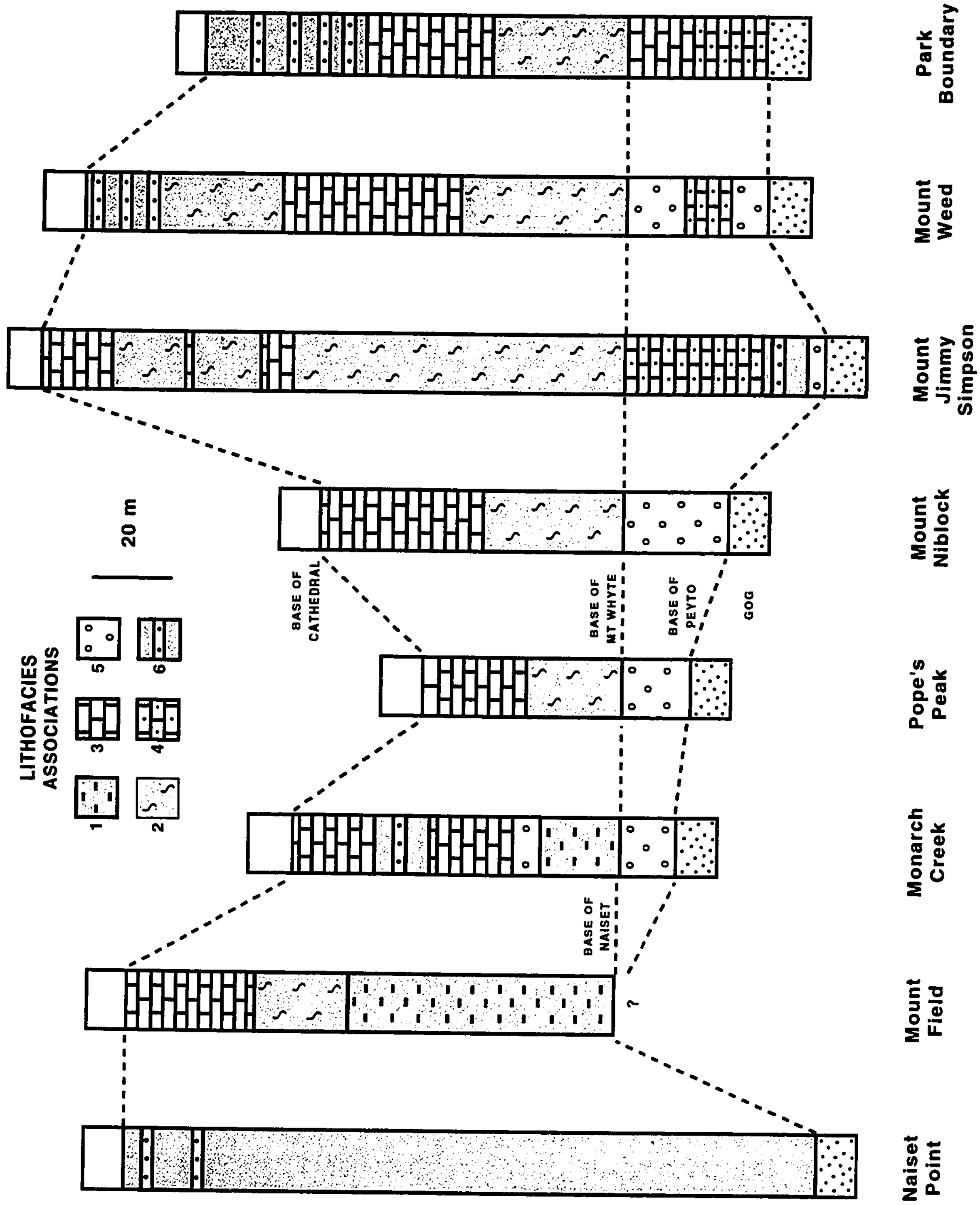
environments. Closest to shore in most places sandstone deposition continued (Figure 31b).

3. In the earliest Middle Cambrian, shales of the Naiset Formation were deposited in slope environments, while bioturbated siltstones of the Mt. Whyte Formation (Weed Member) were deposited on a shallow shelf (Figure 31c).

4. During late Mt. Whyte time, slope-derived shales and deep-water limestones of the Naiset grade upwards into shallow-water limestones, while the Cathedral lithosome (Mt. Whyte Formation) prograded basinward. At the same time, shallow-water limestones of the Mt. Whyte Formation (Chephren Member) were deposited on the shelf (Figure 31d).

5. Massive carbonates of the Cathedral Formation were deposited over top of the Mt. Whyte Formation throughout the study area (Figure 31e).

FIGURE 32. Correlation of measured sections in this thesis, with lithofacies associations as described in text. Basinward locations are to the left, shoreward locations are to the right. Note the thinning of the Peyto Formation towards the basin. Also note that the base of the Cathedral Formation is lowest near the shelf edge (around Pope's Peak). This serves to illustrate how the Cathedral lithosome prograded basinward and shoreward from an outer-shelf point of origin.


LITHOFACIES ASSOCIATIONS
1
2
3
4
5
6
20 m
BASE OF CATHEDRAL
BASE OF MT WHYTE
BASE OF PEYTO
GOG
BASE OF NAISET
?
Naiset Point
Mount Field
Monarch Creek
Pope's Peak
Mount Niblock
Mount Jimmy Simpson
Mount Weed
Park Boundary

CHAPTER 4

TRILOBITE BIOSTRATIGRAPHY OF THE PEYTO, MT. WHYTE AND NAISET FORMATIONS

INTRODUCTION

Numerous studies have documented strong biofacies differentiation of trilobite faunas on Lower Paleozoic shelves (e.g. Fortey, 1975; Robison, 1976; Ludvigsen, 1979a; Ludvigsen and Westrop, 1983; Westrop, 1986; Tremblay and Westrop, 1991; Pratt, 1992). One qualitative study identified trilobite biofacies in strata slightly younger than those of the study interval (Palmer and Halley, 1979). However, the succession of trilobite faunas across the Lower-Middle Cambrian boundary is poorly known, so lowest Middle Cambrian strata have often been recognized by an absence of Olenellus, in conjunction with the presence of supposed 'Middle Cambrian' genera. Such a definition of the Lower-Middle Cambrian boundary is obviously imprecise, and hinders the understanding of geologic events which took place over this interval in the study area. Ludvigsen et al. (1986) have argued that biostratigraphic units, e.g. zones, must be established in the context of environmental distribution patterns of taxa, as expressed by biofacies. This approach will be followed here.

TRILOBITE BIOFACIES

Introduction

The purpose of this portion of the chapter is to identify the small-scale spatial distribution patterns of trilobite genera (biofacies), and to relate these patterns to lithofacies. These biofacies will permit the construction of a biostratigraphic framework that is sensitive to the environmental distribution patterns of trilobite genera.

Biofacies analysis

Following common procedure (e.g. Ludvigsen, 1979a; Ludvigsen and Westrop, 1983; Westrop, 1986; Tremblay and Westrop, 1991), several trilobite biofacies are based upon relative abundance data from large collections which have been gathered mainly from single beds. Twenty-one collections obtained from the three formations in the study interval have yielded 1,686 individuals. Individuals were identified to the genus level for the purpose of the biofacies study. Biofacies are based on recurrent associations of genera, and are named for dominant genera.

Biofacies were first defined by visual comparison of pie-diagrams constructed for each collection. This method is quick, and provides a visually attractive result. Then, Q- and R-mode cluster analysis, using Pearson's product-moment correlation coefficient as a measure of similarity, was performed on the relative abundance data. This technique both confirmed and summarized the results of the pie-diagram assessment. The results were replotted with collections on the Q-mode axis and genera on the R-mode axis. Intersections of Q- and R-mode clusters define biofacies (Figure 33). These analytical methods resulted in the delineation of five

FIGURE 33. Reordered data matrix formed by Q-mode clustering of collections and R-mode clustering of taxa. Percentage values are shown in four graduated size classes. Intersections of Q- and R-mode clusters define five biofacies: _Periomma_ Biofacies, _Onchocephalites_ Biofacies, _Syspacephalus_ Biofacies, _Antagmus_ Biofacies, and _Plagiura_ Biofacies.

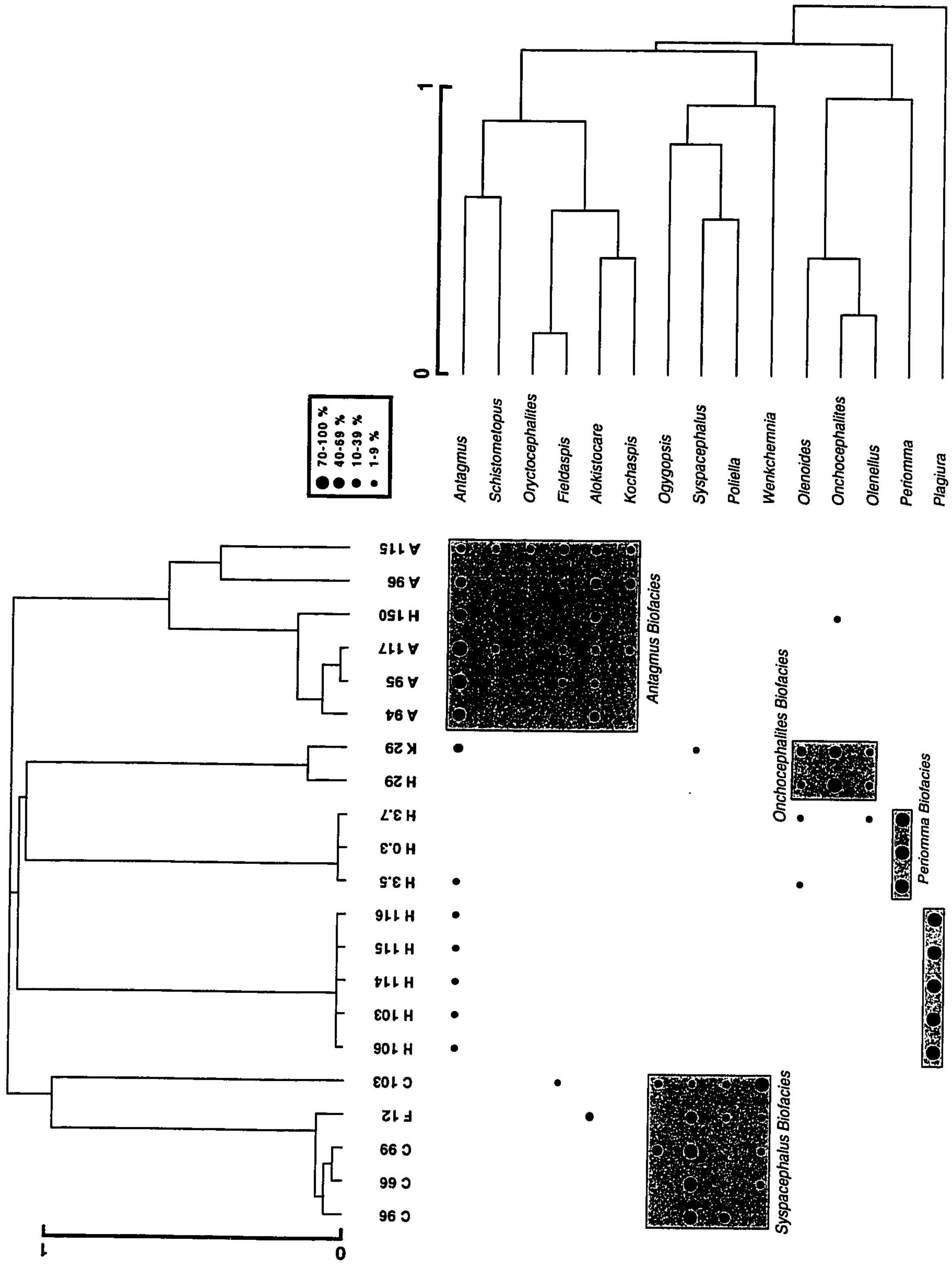
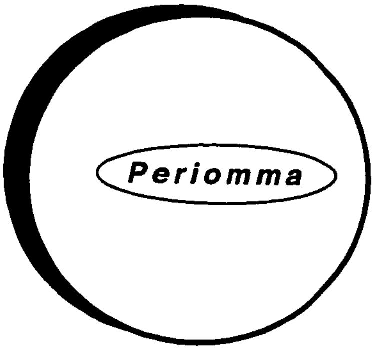

70-100 %
40-69 %
10-39 %
1-9 %
0
1
Antagmus
Schistometopus
Oryctocephalites
Fieldaspis
Alokistocare
Kochaspis
Ogygopsis
Syspacephalus
Poliella
Wenkchemnia
Olenoides
Onchocephalites
Olenellus
Periomma
Plagiura
A 115
A 96
H 150
A 117
A 95
A 94
K 29
H 29
H 3.7
H 0.3
H 3.5
H 116
H 115
H 114
H 103
H 106
C 103
F 12
C 99
C 66
C 96
0
1
Antagmus Biofacies
Onchocephalites Biofacies
Periomma Biofacies
Plagiura Biofacies
Syspacephalus Biofacies

FIGURE 34. Pie graphs illustrating the distribution of trilobite genera in three collections from the *Periomma* Biofacies.

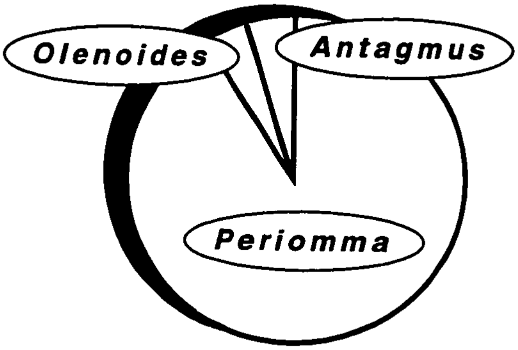
PERIOMMA BIOFACIES

H 0.3



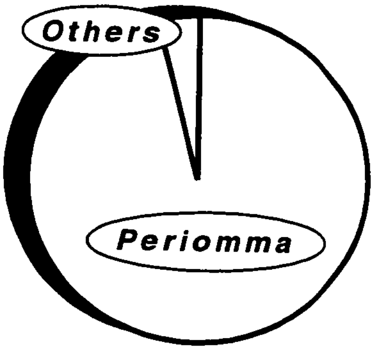
n=50

H 3.5



n=75

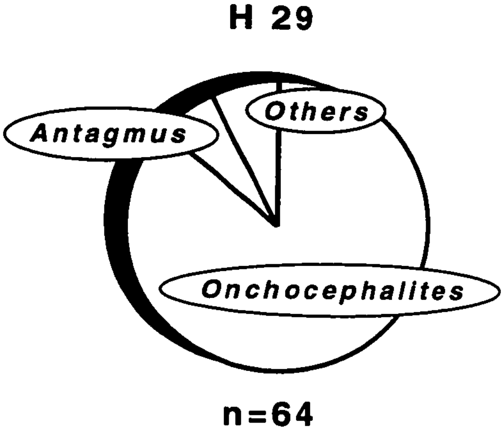
H 3.7



n=95

FIGURE 35. Pie graphs illustrating the distribution of trilobite genera in two collections from the <u>Onchocephalites</u> Biofacies.

ONCHOCEPHALITES BIOFACIES



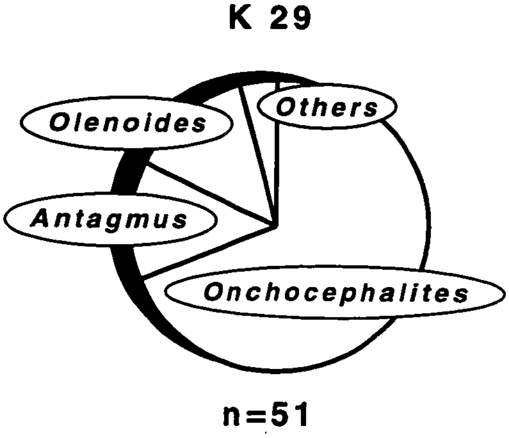
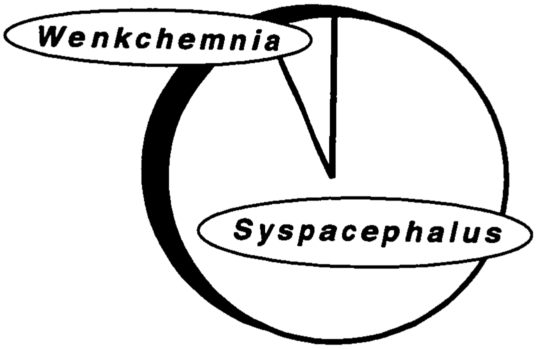


FIGURE 36. Pie graphs illustrating the distribution of trilobite genera in four collections from the *Syspacephalus* Biofacies.

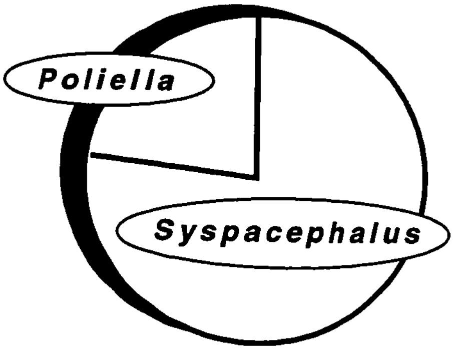
SYSPACEPHALUS BIOFACIES

C 65



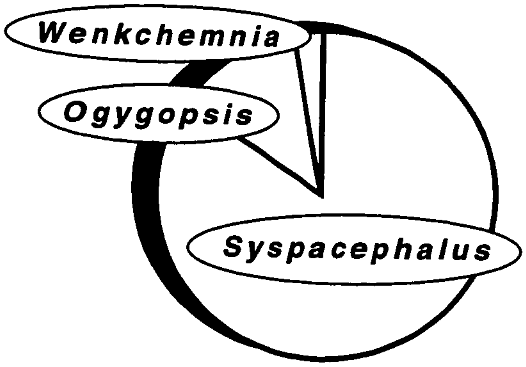
n=61

C 96-97



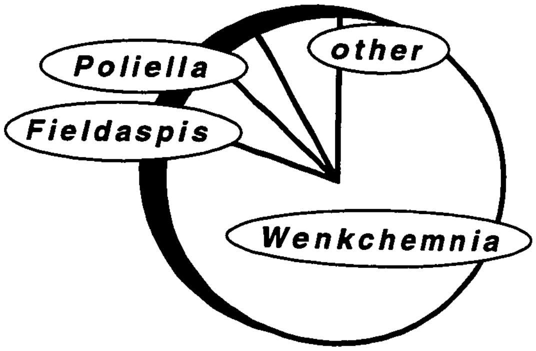
n=47

C 99



n=104

C 103-106

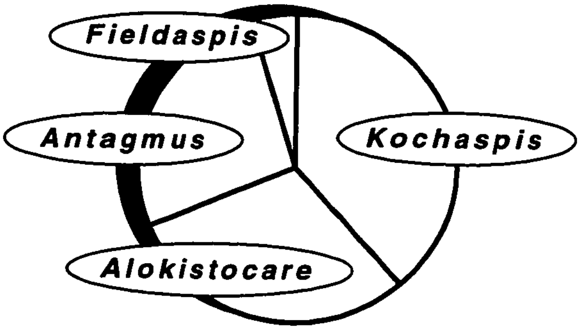


n=41

FIGURE 37. Pie graphs illustrating the distribution of trilobite genera in four collections from the _Antagmus_ Biofacies.

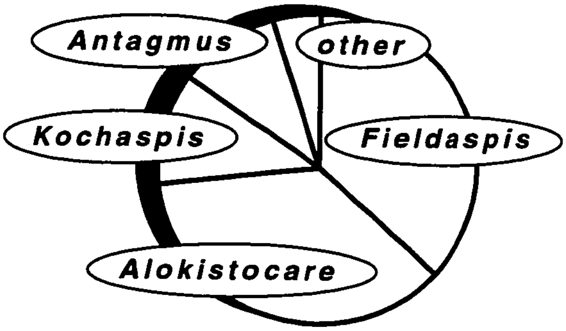
ANTAGMUS BIOFACIES

A 96



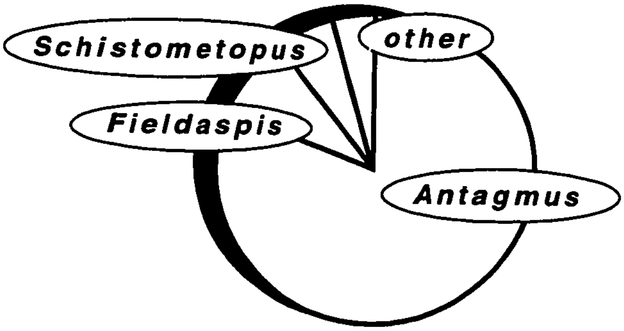
n=42

A 115



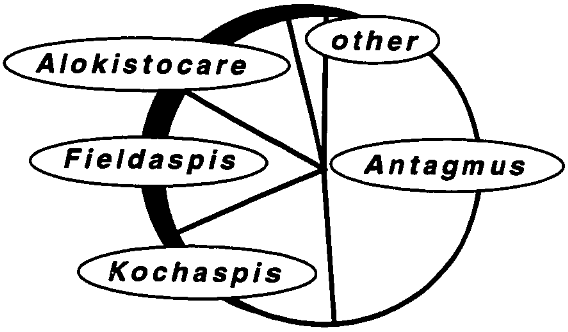
n=205

A 117



n=116

H 150

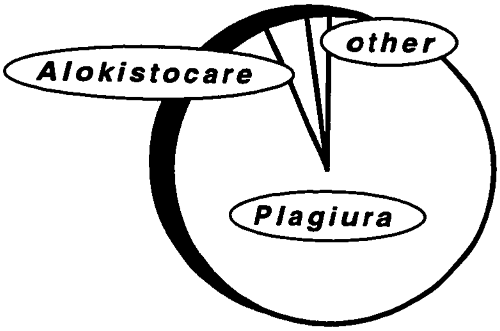


n=60

FIGURE 38. Pie graphs illustrating the distribution of trilobite genera in four collections from the Plagiura Biofacies.

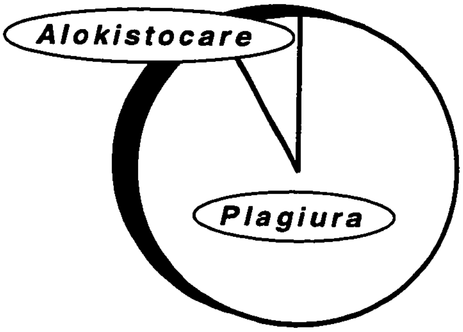
PLAGIURA BIOFACIES

H 103



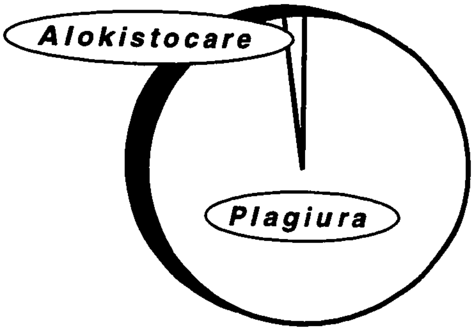
n=106

H 106



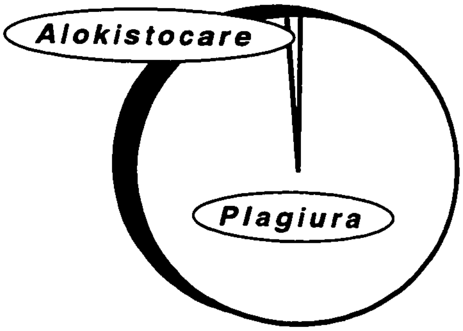
n=66

H 114



n=51

H 116



n=82

biofacies. These are described below, along with a Q- and R-mode data matrix, and pie-diagram illustrations of representative collections.

1. *Periomma* Biofacies (Figure 34) (Collections H0.3, H3.5, and H3.7) — Late Early Cambrian, in light coloured, sandy limestones of the Peyto Formation at Mount Weed, represented by low-diversity collections dominated by *Periomma* and with subordinate *Olenoides*, *Olenellus*, and *Antagmus*. It is associated with high-energy, shallow-subtidal carbonate depositional environments which were likely located shoreward of oolitic sand shoals.

2. *Onchocephalites* Biofacies (Figure 35) (collections H29, and K29) — Late Early Cambrian, in light coloured lime-mudstones of the Peyto Formation at Mount Weed and Mount Shaffer, dominated by *Onchocephalites*, with *Periomma*, *Olenoides*, and *Olenellus*. It is associated with shallow-subtidal carbonate depositional environments.

3. The *Syspachephalus* Biofacies (Figure 36) (Collections C65, C96, C99, C103, and F12) — Latest Early Cambrian to earliest Middle Cambrian, in dark coloured shales and limestones of the Naiset Formation at Mount Stephen, and in green coloured shales at Pope's Peak. Elements also occur at Mount Field and Mount Niblock in shales which should be considered tongues of the Naiset Formation. Associated sedimentary facies represent deep subtidal, outer shelf to upper slope environments. *Syspacephalus* is dominant, while

other taxa include Wenkchemnia, Alokistocare, Poliella, Ogygopsis, and Fieldaspis. All of these trilobites were included by Rasetti (1951) in his Wenkchemnia - Stephenaspis Zone.

4. Antagmus Biofacies (Figure 37) (collections A94, A95, A96, A115, and A117) — Early Middle Cambrian, in Mt. Whyte limestones at most locations. Relatively high diversity collections contain, in decreasing order of dominance, Antagmus, Alokistocare, Fieldaspis, Kochaspis, Solenopleurella, and Oryctocephalites. This biofacies is associated with subtidal, below normal wave base, carbonate facies attributed to an outer shelf depositional environment.

5. Plagiura Biofacies (Figure 38) (collections H103, H106, H114, H115, and H116) — Coeval with the Antagmus Biofacies, in upper Mt. Whyte Formation only at Mount Weed. Very low-diversity collections are dominated by Plagiura. Small numbers of Alokistocare allow for correlation with the Antagmus Biofacies. It is associated with shallow subtidal depositional environments which were located relatively nearshore compared to more diverse, contemporaneous biofacies. This association between very low-diversity trilobite biofacies and very shallow subtidal ("nearshore") depositional environments has been previously documented from Middle Cambrian through Ordovician fossil communities (Westrop et al., 1994; Palmer and Halley, 1979). The present study further demonstrates that low-diversity trilobite associations were present in nearshore environments as early as the Middle Cambrian.

Biofacies distribution and interpretation

With the exception of trilobite biofacies proposed for the *Albertella* Zone of the Carrara Formation in the Great Basin (Palmer and Halley 1979), no paleoecologic analysis has been published for rocks of similar age as the study interval. Moreover, other than studies by Fritz (1972, 1991), there is a paucity of published, reliable data on bed-by-bed, relative abundance of trilobites of this age. Close comparisons can be made, however, between this study and the work of Palmer and Halley (1979). In both the early Middle Cambrian portion of the study interval and the Carrara Formation, there is a similarity in upper-slope/outer-shelf biofacies containing *Ogygopsis*, outer-shelf biofacies containing Corynexochids (*Fieldaspis*, *Albertella*), and inner-shelf biofacies dominated by Alokistocariids (*Plagiura*, *Mexicella*). These similarities, as well as differences, will be discussed below, in addition to comparisons with some of Fritz's Lower Cambrian work.

1. The upper Lower Cambrian *Periomma* Biofacies belongs to the *Olenoides fieldensis* Zone, and thus is the oldest trilobite community identified in this study. It occurs in Lithofacies Association 3, where abundant quartz sand, oncolites, and thin oolitic beds indicate a high-energy, shallow-subtidal shelf depositional environment. Its location eastward of the nearby thick-bedded oolite at Mount Jimmy Simpson suggests that this trilobite community inhabited a site shoreward of oolitic sand shoals. There is scant evidence from the study area to indicate that a coeval *Olenellus* - dominated biofacies may exist basinward of the oolitic shoals. Although the green shales, which occur interbedded with the fossiliferous limestones in

this biofacies at Mount Weed, are barren, a small collection made from similar shales near the base of the Peyto Formation at Mount Jimmy Simpson yielded only a few cephala of Olenellus.

Both Lochman (1952) and Fritz (1991) have suggested that uppermost Lower Cambrian strata (Bonnia - Olenellus Zone) may be characterized by an abundance of ptychopariid trilobites along with olenellids. This certainly seems to be the case with shallow carbonate-shelf facies. Fritz (1991) identified seven ptychopariid genera (recognized as four genera herein) from carbonates of the uppermost Lower Cambrian Illtyd Formation in the Yukon Territory. Of these, Antagmus and Syspacephalus occur in the Peyto Formation, whereas Proliotracus and Variopelta are absent. All of these genera occur in the Bonnia - Olenellus Zone of the Sekwi Formation in the Northwest Territories (Fritz, 1972). Although detailed lithologic information is not presented in Fritz's (1972, 1991) published reports, it is clear that neither the Sekwi nor the Illtyd Formation contains significant amounts of oolite. This contrasts sharply with extensive oolite shoals developed in the Peyto Formation. In fact, both of the Peyto biofacies occur partly in oolitic limestone. This lithologic difference and the implied contrast in depositional environments may account for the apparent biofacies differences between the Peyto and the Illtyd/Sekwi formations.

2. The uppermost Lower Cambrian Onchocephalites Biofacies occurs in similar lithofacies to the Periomma Biofacies, although at Mount Shaffer, it is in non-oolitic lime mudstone. This biofacies is characterized by an abundance of the small, smooth, ptychopariid

Onchocephalites. Onchocephalites occurs throughout Middle Cambrian carbonates, including the Mt. Whyte Formation.

3. The Syspacephalus Biofacies occurs in uppermost Lower Cambrian to lowest Middle Cambrian strata with Lithofacies Association 1 of the Naiset Formation. Characterized by an abundance of the eponymous genus, this deep-water slope biofacies represents a trilobite community that existed during the period in which Olenellus became extinct. At North Gully on Mount Stephen, this biofacies occurs in beds that correlate with units below the highest occurrence of Olenellus, a few hundred metres to the east at Monarch Creek (see Figures 26, 27). At Pope's Peak and Mount Niblock, the Syspacephalus Biofacies occurs about 4 m above the highest occurrence of Olenellus. In most of these cases, Olenellus is restricted to high-energy packstones and grainstones (coquinas), while the Syspacephalus Biofacies occurs in lower-energy, thinly laminated black limestone, or green to black shale. The Olenellus-bearing grainstones were likely reworked by storms. In contrast, the trilobites of the Syspacephalus Biofacies are frequently preserved intact. It is worth noting that complete trilobites are more common in the black shales at Mount Stephen than in the green shales at Popes Peak or Mount Niblock.

It seems possible that towards the end of its stratigraphic range, Olenellus became restricted to shallow carbonate-shelf environments, while pytchopariids and corynexochids exploited deeper water facies where olenellids once dominated.

The trilobite Ogygopsis occurs in thinly laminated, black lime-mudstone beds of the Syspacephalus Biofacies at North Gully on

Mount Stephen. This deep-water occurrence of Ogygopsis in the Naiset Formation compares closely with its occurrence locally in the Stephen Formation (Rasetti, 1951), the Carrara Formation of the Great Basin (Palmer and Halley, 1979), the Kinzers Formation in southeastern Pennsylvania (Campbell, 1971), and other locations (Nelson, 1963). Indeed, Palmer and Halley (1979) concluded that the occurrence of Ogygopsis is indicative of carbonate platform-margin deposition throughout the early half of the Middle Cambrian. This study supports that conclusion.

Although nowhere does the Syspacephalus Biofacies share any species with a carbonate-shelf biofacies, it does include the genera Alokistocare and Fieldaspis which occur widely across younger shelf biofacies described below. A. agnesensis and F. bispinosa from this biofacies are older than A. cleora and species of Fieldaspis from the Antagmus Biofacies.

4. The Antagmus Biofacies belongs to the Middle Cambrian Alokistocare cleora Zone. It occurs in lithofacies C and D, where thin oolitic and bioclastic-grainstone beds indicate deposition on a high-energy, shallow-subtidal shelf. The occurrence of Alokistocare and Fieldaspis, which also occur in the upper-slope Syspacephalus Biofacies, the close association with thick, laminated shales a few metres below at Mount Field and its location in the westernmost outcrop of the Mt. Whyte Formation, suggest that this trilobite community existed near the edge of the carbonate shelf.

In some respects, this biofacies is similar to the Lower Cambrian Periomma Biofacies. Both were deposited close to oolitic shoals, and both are dominated by ptychopariids. Although no Lower

Cambrian corynexochids were encountered in this study, Rasetti (1951) reported Zacanthopsis from the Peyto at Mount Shaffer, and Fritz (1972, 1991) recovered this genus from the Bonnia - Olenellus Zone of the Sekwi and Illtyd formations. The corynexochid Fieldaspis is a major constituent of the Antagmus Biofacies.

The presence of Fieldaspis here allows a comparison with the younger Albertella - Mexicella Biofacies of Palmer and Halley (1979). This biofacies, characterized by a single corynexochid, occurs in carbonate platform/terrigenous clastic sediments. Palmer and Halley's biofacies appears to have had a stronger terrigenous clastic influence, and, apparently, a lower species diversity, than the Antagmus Biofacies.

5. The Plagiura Biofacies, also in the Alokistocare cleora Zone, has no apparent analogue in Lower to Middle Cambrian rocks. Its very low diversity in large collections and association with very shallow subtidal carbonates distinguished by oncolites and stromatolites, compares very closely with Ordovician nearshore biofacies characterized by Bathyurus (Tremblay and Westrop, 1991; Westrop et al., 1995). This association with very shallow subtidal rocks and its eastern location at Mount Weed combine to suggest that the Plagiura Biofacies was deposited shoreward of the Antagmus Biofacies.

TRILOBITE ZONES

Introduction

As discussed in the previous section, trilobites are highly facies-specific and their spatial segregation across the continental shelf and slope can be described with biofacies. Ludvigsen et al. (1986) demonstrated the utility of establishing species-based zones for different, coeval biofacies. The result of this "dual biostratigraphy" method are parallel sets of zones for different biofacies, correlation between which is made by the presence of relatively rare, shared species. In some cases, single sequences of zones extending over two or more biofacies may be recognizable. In this study, assemblage zones with their bases defined by the first appearance of the eponymous species are used.

Every North American biostratigraphic study in the past has relied upon the range of the genus Olenellus to define all, or more recently, the upper third, of trilobitic Lower Cambrian strata. Walcott's Olenellus Zone, the Olenellus - Bonnia Zone of Deiss (1939) and, later, the Bonnia - Olenellus Zone of Rasetti (1951) were used to define the entire Lower Cambrian, until Fritz (1972) added the basal Cambrian Fallotaspis and Nevadella Zones below the Bonnia - Olenellus Zone. But even as the upper part of a tripartite division of the Lower Cambrian, the Bonnia - Olenellus Zone has a considerable thickness — over 800 m in some places. This does not allow correlation on a fine scale. In his work on uppermost Lower Cambrian trilobites from the northern Cordillera, Fritz (1991) alluded to the possibility of further subdividing the Bonnia-Olenellus Zone, but was unable to establish species-based zones that could be correlated between widely separated regions of the Cordillera. Implicitly recognizing biofacies differentiation among these two genera, Palmer and Repina (1993) noted that Bonnia was restricted to carbonate shelf deposits and was restricted to the upper portion of the Olenellus range-zone. Consequently, as an alternative to the Bonnia-Olenellus Zone, they proposed an Olenellus Zone subdivided into three informal parts, the middle being the Wanneria range-zone and the upper and lower parts undefined. With new data from the Peyto and Naiset formations, it is now possible to propose two new, partly coeval species-based zones to replace the upper portion of the Bonnia-Olenellus Zone. The Olenoides fieldensis Zone is recognizable throughout North America, while the Syspacephalus laticeps Zone is more useful locally (see Figure 3).

New zones for the Middle Cambrian of the Naiset and Mt. Whyte formations are also proposed. They recognize the profound biofacies differentiation of trilobite faunas in the study interval.

Description and correlation of zones

1. Upper Lower Cambrian

Strata occupying this interval in the study area encompass the Olenoides fieldensis Zone. This zone is entirely Early Cambrian in age, and contains the youngest occurrence of Olenellus and Olenoides (= Bonnia) in the study interval.

Olenoides fieldensis Assemblage Zone (new).

This zone is developed in the Onchocephalites Biofacies of the Peyto Formation and in a tongue of the Naiset Formation at Mount Jimmy Simpson. The base is defined by the first appearance of Olenellus gilberti Meek and the zone continues upward to include Olenellus sp. 1. The top of the zone is undefined. Other species in the study area include Olenellus sp. 2, O. romensis Resser and Howell, Olenoides columbensis (Resser), O. fieldensis (Walcott), Luxella lux (Walcott), Onchocephalites unca (Walcott), Antagmus cleon (Walcott), A. thia (Walcott), A. pia (Walcott), Periomma cf. walcotti Resser, and Syspacephalus charops (Walcott).

Bonnima Fritz is notably absent from the Peyto Formation. Fritz (1991) suggested that this genus is characteristic of the uppermost Lower Cambrian in the Illtyd Formation, and postulated that its apparent absence in the Sekwi Formation may be due to an erosional unconformity below the Middle Cambrian. However, it is now clear that "Bonnia sp. 3" from the Sekwi (Fritz 1972) almost certainly belongs to Bonnima (see systematic paleontology section). As an alternative, Fritz (1991) also suggested that the contrast of faunas between those two locations may be due to environmental differences. An environmental explanation probably best accounts for the absence of Bonnima from the Peyto Formation.

Bonnima is known from the Illtyd Formation (the type area), the Sekwi Formation (see above), and isolated boulders along the St. Lawrence River (Rasetti 1948). In boulder L2 of the Ville Guay conglomerate, Bonnima laevigata (Rasetti) is associated with Periomma walcotti. The similar Periomma cf. walcotti occurs in the Olenoides fieldensis Zone of the Peyto Formation. This suggests that the absence of Bonnima from the Peyto Formation is due to facies differences rather than an unconformity. Bonnima consistently occurs in non-oolitic limestone, whereas the Peyto contains abundant oolite.

Fritz (1991) recovered numerous specimens of *Olenoides columbensis* from the upper half of the Illtyd Formation. This occurrence suggests that this interval is also in the *Olenoides fieldensis* Zone.

In the seven highest Lower Cambrian collections from the Sekwi Formation in the Mackenzie Mountains (Fritz, 1972), *Antagmus pia* occurs along with *Olenoides columbensis*. These species date this interval of the Sekwi as part of the *Olenoides fieldensis* Zone.

Both *Olenellus gilberti* and *Olenellus puertoblancoensis* range throughout the Lower Cambrian portion of the Carrara Formation in Nevada and California, indicating an *Olenoides fieldensis* Zone age.

2. Lower / Middle Cambrian boundary beds

The only place in the study area where the Lower / Middle Cambrian boundary is recognizable, and occurs without a biofacies shift, is in the Naiset and Mt. Whyte formations at Mount Stephen. Here, the *Syspacephalus* Biofacies contains a zone whose lower portion is correlative with the highest occurrence of *Olenellus* at Mount Stephen.

Syspacephalus laticeps Assemblage Zone (new).

This zone is developed in the *Syspacephalus* Biofacies of the Naiset Formation and is partly coeval with the *Olenoides fieldensis* Zone. No species are shared between the two zones because they occur in different biofacies. The first occurrence of *Syspacephalus laticeps* Rasetti defines the base of this zone, which also includes *Syspacephalus crassus* Rasetti, *Wenkchemnia walcotti* Rasetti, Fieldaspis bispinosa (Rasetti), Poliella denticulata Rasetti, Antagmus tuberculata (Rasetti), and Ogygopsis klotzi Rominger. The top of this zone is defined by the base of the Syspacephalus perola Zone.

The Syspacephalus laticeps Zone is known only from Mount Stephen, and, so far, has not been recognized outside of the study area. This is due in part to the restriction of the biofacies in which most of these trilobites occur to slope deposits, and to the rarity of fossiliferous slope deposits spanning the Lower / Middle Cambrian boundary. Although all of these genera are normally thought of as characteristic of Middle Cambrian rocks, only Poliella and Fieldaspis were previously unrecorded from strata of Early Cambrian age.

3. Middle Cambrian

In the study area, two zones are entirely Middle Cambrian in age. The older zone occurs in the Syspacephalus Biofacies, and the younger one occurs across the three other Middle Cambrian biofacies.

Syspacephalus perola Assemblage Zone (new).

The first occurrence of the Syspacephalus perola defines the base, and this zone also includes Syspacephalus gregarius Rasetti, Wenkchemnia spinicollis Rasetti, Wenkchemnia walcotti Rasetti, Fieldaspis bispinosa Rasetti, Poliella prima (Walcott), and Alokistocare agnesensis (Walcott). Although the top of this zone is undefined, beds yielding Alokistocare agnesensis and Plagiura cercops are overlain by the A. cleora Zone at Mount Weed. The Syspacephalus perola Zone immediately overlies the S. laticeps Zone on Mount Stephen, and also occurs in shales assigned to the Naiset Formation at Popes Peak and Mount Niblock. It is, therefore, the oldest, entirely Middle Cambrian Zone in the study area.

Trilobites of the *S. perola* Zone, as with most from the underlying *S. laticeps* Zone, do not occur outside of the study area. Like the *S. laticeps* Zone, one probable cause for this is the restriction of the *Syspacephalus* biofacies to slope-deposits, and to the rarity of fossiliferous slope-deposits of this age in other regions.

Alokistocare cleora Assemblage Zone (new).

This zone occurs in the *Antagmus* and *Plagiura* biofacies of the Mt. Whyte Formation, and its base is defined by the first appearance of *Alokistocare cleora*. Other species are *Plagiura cercops*, *Fieldaspis furcata*, *F. bilobata*, *F. superba*, *Antagmus fieldensis*, *A. maior*, *A. depresus*, *A. sublaevus*, *A. skapta*,A? gibbosa, *A. columbiana*, *A. lata*, *A. buttsi*, *Onchocephalites laevis*, *Caborcella rara*, *Kochaspis eiffelensis*, *Alokistocare*? *maxeyi*, *Schistometopus collaris*, *S. convexus*, *S. minor*, and *Oryctocephalites resseri*. The top of this zone is defined by the base of the *Albertella* Zone.

Although the *A. cleora* and *S. perola* zones contain no species in common, these two zones may be partly coeval, and their superposition a result of a biofacies shift bringing trilobites of the shallower water *A. cleora* Zone to an area which previously was inhabited by trilobites of the deeper water *S. perola* Zone. This interpretation is suggested by the fact that the *A. cleora* Zone contains *Fieldaspis furcata* which has been recovered from earliest Middle Cambrian rocks of the Illtyd Formation (Fritz, 1991).

Albertella Assemblage Zone (Deiss 1940).

Overlying the *A. cleora* Zone, the *Albertella* Zone is represented in this study only by a small collection from the basal Cathedral Formation at Park Boundary. In this collection, *Syspacephalus tardus* occurs with *Albertella* sp.

Discussion

Rasetti (1951) divided the Middle Cambrian portion of the study interval into two zones: the *Wenkchemnia* - *Stephenaspis* Zone and the overlying *Plagiura* - *Kochaspis* Zone. Figure 3 compares these zones with the zones proposed herein. It is easy to see why Rasetti's zonation scheme has not been useful in other areas. Trilobites of the *Wenkchemnia* - *Stephenaspis* Zone are virtually restricted to the outer-shelf *Syspacephalus* Biofacies, which is poorly represented outside of the study area. In places where trilobites have been recovered from Mid-Cambrian superjacent to Lower Cambrian strata, they belong to the *Antagmus* or *Plagiura* biofacies, and thus represent the *Plagiura* - *Kochaspis* Zone, which Rasetti regarded as overlying the *Wenkchemnia* - *Stephenaspis* Zone. Adhering strictly to Rasetti's zonation, one might assume that a zone is missing in such cases. When placed in the context of biofacies, it can be seen that a zone is not necessarily missing. Furthermore, there is good evidence for the lower portion of Rasetti's *Wenkchemnia* - *Stephenaspis* Zone to be Early Cambrian.

Rasetti's Plagiura - Kochaspis Zone contains trilobites of the Antagmus and Plagiura biofacies. In keeping with the practice of using species for zonal indices, this zone is assigned to the Alokistocare cleora Zone. Note that this zone may include part of Rasetti's Wenkchemnia - Stephenaspis Zone.

The Plagiura - Poliella Zone, which is currently used by most workers, includes all Middle Cambrian strata below the Albertella Zone. Because it includes species of the Syspacephalus laticeps Zone, the lowest portion of the Plagiura - Poliella Zone is Early Cambrian in age. The zonal indices are trilobites from opposite ends of the biofacies spectrum that never occur together. Moreover, Plagiura and Poliella are rare elements in most collections outside of the Plagiura and Syspacephalus biofacies, although their stratigraphic ranges within these biofacies, at least for Poliella, extend above the Plagiura - Poliella Zone (Palmer and Halley, 1979).

Palmer and Halley (1979) used the "Plagiura-Poliella Zone" for the lower Mid-Cambrian interval of the Carrara Formation which they could not place in Rasetti's (1951) zones below the Albertella Zone. Some of the strata were assigned to this zone on the basis of small collections containing new species, i.e. Poliella lomataspis Palmer, plus new species of Syspacephalus, Oryctocephalus, Pagetia, and two indeterminate kochaspids. These were the lowest post-Olenellus collections obtained from sections in the Belted Range and the Groom Range (Palmer and Halley, 1979, Pl. 17). Although the genera included in these collections suggest an affinity with the Syspacephalus Biofacies, no species are shared with the study area. Considering that the next highest collections in the Belted Range yield Albertella Zone trilobites, it seems possible that Palmer and Halley's lowest "Plagiura-Poliella Zone" collections are younger than the S. perola Zone of the study area. In this case they are either younger than, or partly coeval with, the A. cleora Zone of the study area.

CHAPTER FIVE

SYSTEMATIC PALEONTOLOGY

All figured specimens are housed at the Royal Ontario Museum.

Glabellar lobes (L) and furrows (S) are numbered from back to front, and any reference to the glabella does not include the occipital ring.

Order Redlichiida Richter, 1933

Suborder Olenellina Walcott, 1890

Superfamily Olenellaceae Walcott, 1890

Family Olenellidae Walcott, 1890

Subfamily Olenellinae Walcott, 1890

Genus _Olenellus_ Hall, 1861

DIAGNOSIS

See Palmer and Repina (1993).

TYPE SPECIES

Olenellus thompsoni Hall, 1861, from the Lower Cambrian Parker Slate, Georgia, Vermont (subsequent designation by Walcott, 1886).

DISCUSSION

Palmer and Repina (1993) recently proposed that _Olenellus_ includes five subgenera: _Olenellus_ (_Olenellus_), _O_. (_Angustolenellus_),

O. (Mesolenellus), O. (Mesonascis) and O. (Paedeumias). These were based on variations among several characters including position of genal and intergenal spines, length of preglabellar field, and termination and curvature of palpebral lobes. Only one of these characters may be of diagnostic value - the length of the preglabellar field is greater than twice the length of the anterior border only in O. (Paedeumias). Genal angles which are advanced, intergenal spines closer to genal spines or axial furrows, and straight or curved posterior tips of palpebral lobes occur in more than one subgenus and, on their own, can not be used to diagnose any one subgenus. Because Palmer and Repina's (1993) subgenera are based on combinations of characters that occur widely in Olenellus, and cannot be diagnosed with unique characters, they are not used herein. Olenellus occurs rarely in the Peyto and Naiset formations, and the material is generally poorly preserved.

Olenellus gilberti Meek, 1874

Pl. 1, figs. 4-7.

Olenellus gilberti — Palmer and Halley, 1979:71, pl. 3, figs. 6-13 (see for full synonymy).

HOLOTYPE

From the Pioche Hills, Nevada.

DIAGNOSIS

A species of Olenellus with a broad cephalic border, palpebral lobes terminating near the middle of L1, and slightly advanced genal angles.

MATERIAL

Eight partial or complete cephala.

OCCURRENCE

Peyto Formation, Mount Weed (H 29 m), Mount Shaffer (K 29 m), and Mount Jimmy Simpson (I 10 m, I 24 m).

DISCUSSION

Its relatively small L4 distinguishes Olenellus gilberti from O. romensis. It differs from O. puertoblancoensis in having shorter palpebral lobes reaching back to the midpoint of L1, rather than the occipital furrow, and a wider border. Olenellus thompsoni (see Whittington 1989, Fig. 1) has longer palpebral lobes, and less advanced genal angles. Olenellus clarki (see Palmer and Halley 1979, Pl. 3, figs. 1-5) has longer palpebral lobes reaching back to the occipital furrow. Olenellus gilberti is the most common species of Olenellus in the Peyto Formation, occurring at three different locations.

Olenellus romensis Resser and Howell, 1938

Pl. 2, figs. 1-4.

Olenellus romensis Resser and Howell, 1938:221, pl. 7, figs. 4-6, pl. 12, figs. 2, 3.

Olenellus romensis—Resser, 1938:52, pl. 5, fig. 12.

HOLOTYPE

Cotype cephala from the Lower Cambrian Rome Formation, Cleveland, Virginia, illustrated by Resser and Howell, 1938, Pl. 7, figs. 4-6 (by original designation).

DIAGNOSIS

A species of Olenellus having an hourglass-shaped glabella with greatly expanded anterior glabellar lobe, metagenal ridge, small intergenal spine, and advanced genal angle.

MATERIAL

Two partial cephala, and numerous fragments.

OCCURRENCE

Lower Peyto Formation, Park Boundary (J 6 m), and Pope's Peak (F 3 m).

DESCRIPTION

Cephalon with broadly curved anterior margin. Hourglass shaped glabella with axial furrows that gradually converge from occipital ring to base of L2, diverge sharply to L4, then converge gently to merger with anterior furrow. Anterior glabellar lobe strongly curved in front, terminates just behind anterior border. Occipital and glabellar furrows deep, but become shallow across axial crest. S1 straight and angled slightly backward; S2 broadly curved backward; S3 angled slightly less backward than S1. Raised and relatively broad anterior and lateral borders defined by shallow furrows. Palpebral lobe with shallow furrow. Interocular area convex, sloped inward. Posterior border angled slightly backward to three-fifths point, then curves moderately forward to genal spine. Genal spine very short. Metagenal ridge runs nearly parallel to posterior border, then diverges backward to meet minute intergenal spine. Radiating and anastamosing venation on extraocular areas.

DISCUSSION

The material from the upper Olenellus Zone of the Illtyd Formation questionably assigned by Fritz (1991, p. 14, Pl. 17, figs. 11-14) to Olenellus romensis, differs from the Peyto specimens and material from the type area (see Resser and Howell 1938, Pl. 7, figs. 4-6, Pl. 12, figs. 2-3; Resser 1938, Pl. 5, fig. 12) in possessing a smaller anterior glabellar lobe, and should be excluded from O. romensis. Olenellus gilberti Meek, O. puertoblancoensis (Lochman), and O. thompsoni Hall (see Whittington 1989, Fig. 1) differ by having smaller anterior glabellar lobes. Olenellus muralensis Fritz, (1992, Pl. 8, figs. 1-7, Pl. 9, fig. 1), from the lower Olenellus Zone of the Mural Formation near Mount Robson, resembles O. romensis, but differs in possessing a smaller and less strongly expanded anterior glabellar lobe, and poorly developed intergenal spines. Olenellus sphaerulosus Fritz (see Fritz 1991, Pl. 10, figs. 1-13) and Olenellus bufrontatus Fritz (see Fritz 1991, Pl. 12, figs. 6-8) differ in their strongly inflated anterior glabellar lobe. Olenellus truemani Walcott (see Fritz 1972, Pl. 9, figs. 1-14) lacks intergenal spines.

Olenellus sp. 1

Pl. 1, figs. 1,2.

MATERIAL

Two cephala.

OCCURRENCE

Upper Peyto Formation, Mount Weed (H 29 m), Mount Shaffer (K 29 m).

DISCUSSION

Two incomplete small cranidia bear some resemblance to illustrations of Olenellus puertoblancoensis (see Fritz 1972, Pl. 17, figs. 1-7; Palmer and Halley 1979, Pl. 4, figs. 11, 14) particularly in the long palpebral lobes which nearly reach the posterior border, the narrow border, and in the nearly straight posterior border. These features distinguish the cranidia from O. romensis (Pl. 2, figs. 1-3) and O. gilberti (Pl. 1, figs. 4-7) which occur in the Peyto Formation. Olenellus thompsoni has intergenal spines (see Whittington 1989, Fig. 1, Pl. 1, figs. 4, 8, Pl. 2, figs. 9, 12, Fig. 13), O. sp. 5 Fritz 1972 (see Fritz 1972, Pl. 20, figs. 9-14) has a prominent occipital spine, and O. parvofrontatus Fritz (1991, Pl. 12, figs. 1, 2) has a much smaller anterior glabellar lobe.

Olenellus sp 2

Pl. 1, fig. 3.

MATERIAL

One cephalon.

OCCURRENCE

Lower Peyto Formation, Mount Weed (H 0.3 m).

DISCUSSION

A single, large, but poorly preserved cephalon was recovered from the lowest Peyto Formation at Mount Weed. Fritz (1972, p. 19, Pl. 20, figs. 9-14) described and illustrated O. sp. 5 from an interval of the Sekwi formation which correlates with the Peyto. Olenellus sp. 5 bears a prominent spine on the occipital ring but is otherwise very similar to this Peyto cephalon. As the occipital ring is not preserved in the Peyto specimen, it is impossible to compare it fully with O. sp. 5.

Olenellus sp. 3

Pl. 2, figs. 5-7.

MATERIAL

Abundant fragments.

OCCURRENCE

Mt. Whyte Formation, Mount Stephen (B 26 m, B 27 m).

DISCUSSION

The fragmentary nature of this material makes comparisons with known species very difficult. This is the youngest Olenellus recovered in this study.

Order Corynexochida Moore, 1959

DISCUSSION

Prior to this work, the Corynexochida have been considered in terms of six families - Corynexochidae Angelin 1854, Oryctocephalidae Beecher 1897, Zacanthoididae Swinnerton 1915, Dolichometopidae Walcott 1916, Dorypygidae Kobayashi 1935 (= Ogygopsididae Rasetti 1951, see Palmer and Halley, 1979) and Dinesidae Lermontova 1940. However many of these families cannot be diagnosed with apomorphic characters (synapomorphies), and some of them clearly intergrade. An attempt is made here to redefine the Corynexochida using cladistic methods, so that families are clearly diagnosed.

The Corynexochida are characterized primarily by a forwardly expanded glabella which reaches, or very nearly reaches, the anterior border or margin. This character is apparent in early meraspids (Pl. 9, Figs. 2-6), although many corynexochid holaspids have a glabella that is parallel-sided (Pl. 10, Fig. 3) or barrel shaped (Pl. 3, Fig. 1). However, no corynexochid has a forwardly tapered glabella. In addition, a rostral plate fused with the hypostome is characteristic of all Corynexochida except for a small group of Australasian genera and Zacanthopsis.

The Corynexochidae Angelin 1854 are characterized by a strongly forwardly expanded to parallel-sided glabella which has a waisted appearance due to an occipital ring that is wider than the glabella across L1, and palpebral lobes located close to the axis (for example, see Corynexochus plumula Whitehouse, Palmer 1968, Pl. 10, figs. 15, 16, 20). In some genera herein assigned to the Corynexochidae (see Fieldaspis celer (Rasetti), Pl. 8, fig. 1, for example), palpebral lobes are long and curved, but in every case they are located close to the axis. Traditionally, the Zacanthoididae and the Dolichometopidae have been distinguished from the Corynexochidae, although all three groups share basic cranidial morphology. The validity of the former two taxa is discussed below.

Harrington et al. (1959, p. O227) stated that the Zacanthoididae are "Closely allied to and not sharply separated from Corynexochidae." This is indeed the case, since the Zacanthoididae cannot be diagnosed as a monophyletic taxon apart from the Corynexochidae. Although zacanthoidids such as Fieldaspis have long, curved palpebral lobes, and corynexochids such as Corynexochus do not, Corynexochus lacks any apomorphic character not found in zacanthoidids. Thoracic and pygidial spinosity, although common in zacanthoidids (see Fieldaspis bispinosa, Pl. 10, figs. 7-8, for example) and often associated with this group, also occurs in other families, particularly the Oryctocephalidae (see Oryctocephalus sp. indet. 2, Pl. 4, fig. 6). The Zacanthoididae are herein synonymized with the Corynexochidae.

For some time, there have been suggestions that the Dolichometopidae do not merit separate status from the

Zacanthoididae (presently the Corynexochidae). Both Rasetti (1951, p. 139) and Opik (1982, p. 14) indicated that the distinction between these two groups may be arbitrary. The Zacanthoididae and the Dolichometopidae have, in the past, represented two groups of Corynexochid genera sharing similar cranidial characters, distinguished primarily by pygidial spinosity. Dolichometopids generally lack marginal pygidial spines, whereas zacanthoidid pygidia show varying degrees of spinosity. However, pygidial spinosity is not helpful in distinguishing two families. First, not all zacanthoidid species have marginal pygidial spines. For example, *Fieldaspis celer* (see Pl. 8, fig. 3) and *F. bilobata* (see Rasetti 1951, Pl. 16, figs. 1-7) from the Mt. Whyte Formation lack pygidial spines, although their pygidial margins have a medial indentation. On the other hand, *F. superba* (see Rasetti 1951, Pl. 16, figs. 10-18), also from the Mt. Whyte Formation, is characterized by lengthy pygidial spines. *Albertellina aspinosa* (Palmer and Halley, 1979, p. 90, Pl. 10, figs. 1-6) also lacks pygidial spines. Other zacanthoidid species such as *Zacanthoides* cf. *Z. alatus* (Palmer and Halley, 1979, p. 97, Pl. 11, figs. 25, 26), *Parkaspis endecamera* (Rasetti, 1951, p. 170-171, Pl. 31, figs. 7-10), and *Ptarmigania rossensis* (Rasetti, 1951, p. 177, Pl. 19, figs. 9-16), have diminutive marginal spines, like those displayed by the dolichometopids *Poliella denticulata* (Rasetti, 1951, p. 173, Pl. 12, figs. 6-9), and *Wenkchemnia sulcata* (Rasetti, 1951, p. 186, Pl. 11, figs. 9-15). Finally, spinosity is common in the Dorypygidae and Oryctocephalidae, and thus cannot be diagnostic at the familial level. Although some zacanthoidids such as *Zacanthoides* Walcott 1888, *Ptarmigania* Raymond 1928, Ptarmiganoides Rasetti 1951, and Parkaspis Rasetti 1951 have small intergenal spines, not all zacanthoidids share this character, and the presence of an intergenal spine is best regarded as significant only at the generic level. Because no apomorphic characters have been recognized here that can be used to distinguish the Zacanthoididae and the Dolichometopidae, the Dolichometopidae are herein synonymized with the Zacanthoididae in the Corynexochidae.

Therefore the Corynexochidae, as herein defined, also includes species previously assigned to the Zacanthoididae and the Dolichometopidae. The matter of subfamily distinction is discussed below.

Dolichometopidae has, in the past, comprised four subfamilies - Dolichometopinae Walcott 1916, Bathyuriscinae Richter 1933, Glossopleurinae Hupé, and Horonastinae Opik 1982.

Dolichometopinae was restricted by Opik (1982) to include only Dolichometopus. However, as noted by Opik (1982) and Chang and Jell (1987), this genus is very poorly defined, and the type species, D. suecicus Angelin 1854, is known only from isolated cranidia and pygidia. As such, Dolichometopus can be accommodated within the Corynexochidae without any subfamily designation. Regardless of how Dolichometopus is treated, nothing is lost by suppressing the monotypic Dolichometopinae. Since it adds nothing to our understanding of the Corynexochidae, and it cannot be demonstrated to be monophyletic, Dolichometopinae is herein considered obsolete.

Bathyuriscinae were most recently diagnosed by Opik (1982) on the basis of fusion of the rostral plate with hypostome, and a poorly developed anterior border. Both of these characters are widespread among Corynexochida, and are clearly unsuitable for diagnosis at the subfamily level. Indeed, Bathyuriscus lacks any suitable apomorphic character to distinguish it from other Corynexochidae. Although its pygidium is relatively large compared to many corynexochids, such a character is common among the corynexochida (Glossopleura for example). Moreover, other corynexochids lack any common apomorphic feature to distinguish them from Bathyuriscus. Therefore, because Bathyuriscinae cannot be demonstrated to be monophyletic, the subfamily is considered obsolete.

Glossopleurinae was not diagnosed by Opik (1982), but Glossopleura boccar (Walcott), the type species, was illustrated by Rasetti (1951, p. 164, Pl. 24, figs. 1-6). No apomorphic characters are recognized here which can be used to distinguish Glossopleura from the Corynexochidae. Thus, Glossopleurinae is herein considered obsolete.

Horonastinae was established as a subfamily of Dolichometopidae by Opik (1982) primarily on the basis of lack of fusion between hypostome and rostral plate — a character that occurs in most non-corynexochid trilobites. All other Corynexochida except Zacanthopsis have a fused rostral plate and hypostome. The glabellar, palpebral and pygidial morphology of Horonastes Opik (see Opik 1982, Pl. 4, figs. 1-2) and other Horonastine genera is, however, shared with that of other Corynexochidae. In fact, no character could be found that is unique to the Corynexochidae, but absent in the Horonastinae. Because the Horonastinae cannot be demonstrated to be monophyletic, the subfamily is considered an artificial taxon, and therefore obsolete.

The Oryctocephalidae, Dorypygidae and Dinesidae can be distinguished from the Corynexochidae on the basis of palpebral lobe morphology. Species assigned to these three families have relatively small and straight palpebral lobes located close to the cephalic margin. These families comprise the superfamily Oryctocephalacea Beecher 1897.

Dinesidae are distinguished by isolated, triangular L1, and deep furrows connecting axial furrows anteriorly to the cranidial margin.

The Oryctocephalidae and the Dorypygidae are characterized by a barrel-shaped glabella. In some species, the glabella is more parallel-sided than barrel-shaped, but a waisted glabella as in the Corynexochidae is never developed here, and a barrel-shaped glabella is not developed outside of these two families.

The Oryctocephalidae are distinguished by a unique lateral glabellar furrow consisting of pairs of pits, commonly connected across the glabella, and a borderless pygidium.

The Dorypygidae are characterized by three pairs of very short (tr.) and shallow lateral glabellar furrows which are effaced in most species.

Therefore, the Corynexochida are best considered in terms of four families - Corynexochidae, Dinesidae, Oryctocephalidae, and Dorypygidae. Zacanthoididae, Dolichometopidae, and the

Dolichometopid subfamilies Dolichometopinae, Bathyuriscinae, Glossopleurinae and Horonastinae cannot be demonstrated to be monophyletic, and are considered obsolete. Furthermore, this study shows that the superfamily Oryctocephalacea Beecher 1897 can be recognized to include the Dinesidae, Oryctocephalidae, and Dorypygidae.

Superfamily Oryctocephalaceae Beecher, 1897
Family Dorypygidae Kobayashi, 1935

Genus Olenoides Meek, 1877

TYPE SPECIES

Paradoxides? nevadensis Meek 1870, from the Wheeler Shale of Utah (by original designation).

DIAGNOSIS

Dorypygidae having pygidium with axis about one-third pygidial width, and three or four axial rings and a terminal piece, with or without marginal spines.

DISCUSSION

Prior to the work of Melzak and Westrop (1994), three similar genera — Bonnia, Kootenia and Olenoides — were distinguished primarily on the basis of pygidial characters, including number and size of marginal spines, and depth of interpleural furrows. Melzak and Westrop (1994) concluded that effacement of pygidial interpleural furrows cannot be used to diagnose *Kootenia*, and in the absence of other distinguishing features, synonymized *Kootenia* with *Olenoides*. To this synonymy is added *Kooteniella* Lermontova 1940, which apparently differs mainly in having some species with more strongly inflated glabellae.

Sundberg's (1994) attempt to distinguish *Kootenia* from *Olenoides* based on the pygidial character of anterior pleural bands of uniform width in *Kootenia* as opposed to laterally expanded in *Olenoides* is untenable. Sundberg (1994, Figs. 14-6, 14-7, 14-8) offers only photographs of low-quality, exfoliated pygidia of *K. dawsoni* from which the width of the anterior pleural band cannot be determined. Other illustrations of *Kootenia* pygidia (*K.* cf. *K. dawsoni*, Sundberg 1994, Figs. 15-2, 15-3; *K. elongata*, Young and Ludvigsen 1989, Pl. 5, figs. 4, 6, 8; *K. germana*, Palmer and Halley 1979, Pl. 11, figs. 27-30) show, if anything, laterally expanded anterior pleural bands.

Fritz (1972) assessed the similarities between *Bonnia* and *Kootenia* (now *Olenoides*), but could not find reason enough to synonymize these two genera. However, critical review of Fritz's (1972) discussion reveals no significant features which can serve to distinguish *Bonnia* from *Olenoides*. Pygidia of *Olenoides* have five to seven sets of pleural spines, while those of *Bonnia* have only one set. Presently, pygidia of several species assigned to *Bonnia* have more than one set of spines (*B*? *diutina* Fritz 1972, Pl. 2, figs. 1-13; *B. laterispina* Fritz 1991, Pl. 3, figs. 7-15; *B. quadrata* Fritz 1991, Pl. 4, figs. 1-15; *B. decora* Fritz 1991, Pl. 4, figs. 16-23; and *B. carnata* Fritz 1991, Pl. 5, figs. 7-17;), but share features such as shallow axial, pleural and interpleural furrows with the type species. If Kootenia diutina Fritz 1972 is included in Bonnia as Fritz (1991) suggested, then it is apparent from inspection of published photographs of several species assigned to both genera that pygidial spines on Bonnia are smaller than those on any species of Olenoides (for Bonnia, see Fritz 1991, Pl. 3, figs. 13-15, Pl. 5, figs. 14-17, Fritz 1972, Pl. 2, figs. 3-5, 11; for Olenoides, see Palmer and Halley 1979, Pl. 11, figs. 27-30, Rasetti 1951, Pl. 28, figs. 9-11). However, the difference in size is only a matter of a millimeter or two in length and diameter, and, as such, spine size should not be used for generic diagnosis. Moreover, width of pygidial border cannot be used to distinguish Bonnia — border width appears to vary dramatically between species assigned to each genus (for Bonnia, see Fritz 1991, Fig. 5; for Olenoides, compare Palmer and Halley 1979, Pl. 11, figs. 27-29, with Fritz 1972, Pl. 2, figs. 3-5, 11). This leaves shallower axial, pleural and interpleural furrows as the only potentially diagnostic pygidial features for Bonnia. However, inspection of published photographs reveals that furrow depth varies considerably among species assigned to Bonnia, and that some species have furrows as deep as those found on species assigned to Olenoides (for Bonnia, compare Fritz 1991, Pl. 3, figs. 5,6, Pl. 8, figs. 7-15, 19, 20; for Olenoides, see Palmer and Halley 1979, Pl. 11, figs. 27-30, Fritz 1972, Pl. 2, figs. 3-5, 11). Thus, the only consistent pygidial feature that potentially distinguishes two genera is spine size, and given the small difference here, this is not adequate for generic differentiation. Cranidial features of Bonnia vary more widely than pygidial morphology (see Fritz 1991, Fig. 5). Thus, despite Fritz's suggestion, neither a forwardly expanded glabella, nor a broadly curved anterior margin can be used to differentiate cranidia of Bonnia from those of Olenoides (e.g. Bonnia, see Fritz 1991, Pl. 5; for Olenoides, see Palmer and Halley 1979, Pl. 11, figs. 22-24, Rasetti 1951, Pl. 28, fig.11).

For reasons discussed above, Bonnia cannot be properly regarded as a distinct genus, and, therefore, Bonnia Walcott 1916 is herein considered a junior synonym of Olenoides Meek 1877. Ogygopsis, the dorypygid most similar to Olenoides, differs in possessing six or more pygidial axial rings.

Olenoides fieldensis (Walcott, 1917)

Pl. 3, figs. 1-10, Pl. 4, figs. 1,2.

Corynexochus fieldensis Walcott, 1917:65, pl. 10, figs. 2, 2a-c.
Bonnia fieldensis (Walcott) — Rasetti, 1951:82.

HOLOTYPE

Cranidium from the Lower Cambrian Peyto Formation, Ptarmigan Pass, Alberta, illustrated by Walcott, 1917, Pl. 10, figs. 2, 2a-c (by original designation).

DIAGNOSIS

Olenoides having a prosopon of fine pits, a pygidium with parallel-sided axis and nearly effaced pleural and border furrows.

MATERIAL

14 cranidia, 8 pygidia.

OCCURRENCE

Peyto Formation, Mount Weed (H 3.5 m, H 3.7 m, H 29 m) Mount Schaffer (K 29 m) and Mount Stephen (B 26 m, D 0 m).

DESCRIPTION

Cranidial length is equal to slightly more than 3/4 width across palpebral lobes. Slightly forwardly expanded glabella moderately curved longitudinally and transversely, with nearly straight sides, moderately curved at front. Glabellar furrows effaced. Axial furrows moderately deep and narrow, anterior border furrow narrower, shallows sagitally. Deep ovate pits at juncture of axial furrows and anterior border furrow. Anterior border convex, narrows markedly in front of glabella. Eye ridges effaced. Palpebral area convex. Palpebral lobes just over one third glabellar length; palpebral furrows shallow. Posterior border convex, extended nearly straight outward; posterior border furrow deep and wide (exsag.). Occipital ring nearly rectangular in plan view, with medial node; occipital furrow about as wide (exsag.) as posterior border furrow, very shallow medially, deep exsagitally.

Pygidial length to width ratio of about 0.9. Axis of moderate relief with nearly straight and parallel sides, consisting of articulating half-ring, four axial rings and terminal piece that nearly reaches posterior border. Axial ring furrows very shallow to effaced, axial furrows moderately shallow. Pleural field virtually effaced. Contour of border nearly continuous with pleural field, border furrow narrow and shallow.

DISCUSSION

A prosopon of sparse pits serves to readily distinguish *Olenoides fieldensis* from the similar *O. columbensis* which has fine granules. Although Fritz (1972, 1991) included in *O. columbensis* material from the Peyto Formation assigned by Rasetti (1951) to *O. fieldensis*, most of the material from the study area illustrated herein clearly shows a prosopon of sparse pits, and, therefore, is best assigned to *O. fieldensis*. Most other species of *Olenoides* differ in having more than one pair of pygidial spines.

Genus *Ogygopsis* Walcott, 1889

TYPE SPECIES

Ogygia klotzi Rominger 1887, from the Stephen Formation, British Columbia (by original designation).

DIAGNOSIS

Dorypygidae having large pygidium with narrow axis about one-fifth pygidial width, and six or more axial rings, bearing marginal spines or with a smooth margin.

DISCUSSION

Ogygopsis resembles *Olenoides* in cranidial characters, but differs in pygidial morphology. Although *Ogygopsis klotzi* possesses a smooth pygidial margin, most other species assigned to the genus have minute pygidial margin spines. The pygidium of Ogygopsis typicalis (Resser) has a pair of small, anterolateral spines (see Palmer and Halley 1979, Pl. 12, figs. 1-3); O. spinulosa Rasetti 1951 (p. 192, Pl. 21, fig. 4) has nine pairs of minute marginal spines; O. batis (Walcott; Palmer 1964, p. 7, Pl. 2, figs. 1-6) has one pair of anterolateral marginal spines; O. antiqua Palmer 1968 (p. 50, Pl. 3, figs. 3-4) bears two or three pairs of small marginal spines. Except for the size and number of the spines, these pygidia resemble those assigned to Kootenia virginiana Resser 1938b, and K. currieri Resser 1938b, which have seven pairs of large marginal spines, and six and seven axial rings respectively. Egorova et al. (1976) described and illustrated a number of species assigned to Kootenia: K. jakutensis Lermontova (Pl. 13, figs. 8, 9, 12-18, Pl. 17, figs. 2-5, Pl. 18, figs. 4-7), K. anabarensis Lermontova (Pl. 21, figs. 1, 2, 4, 7, 11), K. florens Suvorova (Pl. 21, figs. 3, 8), K. moori Lermontova (Pl. 25, figs. 8-12), and K. virgata E. Romanenko (Pl. 32, figs. 6, 18, Pl. 33, fig. 7). Presumably, these were assigned to Kootenia on the basis of their numerous large pygidial spines. However, the pygidia of all of these species have seven or more axial rings, and in this respect resemble Ogygopsis. From the discussion of Olenoides (including species previously assigned to Bonnia and Kootenia), it is clear that the size, presence or absence and number of pygidial margin spines is not of generic significance, and there is no reason to give the absence of pygidial margin spines generic significance in the case of Ogygopsis. However, the pygidia of all species herein assigned to Ogygopsis differ from that of Olenoides in having six or more axial rings. At this point it seems reasonable to accord generic significance to this characteristic. Therefore, *Ogygopsis* is herein diagnosed to include all Dorypygidae having a large pygidium with six or more axial rings, bearing marginal spines or with a smooth margin. On this basis, *Kootenia virginiana*, *K. currieri* and the aforementioned Siberian species are herein assigned to *Ogygopsis*.

Ogygopsis klotzi **(Rominger, 1887)**

Pl. 4, figs. 3-5.

Ogygopsis klotzi — Walcott 1916:377, pl. 66, figs. 1, 1a,b.

Ogygopsis klotzi — Rasetti 1951:191-192, pl. 12, figs. 1-5, pl. 21, figs. 1-3, pl. 29, figs. 6-8.

Ogygopsis klotzi — Rasetti *in* Harrington et al. 1959, Fig. 160.

Ogygopsis klotzi — Campbell 1971:437-440.

Ogygopsis klotzi — Rudkin 1979:191-192, Fig. 1a-h.

Ogygopsis klotzi — McNamara and Rudkin 1984:164-168, Figs. 9, 10.

Ogygopsis klotzi — Young and Ludvigsen 1989:19-20, pl. 5, fig. 11, pl. 6, figs. 1-4, Fig. 6c.

HOLOTYPE

A complete individual illustrated by Rominger (1887, pl. 1, fig. 1).

DIAGNOSIS

Ogygopsis with pygidium having a smooth margin and nine or ten axial rings.

MATERIAL

15 pygidia, numerous cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (C 81 m, C 85 m).

Family Oryctocephalidae Beecher, 1897

Genus Oryctocephalites Resser, 1939

TYPE SPECIES

Oryctocephalites typicalis Resser 1939b, from the Ptarmigan Formation, northern Wasatch Mountains (by original designation).

DISCUSSION

According to Palmer (in Palmer and Halley 1979, p. 83) Oryctocephalus is distinguished from Oryctocephalites in having at least two transglabellar furrows. If this is the case, then all five species from the Naiset and Stephen formations assigned to Oryctocephalus and described and illustrated by Rasetti (1951), belong to Oryctocephalites because they have only one transglabellar furrow.

Oryctocephalites sp. indet. 2 Rasetti, 1951

Pl. 4, fig. 6.

MATERIAL

One thorax with pygidium.

OCCURRENCE

Naiset Formation, Mount Stephen (E float).

DISCUSSION

A single articulated thorax with pygidium was recovered near the base of the Naiset Formation at Fossil Gully. This likely belongs to Oryctocephalites sp. indet. 2 which Rasetti (1951, p. 193, Pl. 9, fig. 23) collected from the same locality.

Superfamily Corynexochaceae Angelin, 1854

Family Corynexochidae Angelin, 1854

Genus Poliella Walcott, 1916

TYPE SPECIES

Bathyuriscus (Poliella) anteros Walcott, 1916, from the Mt. Whyte Formation (by original designation).

DIAGNOSIS

Corynexochidae with palpebral lobes directed out at about 45 degrees from anterior juncture with axial furrows, then curved straight back, so that posterior tips of lobes end just ahead of posterior margin furrows and are separated by more than one half glabellar width from axial furrows. Glabellar furrows faint to effaced, 1s most strongly impressed. Small pygidium with 1-3 distinct axial rings and a smooth margin.

DISCUSSION

Poliella is readily distinguished from other corynexochids such as Albertella, Bathyuriscus, Fieldaspis, Glossopleura, Wenkchemnia and Zacanthoides by the location of the posterior tips of its palpebral lobes, and its small pygidium. Ptarmigania differs in possessing small intergenal spines, and Ptarmiganoides and Parkaspis have spinose pygidia.

Poliella prima (Walcott, 1908)

Pl. 5, figs. 1-3.

Bornemannia prima Walcott 1908:213.

Bathyuriscus (Poliella) primus Walcott 1916:352, pl. 45, figs. 6, 6a (only).

Bornemannia prima — Vogdes 1925:92.

Poliella prima — Resser 1935:44.

?Poliella castlensis Resser 1935:44.

Poliella prima — Rasetti 1951:172-173, Pl. 12, figs. 10-13.

LECTOTYPE

Lectotype designated by Resser (1935) is a complete exoskeleton from the Mt. Whyte Formation, Lake Louise, Alberta, illustrated by Walcott (1916, Pl. 46, Fig. 6a).

DIAGNOSIS

Poliella having an occipital ring without a median node, eight thoracic segments, and a smooth pygidial margin.

MATERIAL

1 complete, 6 cranidia, 1 pygidium.

OCCURRENCE

Naiset Formation, Mount Stephen (C 85-88 m), Pope's Peak (F 12 m).

DESCRIPTION

Slightly waisted and forwardly expanded glabella moderately convex, broadly curved at front. Glabellar furrows very shallow. Axial furrows shallow and narrow, anterior border furrow narrower, of uniform depth. Anterior border very weakly convex, narrows in front of glabella. Palpebral area weakly convex. Palpebral lobes over two thirds glabellar length, directed out at about 45 degrees from anterior end very close to axial furrows, then curved straight back, so that posterior tips of lobes terminate just ahead of posterior margin furrows and are separated by more than one half glabellar width from axial furrows; palpebral furrows shallow. Posterior border convex, extended nearly straight outward; posterior border furrow deep and wide (exsag.), shallows distally. Occipital ring as long (sag.) as L1 at axial furrow; occipital furrow shallow, about as wide (exsag.) as posterior border furrow.

Pygidial length to width ratio of about 0.7. Axis occupying about two thirds pygidial length, of low relief with nearly straight converging sides, consisting of articulating half-ring, first axial ring distinct and bearing a median node, a second ring poorly defined by a very shallow furrow, and terminal piece. Indistinct pleura of low relief curved sharply backward. Sharply defined border with minor posterior indentation.

DISCUSSION

This species differs from _Poliella denticulata_ in having a longer (sag. and exsag.) anterior border, an occipital ring without a median node, eight thoracic segments (see Rasetti 1951, Pl. 12, figs 11-13), a shorter pygidial axis, and a smooth pygidial margin. _P. leipalox_ Fritz (1968, Pl. 38, figs. 22-28) is similar but has a slightly longer pygidial axis and ten thoracic segments. _P. germana_ (Resser) (see Palmer and Halley 1979, Pl. 11, figs. 1-8) has a longer pygidial axis. _P. lomataspis_ Palmer and Halley (1979, Pl. 6, figs. 1-6) has a pygidium with two distinct axial rings and a much wider border.

Poliella denticulata Rasetti, 1951

Pl. 5, figs. 4-8.

HOLOTYPE

A nearly complete exoskeleton from the Naiset Formation, Fossil Gully, Mount Stephen.

MATERIAL

13 cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (C 78-79, E float).

DISCUSSION

Isolated cranidia recovered from Fossil Gully and North Gully are assigned to Poliella denticulata on the basis of a shorter anterior border, and an occipital ring with a median node (compare this thesis Pl. 5, figs. 7, 8, with Rasetti 1951, Pl. 12 figs. 6-8).

Genus Wenkchemnia Rasetti, 1951

TYPE SPECIES

Wenkchemnia walcotti Rasetti, 1951, from the Naiset Formation, Alberta (by original designation).

DIAGNOSIS

Corynexochidae with palpebral lobes about one-third glabellar length, distance between posterior tips of palpebral lobes and posterior margin equal to about two-thirds length of palpebral lobes, posterior tips of palpebral lobes separated by about one half glabellar width from axial furrows. Pygidium twice as wide as long, with small anterolateral spines.

DISCUSSION

Wenkchemnia differs from Poliella in having a shorter palpebral lobe and wider (exsag.) posterior border, and from Bathyuriscus in having a smaller, transverse pygidium. Parkaspis Rasetti (1951) differs from *Wenkchemnia* in possessing a small intergenal spine, an additional thoracic segment (*Parkaspis* = 10-11, *Wenkchemnia* = 9), and a denticulated to spinose pygidium.

Wenkchemnia walcotti **Rasetti, 1951**

Pl. 6, figs. 1-4, Pl. 7, figs. 1-7.

Wenkchemnia walcotti Rasetti, 1951:184-185, pl. 11, figs. 1-3.
Wenkchemnia sulcata Rasetti, 1951:186-187, pl. 11, figs. 9-15.

HOLOTYPE

A nearly complete external mold from the Naiset Formation, Pope's Peak, from which a latex cast was made and illustrated by Rasetti (1951), Pl. 11, fig. 2.

DIAGNOSIS

Wenkchemnia with occipital ring having a medial node rather than a spine. Thoracic axis lacks spines. Pygidium may have small anterolateral spines.

MATERIAL

6 complete, 47 cranidia, several pygidia.

OCCURRENCE

Naiset Formation, Pope's Peak (F 12 m), Mount Stephen (C 87 m, C 88 m).

DESCRIPTION

Strongly waisted glabella broadly curved at front. Glabellar furrows very shallow. Axial furrows shallow and narrow, anterior border furrow narrow, moderately deep. Anterior border weakly convex, very short (sag. and exsag.). Palpebral lobes just over one third glabellar length, directed out at about 45 degrees from anterior end, then curved straight back, posterior tips terminating more than half their length ahead of posterior margin furrows, separated by more than one half glabellar width from axial furrows; palpebral furrows shallow. Posterior border convex, extended nearly straight outward; posterior border furrow deep and wide (exsag.), shallows distally. Occipital ring as long (sag.) as L1 at axial furrow, has medial node; occipital furrow shallow, about as wide (exsag.) as posterior border furrow. Free cheeks with long genal spine.

Thorax of nine segments bearing small terminal spines.

Pygidial axis of low relief with nearly straight converging sides, consisting of articulating half-ring, three well-defined axial rings, a fourth ring poorly defined by a very shallow furrow, and terminal piece. First set of pleural and interpleural furrows shallow but distinct, second set less distinct, third and last set poorly defined.

DISCUSSION

The development of pygidial anterolateral spines on specimens assigned by Rasetti (1951) to Wenkchemnia spinicollis and W. sulcata is variable (compare Rasetti 1951, pl. 11, figs. 4, 5, 8, 9, 14, 15), and some pygidia have virtually no spines. A pygidium collected in this study from an horizon of the Naiset Formation at Pope's Peak containing *W. walcotti*, displays a minute anterolateral spine (see Pl. 7, fig. 4). Judging from Rasetti's (1951) discussion and photographs, other than the presence of pygidial spines there are no preservation-independent characters that can be used to distinguish *W. walcotti* from *W. sulcata*. The material collected in this study together with Rasetti's (1951) illustrated material supports the contention that the presence and size of pygidial anterolateral spines varies among individuals of *Wenkchemnia* and can not be used to differentiate species. For these reasons, *W. sulcata* is herein synonymized with the type species *W. walcotti*. The presence of an occipital spine and thoracic axial spines differentiates *W. spinicollis* from *W. walcotti*.

Genus *Albertella* Walcott, 1908

TYPE SPECIES

Albertella helena Walcott, 1908, from the Cathedral Formation of British Columbia.

DIAGNOSIS

Corynexochidae with narrow free cheeks bearing advanced genal spines, seven thoracic segments, narrow thoracic and pygidial pleura, and pygidial border spines.

DISCUSSION

Albertella differs from Zacanthoides and Parkaspis in having only one pair of pygidial spines, and from Fieldaspis in having advanced genal spines, narrower free cheeks and thoracic and pygidial pleura.

?**Albertella** sp.

Pl. 7, fig. 8.

MATERIAL

Two pygidia.

OCCURRENCE

Cathedral Formation, Park Boundary (J 140 m).

DISCUSSION

Two small pygidia with very narrow pleura and one pair of anterolateral spines were recovered from the basal Cathedral Formation at Park Boundary, and are herein tentatively assigned to Albertella. The pygidia differ from previously described species in having only two axial rings and a terminal piece. These specimens occur with Syspacephalus tardus Rasetti 1951, which is indicative of the Albertella Zone.

Genus **Fieldaspis** Rasetti, 1951

TYPE SPECIES

Crepicephalus celer Walcott, 1917b, from the Mt. Whyte Formation of British Columbia.

DIAGNOSIS

Corynexochidae with waisted, anteriorly expanded glabella, nine thoracic segments and sub-rectangular pygidium with medial notch or pair of posterolateral spines extending backward from margin.

DISCUSSION

Rasetti (1951) established the monotypic genus Stephenaspis for a species which differs from described species of Fieldaspis primarily in the form of its pygidium. However, the pygidial characters of Stephenaspis bispinosa, including its notched posterior margin and anterolateral spines, occur in species of Fieldaspis (compare S. bispinosa, Rasetti 1951, Pl. 10, figs. 1-2, 5-9 with F. bilobata, Rasetti 1951, Pl. 16, figs. 4-7, and F. superba, Rasetti 1951, Pl. 16, figs. 16-18), and thus they are not characters on which a distinct genus can be based. Rasetti (1951) claimed that the posterior tips of the palpebral lobes in Stephenaspis are located farther from the axial furrows than in Fieldaspis, but comparison of Rasetti's (1951) photographs of F. bilobata (Pl. 16, figs. 1-2) and S. bispinosa (Pl. 10, figs. 1-4) reveals virtually no difference in this character. These two genera are therefore synonymized. Fieldaspis is given priority because its type species, F. celer (Walcott, 1917b), was the first described in this group.

Fieldaspis is one of few Corynexochidae which posess a forwardly expanded glabella, and long palpebral lobes extending nearly to the posterior margin furrow, terminating close to the axial furrow. Zacanthoides is similar, but posesses a less forwardly expanded glabella, an intergenal spine, advanced genal spine, and a pygidium with greater spinosity. *Bathyuriscus* has a similar cranidium, but its large, semicircular pygidium differs greatly from *Fieldaspis*.

Fieldaspis celer (Walcott, 1917)

Pl. 8, figs. 1-9, Pl. 9, figs. 1-13.

Crepecephalus celer Walcott, 1917b:101, pl. 11, fig. 2.
Kochaspis celer—Resser, 1935:36.
Fieldaspis celer—Rasetti, 1951:110.
Fieldaspis furcata Rasetti, 1951:159, pl. 15, figs. 1-8.
Fieldaspis celer—Rasetti, 1957:957, pl. 118, figs. 1-8, text fig. 4.

HOLOTYPE

A pygidium from the Mt. Whyte Formation, Mount Stephen, illustrated by Walcott (1917), Pl. 11, fig. 2.

DIAGNOSIS

Fieldaspis lacking occipital spine, with strongly divergent anterior facial sutures, posterior tips of palpebral lobes terminating at posterior border furrow, and pygidium having long border bearing a deep median notch that is equal to about 1/3 pygidial length.

MATERIAL

86 cranidia, 5 pygidia, 3 hypostoma.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m), Mount Weed (H 150 m).

DESCRIPTION

Strongly waisted glabella broadly curved at front. Glabellar furrows firmly impressed, S1 deepest. Axial furrows moderately deep and narrow, anterior border furrow narrow, moderately deep at corners, very shallow medially. Anterior border very short medially, wider at corners. Crescentic palpebral lobes about two-thirds glabellar length, posterior tips terminating at posterior border furrows; palpebral furrows shallow. Posterior border convex, extended nearly straight outward; posterior border furrow deep and wide (exsag.), shallows distally. Occipital ring as long (sag.) as L1 at axial furrow; occipital furrow shallow medially, deeper at axial furrows, about as wide (exsag.) as posterior border furrow.

Pygidium as long as wide, axis of moderate relief with converging sides, consisting of articulating half-ring, three well-defined axial rings and terminal piece. Border longer (exsag.) than axis, with long (sag.), u-shaped median notch.

ONTOGENY

The most striking aspect in the meraspid ontogeny of this species is the transformation of the palpebral lobes. Throughout the process, they retain their crescentic shape, and increase their relative length only slightly, but their relative position on the cranidium changes dramatically. In small meraspids, the anterior tip of the palpebral lobe is located adjacent to the anterior glabellar lobe, and distal by about one third glabellar width from the axial furrow (Pl. 9, Figs. 2-6). At the same stage, the posterior tip of the palpebral lobe is located distally from the axial furrow by more than one glabellar width, and somewhat anterior to the posterior border furrow (Pl. 9, Figs. 2-6). In small holaspids, the anterior tip of the palpebral lobe is adjacent to S4 and very close to the axial furrow, while the posterior tip is situated at the posterior border furrow, and just less than one glabellar width from the axial furrow (Pl. 9, Figs. 7-9). In large holaspids, the anterior tip of the palpebral lobe is adjacent to L4 at the axial furrow, and the posterior tip is situated at the posterior border furrow, less than one-half glabellar width from the axial furrow (Pl. 8, Figs. 1, 6-9). The position of the posterior tips of the palpebral lobes in meraspid cranidia of Fieldaspis celer is retained in adults of F. bilobata (Pl. 10, Figs. 2, 4-5). This suggests that F. bilobata may be paedomorphic relative to F. celer.

Other ontogenetic changes include an increasing glabellar length/palpebral area width ratio associated with the inward migration of the palpebral lobes, and more firmly impressed lateral glabellar furrows in holaspids (compare meraspid cranidium, Pl. 9, Fig. 3 with holaspid cranidium, Pl. 8 Fig. 1).

DISCUSSION

Rasetti (1951) mistakenly established Fieldaspis furcata without reference to, and apparently without knowledge of the identical trilobite Crepicephalus celer Walcott 1917b. F. celer was described and illustrated by Rasetti (1957). In his (1957) discussion, Rasetti acknowledged that, with respect to the two forms, "it is entirely arbitrary whether we call them separate species or not". With no discernible differences, the two species are herein synonymized.

Fieldaspis bilobata Rasetti, 1951

Pl. 10, figs. 1-5.

Fieldaspis bilobata Rasetti, 1951:161, pl. 16, figs. 1-7.
Fieldaspis bilobata—Rasetti, 1957:956, pl. 121, figs. 12,13.
Dolichometopsis? sp. undet.—Rasetti, 1957:958, pl. 118, figs. 9-13, pl. 119, figs. 12-15.

HOLOTYPE

A pygidium from the Mt. Whyte Formation, Eiffel Peak, illustrated by Rasetti (1951), Pl. 16, figs. 6-7.

DIAGNOSIS

Fieldaspis with occipital spine, weakly divergent anterior facial sutures, pygidium having shorter median notch than F. celer, and lacking marginal spines.

MATERIAL

9 cranidia.

OCCURRENCE

Mount Whyte Formation, Mount Field (A 115 m), Mount Weed (H 150 m).

DISCUSSION

Nine cranidia but no pygidia were recovered in this study. The cranidium of *Fieldaspis bilobata* is most similar to that of *F. bispinosa*, but is distinguished by having more weakly divergent anterior facial sutures.

Fieldaspis bispinosa **(Rasetti, 1951)**

Pl. 10, figs. 6-8.

Stephenaspis bispinosa Rasetti, 1951:181, pl. 10, figs. 1-6.
Stephenaspis cf. *S. bispinosa* — Rasetti, 1951:182, pl. 10, figs. 7-9.

HOLOTYPE

A nearly complete individual from the Naiset Formation, Fossil Gully, Mount Stephen, illustrated by Rasetti (1951, Pl. 10, fig. 2).

DIAGNOSIS

Fieldaspis with occipital spine, strongly divergent anterior facial sutures, and sub-rectangular pygidium with one pair of marginal spines.

MATERIAL

1 complete, 4 cranidia, 1 pygidium.

OCCURRENCE

Naiset Formation, Mount Stephen (C 85-88, E float).

DISCUSSION

Originally assigned to Stephenaspis by Rasetti (1951), this species is most readily distinguished by its sub-rectangular pygidium.

Order Ptychopariida Swinnerton, 1915
Suborder Ptychopariina Richter, 1933

DISCUSSION

Rasetti (1951, p. 198-202) accurately described the problems involved with Lower to Middle Cambrian Ptychopariid taxonomy, including intergrading morphologies, poorly represented type species, and the necessary reliance primarily on cranidial characters. Rasetti (1951) also justifiably criticized past efforts (e.g. Lochman 1947) to classify Ptychopariid genera, recognizing that these methods involving relative proportions and angles between cranidial surfaces could "lead to an excessively artificial grouping of forms" (p. 202).

Many ptychopariid families may very well be artificial (paraphyletic) taxa, but cladistic analysis of the Ptychopariina will be an enormous task that is well beyond the scope of this thesis. With this in mind, traditional families are used here with reservation and no attempt is made to recognize subfamilies. A more rigorous approach is taken for the diagnosis of genera. Genera which cannot be distinguished on the basis of apomorphic characters (i.e. synapomorphies) are suppressed, resulting in generic concepts that are broader than those traditionally held.

Family Ptychopariidae Matthew, 1887

Genus Antagmus Resser, 1936

TYPE SPECIES

Ptychoparia teucer Walcott, 1887 (designated by Resser 1936).

DIAGNOSIS

Ptychopariidae with relatively short preglabellar field, and gently tapering, straight-sided glabella of high relief that is as wide as, or wider than palpebral area.

DISCUSSION

In the past, a number of characters including, but not restricted to, prosopon, glabellar and palpebral area convexity, presence of a plectrum, width of post-ocular fixed cheeks, and divergence of anterior facial sutures have been used to differentiate genera in the group including Antagmus Resser 1936, Poulsenia Resser 1936, Onchocephalus Resser 1937a, Piaziella Lochman 1947, Eoptychoparia Rasetti 1955, Parapoulsenia Rasetti 1957, Spencella Rasetti 1963, Nyella Palmer 1979, and Illtydaspis Fritz 1991. However, as discussed below, all of these genera share features with the senior taxon Antagmus, and none of the others can be diagnosed on the basis of a derived character which does not occur in Antagmus. Rasetti (1955, p. 10) recognized the difficulty in distinguishing Antagmus from Onchocephalus and Piaziella, and stated that "intergrading forms between all these three genera are known and the boundaries must be set arbitrarily". This criticism may be applied to all of the genera described above, and they are discussed here.

Antagmus is based on Ptychoparia teucer Walcott (1887, p. 197, Pl. XVI), fig. 3), and was poorly diagnosed by Resser (1936, p. 3-4). It is clear that Rasetti (1955, p. 9) placed considerable diagnostic weight on divergence of the anterior facial sutures and the presence of a plectrum. However, these characters occur in other genera such as Luxella (see Rasetti 1955, Pl. 6, fig. 9) and Periomma (see Rasetti 1955, Pl. 4, figs. 11, 14, 15), and thus can not be used as apomorphies in the diagnosis of Antagmus. Both Luxella and Periomma can be diagnosed on the basis of other characters (long preglabellar field, and long, strongly convex anterior border, respectively). A relatively short preglabellar field, and gently tapering glabella of high relief that is as wide as, or wider than the palpebral area can be used to diagnose Antagmus, including the groups of Ptychopariid species discussed here.

Shaw (1962) cited an ovate glabella and a coarsely granular test as characters which serve to align Poulsenia with the Solenopleuridae. However, the type species Solenopleura canaliculata (see Rasetti in Moore 1959, Fig. 203) does not have an ovate glabella, and is further distinguished in having a very wide palpebral area. Moreover, the glabellar outline of the type species P. gronwalli (see Poulsen 1927, Pl. 15, fig. 28) can scarcely be considered different from that of species assigned to Antagmus (see Walcott 1886, Pl. XXVI, fig. 3; Rasetti 1955, Pl. 2, figs. 7, 8). Finally, the granular prosopon cannot be given familial significance. Because the morphology of P. gronwalli does not show any characters which serve to distinguish it from Antagmus, Poulsenia is herein synonymized with Antagmus.

Rasetti (1955, p. 16) characterized Onchocephalus by a downsloping, truncated glabella, parallel to converging anterior facial sutures, and downsloping to horizontal palpebral area. A downsloping, truncated glabella, and downsloping to horizontal palpebral area also occur in genera such as Antagmus (see Rasetti 1955, Pl. 2, fig. 6), Austinvillia (see Rasetti 1955, Pl. 4, figs. 9, 10), and Periomma (see Rasetti 1955, Pl. 4, figs. 12, 13). Parallel to converging anterior facial sutures also characterize Periomma, Bicella, Periomella, and Rimouskia (see Rasetti 1955, Pl. 1, figs. 6, 7, 8, 10). Due to the absence of any distinctive character, Onchocephalus is synonymized with Antagmus.

Lochman's (1947) original characterization of Piaziella highlighted no distinguishing features, but recognized the wide post-ocular cheeks as compared to the occipital ring. Fritz (1972, p. 42) also recognized wide palpebral areas and post-ocular cheeks in his diagnosis of Piaziella. Indeed, it is apparent from published photographs of the holotype of Piaziella pia (Lochman 1947, figs. 4, 6) and of other material from the type area (Lochman 1947, fig. 5; Rasetti 1951, Pl. 8, fig. 3) that the post-ocular cheek is wide compared to the occipital ring. However, relatively wide palpebral areas and post-ocular cheeks also occur in Syspacephalus (see Pl. 15, figs. 6, 7) and in species assigned to Antagmus (A. gigas Rasetti 1955, Pl. 1, fig. 1, Pl. 2, figs. 1-8), and therefore can not be used to diagnose a separate genus. Rasetti (in Moore 1959) suggested that

Piaziella intergrades with Antagmus, and for the reasons given above, the two genera are synonymized.

Eoptychoparia was established by Rasetti (1955, p. 13) as a genus which "is difficult to characterize and intergrades with Antagmus, Piazella (sic), and Onchocephalus". Species assigned to Eoptychoparia have the diagnostic characters of Antagmus, but lack any other unique features, and therefore Eoptychoparia is synonymized with Antagmus.

Rasetti (1957) established Parapoulsenia for species which resemble Poulsenia, but have wider palpebral areas, and deeper glabellar furrows. In fact, the glabella is wider than the palpebral area, and thus this character does not differ from other species of Antagmus (compare Pl. 11, figs. 2, 4-9 with Rasetti 1957, Pl. 120, figs. 4, 7). Since the depth of the glabellar furrows is not greater than those of many species of Antagmus, and no other distinct characters occur in these species, Parapoulsenia is synonymized with Antagmus.

Spencella was established by Rasetti (1963, p. 590) for species previously assigned to Solenopleurella Poulsen 1927 by Resser. Solenopleurella ulrichi Poulsen 1927 (Pl. XVI, fig. 36), the type species, differs from species assigned by Rasetti (1963) to Spencella in having a more quadrate rather than ovate glabella, an anterior border without a plectrum, and in completely lacking a preglabellar field. Spencella montanensis (Rasetti 1963, Pl. 68, figs. 1-11), the type species, differs from most species assigned to Antagmus mainly in having a shorter preglabellar field and narrower palpebral areas. However, both of these characters occur in

Antagmus (Pl. 11, figs. 7-9; Pl. 12, figs. 1, 4), while a plectrum, another feature of *S. montanensis*, is common in *Antagmus* (for example, see *A. maior*, Pl. 13, figs. 1-10). *Spencella* is herein synonymized with *Antagmus*.

Palmer (1979, p. 110) established *Nyella* for species previously assigned to *Poulsenia*, *Caborcella* and *Onchocephalus*, on the basis of a coarsely granular prosopon and "a narrow well-defined border furrow separating a convex border from a generally narrow flat slightly downsloping brim" (see Palmer and Halley 1979, Pl. 14, figs. 1-12). These characters occur in species assigned to *Antagmus* (see Pl. 13, Figs. 1-10; Rasetti 1955, Pl. 1, figs. 6, 7, 8, 10); none can be considered unique among the Ptychopariidae, and species assigned to *Nyella* by Palmer (1979) are herein placed in *Antagmus*.

Fritz (1991) diagnosed *Illtydaspis* (see Fritz 1991, Pl. 8, figs. 24-26) on the basis of a forwardly sloping, rectangular glabella, short preglabellar field, slightly medially expanded anterior border, narrow palpebral area, and relatively long palpebral lobes centred posterior to glabellar midpoint. None of these characters is unique to *Illtydaspis*, although relatively long palpebral lobes occur rarely in Ptychopariidae (see *Antagmus duckettі*, Fritz 1991, Pl. 9, figs. 16-18; *Bicella bicensis*, Rasetti, 1955, Pl. 4, figs. 1-7). Palpebral lobes are relatively longer in smaller cranidia, which comprise the bulk of Fritz's (1991) illustrated specimens, than they are in larger cranidia (compare Fritz 1991, Pl. 17, fig. 1 and fig. 10). Species assigned by Fritz (1991) to *Illtydaspis* are herein considered to belong to *Antagmus*.

With this broader interpretation of the genus, the following species are herein assigned to Antagmus.

Antagmus cf. buttsi (Resser, 1938)

Pl. 12, figs. 6-11.

MATERIAL

29 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Weed (H 150 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, nearly straight at front. Glabellar furrows very shallow, S4 effaced. Axial and preglabellar furrows moderately deep and narrow. Occipital ring with median node, occipital furrow curved forward slightly, moderately deep laterally, shallow medially. Anterior border convex, expanded medially with plectrum; anterior border furrow deep laterally, shallow medially. Relatively straight, slightly prominent palpebral lobes located adjacent L2 and L3; palpebral area about equal to one-half glabellar width. Palpebral ridges weakly expressed. Posterior border convex; posterior border furrow deep. Anterior facial sutures nearly straight, convergent. Prosopon of fine granules.

DISCUSSION

A. cf. buttsi differs from A. buttsi (Resser) by having a plectrum. It is also similar to other species previously assigned to Spencella (for example, see Rasetti 1963, Pl. 68, figs. 1-21) which also have narrow palpebral areas, but it differs from most of these in having a strong plectrum. A. montanensis (Rasetti) and A. spinosa (Rasetti) both have plectra, but A. montanensis has shallower glabellar furrows, and A. spinosa has an occipital spine. A. cf. buttsi differs from most other species of Antagmus in having narrow palpebral areas. A. cf. sp. 1 (Fritz) (Pl. 12, figs. 1-5) also has narrow palpebral areas but lacks a plectrum, has a more quadrate glabella and a shorter preglabellar field.

Antagmus tuberculata (Rasetti, 1951)

Pl. 11, fig. 6.

Piaziella tuberculata Rasetti, 1951:236, pl. 8, figs. 6-10.

HOLOTYPE

A cranidium, from the Naiset Formation, North Gully, Mount Stephen, illustrated by Rasetti (1951, Pl. 8, figs. 6-8).

DIAGNOSIS

Antagmus with a prosopon of mainly fine granules and scattered coarse tubercles, palpebral lobes relatively straight.

MATERIAL

1 cranidium.

OCCURRENCE

Naiset Formation, Mount Stephen (C 97 m).

DESCRIPTION

Moderately convex, tapered glabella with gently concave sides, nearly straight at front. Glabellar furrows shallow, S4 nearly effaced. Axial and preglabellar furrows moderately deep and narrow. Occipital ring with median node, occipital furrow deep. Anterior border convex, slightly expanded medially; anterior border furrow narrow, deep laterally, shallow medially. Relatively straight, slightly prominent palpebral lobes located adjacent L2 and L3; palpebral area about equal to glabellar width. Palpebral ridges prominent. Posterior border narrow (exsag.), convex; posterior border furrow deep, wider than border (exsag.). Anterior facial sutures diverge slightly in front of eyes, then curve inward to converge. Prosopon of mainly fine granules with a few scattered coarse tubercles.

DISCUSSION

Antagmus tuberculata can be distinguished from all other species by its prosopon of mainly fine granules with a few scattered coarse tubercles. Taken together, other species of Antagmus display a range of granule and tubercle size (see Pl. 11, figs. 2, 8; Pl. 13, fig. 2 for example), but none has the combination peculiar to A. tuberculata. A? gibbosa and ?A. sp. (Pl. 14, figs. 1-10) have fine granules and coarse tubercles, but differ in having long, curved palpebral lobes.

Antagmus fieldensis (Rasetti, 1951)

Pl. 11, figs. 1-5.

Onchocephalus fieldensis Rasetti, 1951:232, pl. 14, figs. 11-14.

HOLOTYPE

A cranidium, from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti (1951, Pl. 14, figs. 11-13).

DIAGNOSIS

Antagmus with a prosopon of fine granules; palpebral lobes extend from a point opposite L3, and terminate adjacent to anterior portion of L1.

MATERIAL

149 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 94 m, A 95 m, A 96 m, A 115 m, A 117 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, gently curved at front. Glabellar furrows shallow, S4 nearly effaced. Axial furrows moderately deep and narrow, preglabellar furrow shallow and narrow, deeper and wider medially. Occipital ring with median node, occipital furrow narrow, deep laterally, very shallow medially. Anterior border convex; anterior border furrow narrow, deep laterally, shallow medially. Relatively straight, slightly prominent palpebral lobes extend from a point adjacent L3, and terminate adjacent to anterior portion of L1; palpebral area just over one-half glabellar width. Palpebral ridges very weak. Posterior border convex; posterior border furrow moderately deep, as wide as border (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of fine granules.

DISCUSSION

Antagmus fieldensis can be distinguished from the similar A. maior by its finer surface granulation, and more anteriorly placed palpebral lobes. Antagmus depressus Rasetti 1951 has a shorter preglabellar field and shallower glabellar furrows, while A. c.f. A sp. 1 (Fritz 1991) has a much shallower preglabellar furrow as well as a much shorter preglabellar field.

Antagmus depressus (Rasetti, 1951)

Pl. 11, figs. 7-9.

Onchocephalus depressus Rasetti, 1951:233, pl. 14, figs. 15-17.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti (1951, Pl. 14, figs. 15-16).

DIAGNOSIS

Antagmus with a prosopon of fine granules, palpebral lobes extend from a point adjacent S3, and terminate adjacent to anterior portion of S1, preglabellar field shorter (sag.) than anterior border.

MATERIAL

3 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 94 m), Mount Stephen (B 53 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, gently curved at front. Glabellar furrows nearly effaced. Axial and preglabellar furrows moderately deep. Occipital ring with median node, occipital furrow narrow, deep laterally, shallow medially. Anterior border convex; anterior border furrow narrow, deep laterally, shallow medially. Relatively straight, slightly prominent palpebral lobes extend from a point adjacent S3, and terminate adjacent to anterior portion of S1; palpebral area more than one-half glabellar width. Palpebral ridges weak. Posterior border convex; posterior border furrow moderately deep, narrower than border (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of very fine granules.

DISCUSSION

Antagmus depressus is most similar to *A. fieldensis* but differs in having a shorter preglabellar field and shallower glabellar furrows. Its very fine surface granulation distinguishes *A. depressus* from other species of *Antagmus* with similar cranidial proportions.

Antagmus maior **(Rasetti, 1951)**

Pl. 13, figs. 1-10.

Onchocephalus maior Rasetti, 1951:234, pl. 14, figs. 19-23.
Onchocephalus maior—Rasetti, 1957:962, pl. 120, fig. 11.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti (1951, Pl. 14, figs. 19-21).

DIAGNOSIS

Antagmus with a prosopon of coarse granules, relatively straight, posteriorly located palpebral lobes extend from a point adjacent to S2, and terminate adjacent to posterior portion of L1.

MATERIAL

101 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m, A 117 m).

DESCRIPTION

Moderately convex, tapered glabella with concave sides, very broadly curved at front. Glabellar furrows shallow, S4 nearly effaced. Axial and preglabellar furrows moderately deep and narrow. Occipital ring with median node, occipital furrow slightly curved forward, narrow, deep. Anterior border convex, weak plectrum; anterior border furrow deep laterally, shallow medially. Relatively straight, slightly prominent palpebral lobes extend from a point adjacent S2, and terminate adjacent to posterior portion of L1; palpebral area slightly less than glabellar width. Palpebral ridges very weak. Posterior border convex; posterior border furrow moderately deep, as wide as border (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of coarse granules.

ONTOGENY

The cranidial ontogeny of A. maior is similar to that of related species (see A? gibbosa for example) in the anterior tapering of the glabella, the lengthening of the preglabellar field and anterior border, and in the posterior migration and reduction in relative size of the palpebral lobes. In small meraspid cranidia (Pl. 13, Fig. 10) the glabella is expanded anteriorly and extends to a narrow anterior border. The palpebral lobes are long and curved with an anterior terminus adjacent to S3. In larger meraspids (Pl. 13, Fig. 9) the anterior border is longer, and the palpebral lobes are shorter and straighter, centred adjacent to L3. In small holaspids (Pl. 13, Fig. 6) the preglabellar field is nearly as long as the anterior border, the glabella is tapered anteriorly, and the palpebral lobes are short, straight and centred adjacent to L2. These proportions are essentially those of a large holaspid (Pl. 13, Figs. 2, 5) which differs mainly in having the palpebral lobes centred adjacent to S1, and in the development of a plectrum.

DISCUSSION

Antagmus maior differs from most other species of *Antagmus* in its combination of a coarsely granular prosopon and posteriorly located palpebral lobes.

Antagmus cf. *A*. sp. 1 Fritz, 1991

Pl. 12, figs. 1-5.

MATERIAL

3 cranidia.

OCCURRENCE

Peyto Formation, Mount Weed (H 29 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, nearly straight at front. Glabellar furrows very shallow. Axial furrows deep and narrow, preglabellar furrow narrow, very shallow to effaced. Occipital ring with median node, occipital furrow narrow, moderately deep. Anterior border convex, anterior border furrow uniformly deep. Preglabellar field short (sag.). Prominent palpebral lobes extend from a point adjacent L3, and terminate adjacent to posterior portion of L1; palpebral area less than glabellar width. Palpebral ridges very weak. Anterior facial sutures nearly straight, convergent. Prosopon of fine granules.

DISCUSSION

Fritz (1991) declined to formally establish *Illtydaspis* sp. 1 because his material from the Illtyd Formation consisted of only sixteen very small cranidia. The material of similar trilobites from the Peyto Formation is similarly scant, and the largest cranidia are only slightly larger than those collected by Fritz (1991), suggesting that this trilobite had a relatively small adult size. The Peyto material compares very closely with the Illtyd specimens, differing slightly in glabellar profile (compare Pl. 12, fig. 3 with Fritz 1991, Pl. 16, fig. 11).

Antagmus sp.

Pl. 11, fig. 10.

MATERIAL

1 hypostome.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m).

DESCRIPTION

Strongly inflated central body with tubular anterior and lateral borders. Prosopon of fine granules.

DISCUSSION

A very small hypostome attributable to Antagmus was recovered from the Mt. Whyte Formation at Mount Field. It can not be assigned with certainty to any species in particular.

Antagmus? gibbosa (Rasetti, 1957)

Pl. 14, figs. 1-9.

Kochiella? gibbosa Rasetti, 1957:961, pl. 121, figs. 1-4.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti (1957, Pl. 121, figs. 1-2).

DIAGNOSIS

Antagmine with a prosopon of coarse granules and tubercles, strong plectrum, large, curved palpebral lobes extend from a point adjacent L4, and terminate adjacent to posterior portion of L1.

MATERIAL

10 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m, A 117 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, nearly straight at front. Glabellar furrows moderately deep, S4 very shallow. Axial furrows deep, moderately wide, preglabellar furrow narrow, shallow. Occipital ring with median node, occipital furrow narrow, deep. Anterior border convex, with strong plectrum; anterior border furrow deep laterally, effaced by plectrum medially. Large, curved, very prominent palpebral lobes extend from a point adjacent L4, and terminate adjacent to posterior portion of L1; palpebral area slightly less than glabellar width. Palpebral ridges very prominent. Posterior border convex; posterior border furrow deep, as wide as border (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of coarse granules and tubercles.

ONTOGENY

The cranidial ontogeny of A? gibbosa is like that of A. maior in the anterior tapering of the glabella, and the lengthening of the preglabellar field and anterior border (compare Pl. 14, Fig. 9 with Pl. 14, Fig. 1). A? gibbosa differs, however, in the development of large, curved palpebral lobes and a stronger plectrum. In large meraspid cranidia of A? gibbosa (Pl. 14, Fig. 8) the palpebral lobes are nearly as long as the glabella, and they are strongly curved. The relative size of the palpebral lobes is diminished somewhat in small holaspids, but the curvature is retained (Pl. 14, Fig. 7). The relative size and curvature of the palpebral lobes is then maintained through the large holaspid stage (Pl. 14, Figs. 1, 2). Moreover, the palpebral lobes appear to merge with the palpebral ridges in smaller individuals (Pl. 14, Fig. 8), whereas in larger individuals they are clearly separated (Pl. 14, Fig. 7).

DISCUSSION

Rasetti (1957) questionably assigned this species to *Kochiella* Poulsen 1927, from which it differs in most aspects except the curvature of the palpebral lobes, and the tuberculate prosopon (see Poulsen, 1927, Pl. XV, figs. 7-13) — characters also shared with *Kochaspis* Resser 1935. The cranidial convexity and the length of the preglabellar field of *Antagmus*? *gibbosa* rules out an affinity with *Kochiella*. Although *Kochaspis* *ceccina* (Pl. 21, Figs. 1, 2, 4, 7-9) also has strongly curved palpebral lobes, they are much less prominent than in *A*? *gibbosa*. Moreover, *K*. *ceccina* has a shorter glabella and a less convex anterior border than *A*? *gibbosa*, indicating that the species are not congeneric. The size and shape of the glabella, and the convexity of the anterior border of *A*? *gibbosa* and *A*? sp. suggest a relationship with *Antagmus*. Since *A*? *gibbosa* and *A*? sp. differ from other species of *Antagmus* in their long, strongly curved and prominent palpebral lobes, they are only tentatively assigned to the genus. *A*? *gibbosa* can be distinguished from the similar *A*? sp. by its very strong plectrum.

***Antagmus*? sp.**

Pl. 14, fig. 10.

DIAGNOSIS

Antagmine with a prosopon of fine granules and tubercles, without a plectrum. Large, strongly curved palpebral lobes extend from a point adjacent L4 and terminate adjacent to posterior portion of L1.

MATERIAL

1 cranidium.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 117 m).

DESCRIPTION

Moderately convex, tapered glabella with nearly straight sides, nearly straight at front. Glabellar furrows moderately deep, S4 very shallow. Axial and preglabellar furrows moderately deep and narrow. Occipital furrow nearly straight, narrow, deep laterally, shallow medially. Anterior border convex; anterior border furrow uniformly deep. Very prominent, strongly curved palpebral lobes extend from a point adjacent L4, and terminate adjacent to posterior portion of L1; palpebral area about equal to glabellar width between midlength of palpebral lobes. Palpebral ridges prominent. Posterior border narrow, convex; posterior border furrow deep, wider than border (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of fine granules and coarse tubercles.

DISCUSSION

Because only one cranidium was collected, this species is not formally established. _Antagmus_? sp. is most similar to _A_? _gibbosa_ from which it differs in having more sharply curved palpebral lobes, and in completely lacking a plectrum. The prominent and strongly curved palpebral lobes distinguish it from species of Antagmus.

Genus Syspacephalus Resser, 1936

TYPE SPECIES

Agraulos charops Walcott, 1917, from the Peyto Formation, Mount Stephen (designated by Resser, 1936).

DIAGNOSIS

Ptychopariidae with long, downsloping frontal area, and short, anteriorly placed palpebral lobes with posterior tips ahead of or adjacent to L2.

DISCUSSION

Syspacephalus includes ptychopariids that resemble Antagmus in general cranidial proportions but differ in having short, anteriorly placed palpebral lobes, and in having a smooth or, at most, a finely granular prosopon. This is consistent with previous concepts of the genus (Lochman 1947, Rasetti 1951, Palmer and Halley 1979).

Syspacephalus charops (Walcott), 1917

Pl. 15, figs. 4,5.

Agraulos charops Walcott, 1917:72, pl. 13, figs. 2, 2a.
Syspacephalus charops—Resser, 1936:28.

Syspacephalus charops—Lochman, 1947:64.

Syspacephalus charops—Rasetti, 1951:242, pl. 8, figs. 11-13.

HOLOTYPE

A cranidium from the Peyto Formation, Mount Stephen, illustrated by Walcott, 1917, Pl. 13, figs. 2, 2a.

DIAGNOSIS

Syspacephalus with relatively long (sag.) anterior border, and effaced glabellar furrows.

MATERIAL

2 cranidia.

OCCURRENCE

Peyto Formation, Mount Shaffer (K 29 m).

DESCRIPTION

Moderately convex, tapered glabella with straight sides, curved at front. Glabellar furrows effaced. Axial and preglabellar furrows shallow and narrow. Occipital furrow nearly straight, narrow, shallow; occipital ring long (sag.), strongly curved backward, with median node. Anterior border slightly convex; anterior border furrow shallow laterally, very shallow medially. Poorly defined, straight palpebral lobes extend from a point adjacent S4, and terminate adjacent to middle portion of L2; palpebral area equal to about two-thirds glabellar width between midlength of palpebral lobes. Palpebral ridges barely visible. Convex posterior border narrow at axial furrow, much wider distally; posterior border furrow moderately deep, narrow (exsag.). Anterior facial sutures nearly straight, slightly divergent.

DISCUSSION

Effaced glabellar furrows distinguish *Syspacephalus charops* from other species illustrated in this study. *S. gregarius* (Rasetti, 1951, Pl. 8, figs. 14-19) has much deeper glabellar furrows. *S. laevigatus* (Pl. 16, figs. 4-5) has very shallow glabellar furrows, a longer preglabellar field, and straighter anterior margin and preglabellar furrow. *S.* sp. indet. (Fritz, 1968, Pl. 37, figs. 27-30) has long palpebral lobes that extend back to L1, and thus should be excluded from *Syspacephalus*. *S. vapidus* (Fritz, 1972, Pl. 20, figs. 1-8) has much deeper glabellar furrows. *S. longus* Palmer (Palmer and Halley, 1979, Pl. 7, figs. 14, 16-18) has a triangular anterior border, and *S. obscurus* Palmer (Palmer and Halley, 1979, Pl. 7, figs. 6-13, 15) has narrower palpebral areas and a unique granular prosopon.

Syspacephalus perola **(Walcott), 1917**

Pl. 15, figs. 1-3.

Ptychoparia perola Walcott, 1917:91, pl. 12, figs. 7, 7a.
Inglefieldia perola—Resser, 1937:14.
Antagmus perola—Lochman, 1947:62.
Syspacephalus perola—Rasetti, 1951:244, pl. 9, figs. 17-22.

HOLOTYPE

A nearly complete individual from the Naiset Formation ("Lake Agnes Shale"), Mount Whyte, from which a cast was made and illustrated by Walcott, 1917, Pl. 12, figs. 7, and Rasetti, 1951, Pl. 9, fig. 17.

DIAGNOSIS

Syspacephalus with relatively long, flat, triangular anterior border.

MATERIAL

63 cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (B 53 m, C 85-88 m), Pope's Peak (F 12 m).

DESCRIPTION

Weakly convex, tapered glabella with straight sides, curved at front. Glabellar furrows shallow, S1 deepest, S4 nearly effaced. Axial and preglabellar furrows moderately deep and narrow. Occipital furrow nearly straight, narrow, moderately deep; occipital ring short (sag.), gently curved backward, with median node. Anterior border relatively long (sag.), nearly flat, somewhat pointed; anterior border furrow shallow laterally, very shallow medially. Poorly defined, straight palpebral lobes extend from a point adjacent S3, and terminate adjacent to middle portion of L2; palpebral area equal to about three quarters glabellar width between midlength of palpebral lobes. Palpebral ridges moderately expressed. Convex posterior border narrow (exsag.); posterior border furrow moderately deep, about as wide as border (exsag.). Anterior facial sutures slightly curved, convergent.

DISCUSSION

A relatively long, "pointed" anterior border differentiates _Syspacephalus perola_ from most other species. _S. longus_ Palmer (Palmer and Halley, 1979, Pl. 7, figs. 14, 16-18) also has this character but has much shallower glabellar furrows, a well-developed genal spine, and at least two more thoracic segments. _S. tardus_ (Pl. 16, figs. 6-9) has a convex, triangular anterior border but is differentiated by its narrow palpebral areas.

Syspacephalus laticeps Rasetti, 1951

Pl. 15, figs. 6-8, Pl. 16, figs. 1-3.

Syspacephalus laticeps Rasetti, 1951:243, pl. 9, figs. 1-6.

HOLOTYPE

A cranidium from the Naiset Formation, Mount Stephen, illustrated by Rasetti, 1951, Pl. 9, figs. 1-3.

DIAGNOSIS

Syspacephalus with short (sag.), convex anterior border, straight preglabellar furrow, extremely anteriorly placed eyes, and medially effaced occipital furrow.

MATERIAL

123 complete individuals or cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (C 78-79 m, C 81 m).

DESCRIPTION

Moderately convex, tapered glabella with straight sides, straight at front. Glabellar furrows very shallow. Axial furrow moderately deep and narrow, preglabellar furrow shallow and narrow. Occipital furrow nearly straight, narrow, shallow at sides, effaced medially; occipital ring gently curved backward, with median node. Anterior border short (sag.), slightly convex; anterior border furrow shallow laterally, very shallow medially. Poorly defined, straight palpebral lobes extend from a point adjacent S4, and terminate adjacent S2; palpebral area nearly equal to glabellar width between midlength of palpebral lobes. Palpebral ridges well expressed. Convex posterior border narrow (exsag.); posterior border furrow moderately deep, as wide as border. Anterior facial sutures curved, strongly convergent.

DISCUSSION

Syspacephalus _laticeps_ is distinguished by extremely anteriorly placed eyes, and a medially effaced occipital furrow. Glabellar furrows are more firmly impressed than in _S_. _charops_, and the anterior border is shorter than in _S_. _perola_.

Syspacephalus _laevigatus_ Rasetti, 1951

Pl. 16, figs. 4,5.

Syspacephalus laevigatus Rasetti, 1951:245, pl. 9, figs. 9-11.

HOLOTYPE

A cranidium from the Naiset Formation, Mount Stephen, illustrated by Rasetti (1951, Pl. 9, fig. 9).

DIAGNOSIS

Syspacephalus with almost flat anterior border, and nearly straight anterior margin, giving cranidium a trapezoid shape.

MATERIAL

59 complete individuals or cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (C 65 m), Pope's Peak (F 12 m).

DESCRIPTION

Moderately convex, very gently tapered glabella with straight sides, straight at front. Glabellar furrows very shallow. Axial and preglabellar furrows moderately deep and narrow. Occipital furrow straight, narrow, moderately deep. Anterior border nearly flat; anterior border furrow shallow laterally, effaced medially. Poorly defined, straight palpebral lobes extend from a point adjacent S3, and terminate adjacent to middle portion of L2; palpebral area equal to about two-thirds glabellar width between midlength of palpebral lobes. Palpebral ridges weakly expressed. Convex posterior border narrow; posterior border furrow moderately deep, as wide as border. Anterior facial sutures nearly straight, convergent.

DISCUSSION

Syspacephalus laevigatus most closely resembles *S. laticeps* (Pl. 15, figs. 6-8; Pl. 16. figs. 1-3) from which it differs in possessing a nearly straight anterior margin, and an occipital furrow which is uniformly deep along its full width.

Syspacephalus crassus **Rasetti, 1951**

Pl. 16, fig. 10.

Syspacephalus crassus Rasetti, 1951:246, pl. 9, figs. 12-16.

HOLOTYPE

A cranidium from the Naiset Formation, Mount Stephen, illustrated by Rasetti (1951, Pl. 9, figs. 12-14).

DIAGNOSIS

Syspacephalus with a nearly square, strongly convex glabella.

MATERIAL

2 cranidia.

OCCURRENCE

Naiset Formation, Mount Stephen (C 97 m).

DESCRIPTION

Strongly convex, nearly square glabella with straight sides, nearly straight at front. Glabellar furrows moderately deep, S1 deepest, S4 effaced. Axial furrow moderately deep and narrow, preglabellar furrow shallow. Occipital furrow nearly straight, narrow, deep; occipital ring relatively long (sag.), with median node. Anterior border slightly convex; anterior border furrow moderately deep laterally, effaced medially. Poorly defined, straight palpebral lobes extend from a point adjacent S3, and terminate adjacent to middle portion of L2; palpebral area equal to about two-thirds glabellar width between midlength of palpebral lobes. Palpebral ridges moderately well expressed. Convex posterior border; posterior border furrow deep, narrow (exsag.). Anterior facial sutures curved, convergent.

DISCUSSION

A nearly square and strongly convex glabella with deep furrows distinguishes S. crassus from all other species of Syspacephalus.

Syspacephalus tardus Rasetti, 1951

Pl. 16, figs. 6-9.

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

HOLOTYPE

A cranidium from the Cathedral Formation, Mount Stephen, illustrated by Rasetti (1951, Pl. 22, fig. 7).

DIAGNOSIS

Syspacephalus with narrow palpebral area (about 1/2 glabellar width), and triangular, convex anterior border.

MATERIAL

4 cranidia.

OCCURRENCE

Cathedral Formation, Park Boundary (J 139 m).

DESCRIPTION

Cranidia having moderately convex, tapered glabella with straight sides, straight at front. Anterior border long, convex. Straight palpebral lobes extend from a point adjacent S3, and terminate adjacent to posterior portion of L2; palpebral area equal to about one-half glabellar width between midlength of palpebral lobes. Convex posterior border narrow; posterior border furrow wide (exsag.). Anterior facial sutures straight, convergent.

DISCUSSION

The triangular anterior border of Syspacephalus tardus resembles that of S. perola (Pl. 15, figs.1-3) and S. longus Palmer (Palmer and Halley, 1979, Pl. 7, figs. 14, 16-18) in outline, but is more convex. S. tardus further differs from S. perola in having a narrower palpebral area, and from *S. longus* in having deeper glabellar furrows. *S. crassus* (Pl. 16, fig. 10) has a narrow palpebral area but is distinguished by its nearly square glabella.

Genus *Periomma* Resser, 1937

TYPE SPECIES

Periomma typicalis Resser 1937b, from the Lower Cambrian, south of Highgate Falls, Vermont (by original designation).

DIAGNOSIS

Ptychopariidae with long frontal area, strongly inflated anterior border which crests above preglabellar furrow, and relatively small, strongly tapered glabella.

DISCUSSION

Rasetti's (1955, p. 24) remarks on *Periomma* emphasized elevation of the palpebral area as a diagnostic character, but comparison of Rasetti's (1955) photographs of *P. walcotti* (Pl. 5, fig. 10) and *Antagmus elongatus* (Pl. 2, fig. 12) reveals little difference in this respect. It is clear, however, from illustrations of *Periomma* (Rasetti, 1955, Pl. 4, figs. 11-15; Pl. 5, figs. 9-14; this thesis Pl. 17, figs. 1-10) that the anterior border is very strongly inflated. This characteristic can be used to distinguish *Periomma* from *Antagmus* with which it is otherwise similar.

Periomma cf. *walcotti* Resser, 1938

Pl. 17, figs. 1-10.

MATERIAL

212 cranidia.

OCCURRENCE

Peyto Formation, Mount Weed (H 0.3 m, H 3.5 m, H 3.7 m, H 29 m), Mount Jimmy Simpson (I 45 m).

DESCRIPTION

Moderately convex, strongly tapered glabella. Glabellar furrows nearly effaced. Axial furrow straight, narrow, moderately deep, preglabellar furrow very shallow, may be effaced laterally. Occipital ring long, strongly curved backwards, occipital furrow nearly straight, narrow, very shallow. Anterior border long, strongly inflated; anterior border furrow deep. Relatively straight, slightly prominent palpebral lobes roughly adjacent glabellar midpoint; palpebral area about equal to glabellar width. Palpebral ridges very weakly expressed. Posterior border convex; posterior border furrow moderately deep, narrow (exsag.). Anterior facial sutures nearly straight, convergent. Prosopon of fine pits.

DISCUSSION

The Peyto material closely resembles specimens illustrated by Rasetti (1955, Pl. 1, fig. 6; Pl. 5, figs. 9-14) from the Quebec conglomerates except that Rasetti's material has a prosopon of "indistinct granules" rather than fine pits. <u>Periomma gaspensis</u>

Rasetti (1955, Pl. 4, figs. 11-15) has a low boss in the anterior border furrow, and P. typicalis Resser (1937, Pl. 8, figs. 56-58) has a plectrum.

Genus Solenopleurella Poulsen, 1927

TYPE SPECIES

Solenopleurella ulrichi Poulsen 1927, from the Cape Wood Formation of Northwest Greenland (by original designation).

DIAGNOSIS

Ptychopariidae completely lacking a preglabellar field.

DISCUSSION

Poulsen (1927) established Solenopleurella for the Antagmus-like S. ulrichi (Poulsen, 1927, Pl. XVI, fig. 36) in which a preglabellar field is completely absent. Resser (1938a) established the monotypic Schistometopus based on S. typicalis (Resser, 1938a, Pl. 1, fig. 12) which shares this feature and lacks any other derived character that could be used in diagnosing a separate genus. Subsequently, Rasetti added S. convexus (1951, Pl. 13, figs. 17-22), S. collaris (1951, Pl. 14, figs. 1-3), and ?S. minor (1957, Pl. 120, figs. 13-15), all of which lack a preglabellar field. It is clear that the distinguishing characteristic of Schistometopus is the complete absence of a preglabellar field, and for this reason the genus is herein synonymized with the senior Solenopleurella.

Solenopleurella minor (Rasetti, 1957)

Pl. 21, fig. 9.

Schistometopus? minor Rasetti, 1957:966, pl. 120, figs. 13-15.

HOLOTYPE

Cranidium from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti 1957, Pl 120, figs. 14, 15.

DIAGNOSIS

Solenopleurella with quadrate glabella having short (tr.), very shallow glabellar furrows, and a prosopon of fine granules and scattered tubercles.

MATERIAL.

1 cranidium.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m).

DESCRIPTION

Strongly convex, quadrate glabella. Glabellar furrows very shallow, S4 nearly effaced. Axial furrow straight, narrow, moderately deep, preglabellar furrow indistinguishable from anterior border furrow. Occipital furrow straight, narrow (sag.), shallow. Anterior border convex; anterior border furrow deep. Relatively straight, slightly prominent palpebral lobes adjacent L2 and L3; palpebral area about equal to one-half glabellar width. Palpebral ridges weakly expressed. Anterior facial sutures nearly straight, convergent. Prosopon of fine granules and scattered tubercles.

DISCUSSION

The lack of a preglabellar field provides adequate grounds for confident assignment here to *Solenopleurella*. *S. typicalis* has a longer glabella (Resser 1938a, Pl. 1, fig. 12). *S. convexus* has deeper glabellar furrows (Rasetti 1951, Pl. 13, figs. 17-22), whereas *S. collaris* (Rasetti 1951, Pl. 14, figs. 1-3) has a more strongly tapered glabella and an occipital spine.

Genus *Onchocephalites* Rasetti, 1957

TYPE SPECIES

Onchocephalites laevis Rasetti 1957, from the Mt. Whyte Formation, Mount Field (by original designation).

DIAGNOSIS

Ptychopariidae with strongly convex transverse cranidial profile, frontal and palpebral areas downsloped, ovoid glabella about as wide at base as long, poorly defined short palpebral lobes located adjacent glabellar midlength.

DISCUSSION

As defined herein, *Onchocephalites* includes both furrowed (*O. versilis* Palmer 1968, Pl. 4, figs. 1-5 for example) and effaced forms such as O. laevis and O. unca. An ovoid glabella, and strongly downsloped frontal and palpebral areas (see Pl. 18, figs. 1-14) distinguish Onchocephalites from genera such as Antagmus and Syspacephalus. The occurrence of O. unca in the Peyto Formation extends the range of this genus down into Lower Cambrian strata.

Onchocephalites laevis Rasetti, 1957.

Pl. 18, figs. 1-5.

Onchocephalites laevis Rasetti, 1957:962, pl. 121, figs. 5-9, text-fig. 2.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Mount Field, illustrated by Rasetti 1957, Pl. 121, figs. 5-7.

DIAGNOSIS

A species of Onchocephalites with a strongly effaced cranidium in which the posterior tip of the palpebral lobe is located adjacent to L1.

MATERIAL

4 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 111 m), Mount Weed (H 150 m).

DESCRIPTION

Moderately convex glabella poorly defined anteriorly. Except for very shallow S1, glabellar furrows nearly effaced. Axial furrow very shallow adjacent L1 and L2, nearly effaced ahead of L2. Preglabellar furrow nearly effaced. Occipital ring with median node, occipital furrow nearly straight, narrow, moderately deep laterally, nearly effaced medially. Preglabellar field and anterior border strongly downsloped; anterior border furrow very shallow laterally, nearly effaced medially. Very poorly defined, nearly straight palpebral lobes extend from a point adjacent posterior of L3, and terminate adjacent to anterior portion of L1; strongly downsloped palpebral area equal to about one-half glabellar width. Palpebral ridges poorly expressed. Posterior border convex; posterior border furrow moderately deep, narrow (exsag.). Anterior facial sutures nearly straight, strongly convergent. Prosopon of fine punctae.

DISCUSSION

Onchocephalites laevis most closely resembles O. punctatus Rasetti (1963, Pl. 67, figs. 22-25), from which it differs in having more posteriorly placed palpebral lobes. O. spinulosus Rasetti (1963, Pl. 67, figs. 15-18) has more firmly impressed axial and preglabellar furrows, and O. redpathi (Resser) (Rasetti, 1963, Pl. 67, figs. 11-14) has more anteriorly placed palpebral lobes.

Onchocephalites unca (Walcott, 1917).

Pl. 18, figs. 6-14.

Agraulos? *unca* Walcott, 1917:73, pl. 13, figs. 1,1a.

Syspacephalus *unca* — Resser, 1936:28.

"*Agraulos*" *unca* — Rasetti, 1955:82.

HOLOTYPE

A cranidium from the Peyto Formation, Mount Shaffer, illustrated by Walcott 1917, Pl. 13, figs. 1,1a.

DIAGNOSIS

Onchocephalites with very short preglabellar field, well-defined axial and preglabellar furrows, nearly effaced glabellar furrows, and posterior tip of palpebral lobe located adjacent S1.

MATERIAL

86 cranidia.

OCCURRENCE

Peyto Formation, Mount Weed (H 29 m), Mount Shaffer (K 29 m).

DESCRIPTION

Moderately convex glabella slightly longer than wide. Glabellar furrows nearly effaced. Axial and preglabellar furrows very narrow and shallow. Occipital ring with very faint median node, occipital furrow nearly straight, narrow, shallow laterally, nearly effaced medially. Very short preglabellar field and anterior border strongly downsloped; anterior border furrow very shallow. Very poorly defined, nearly straight palpebral lobes roughly adjacent glabellar midpoint; strongly downsloped palpebral area equal to about one-half glabellar width. Palpebral ridges poorly expressed. Posterior border convex; posterior border furrow shallow, narrow (exsag.). Anterior facial sutures nearly straight, strongly convergent. Cranidial surface smooth.

DISCUSSION

Agraulos Hawle and Corda, 1847, to which Walcott (1917) tentatively assigned this species, is characterized by a much longer frontal area, a longer more quadrate glabella, and anteriorly placed eyes (Moore, 1959, Fig. 205). Its very short preglabellar field, and more inflated glabella distinguish *O. unca* from *O. laevis* and all other species of *Onchocephalites*.

Family Alokistocariidae Resser, 1939

Genus *Alokistocare* Lorenz, 1906

TYPE SPECIES

Conocephalites subcoronatus Hall and Whitfield, 1877 (designated by Lorenz, 1906).

DIAGNOSIS

Alokistocariidae with cephalon of very low relief, long (sag.), nearly flat frontal area, and broadly curved anterior margin.

DISCUSSION

Since Walcott (1924) established *Amecephalus*, a number of authors have suppressed this genus in favour of *Alokistocare* Lorenz (1906). Early efforts to differentiate (Rasetti, 1951) or synonymize (Palmer, 1954) the two genera focused on fixed cheek relative width, and thoracic pleura morphology. But as Palmer (1954) demonstrated, intraspecific variation in thoracic pleura morphology (falcate to non-falcate terminations) in *Alokistocare septum* Resser, and overlapping fixed cheek relative widths for *Alokistocare subcoronatum* and *Amecephalus piochensis* suggest that these characters do not support the recognition of two genera. Robison (1971) also concluded that *Amecephalus* is a junior synonym of *Alokistocare*, and this approach is followed here.

Inglefieldia Poulsen 1927 resembles *Alokistocare* in every respect, and should be considered a junior synonym. *Kochiella* Poulsen 1927 is characterized by a medial posterior excursion of the paradoublural band (see Poulsen 1927, Pl. XV, figs. 7-11, 14, 16, 17), *Chancia* Walcott 1924 has a wider (tr.) pygidium, and *Mexicella* Lochman 1948 has a shorter (sag.), more convex glabella.

Alokistocare agnesensis (Walcott, 1912)

Pl. 19, figs. 2-3, Pl. 20, Fig. 2.

Olenopsis? agnesensis Walcott, 1912:242, pl. 36, fig. 2, 15.
Olenopsis? agnesensis—Walcott, 1917, pl. 13, figs. 5, 5a-c.
Kochiella agnesensis —Walcott, 1928:302.
Alokistocare agnesensis—Resser, 1935:9.
Amecephalus agnesensis—Rasetti, 1951:207, pl. 10, figs. 11-15.

HOLOTYPE

A complete individual from the Naiset Formation (Lake Agnes shale), Mount Whyte, illustrated by Walcott, 1917, Pl. 13, fig. 5, and Rasetti, 1951, Pl. 10, fig. 11.

DIAGNOSIS

Alokistocare with anterior border length about equal to preglabellar field length, sides of glabella constricted at S2-S3, long (exsag.) palpebral lobes, and a relatively large pygidium.

MATERIAL

1 complete individual, 33 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Weed (H 103 m, H 106 m); Naiset Formation, Mount Stephen (E float), Popes Peak (F 12 m).

DISCUSSION

This species has been described fully by Rasetti (1951, p. 207-208). It differs from *A. cleora* (Walcott 1917) (see Pl. 19, Figs. 1, 4-10) in having an anterior border that is about as long as the preglabellar field, a constricted glabella, and a larger pygidium. *A. subcoronatum* (Hall and Whitfield) (see Palmer 1954, Pl. 15, fig. 8) has an anterior border that is much longer than the preglabellar field. *A. piochensis* (Walcott 1886) (see Palmer 1954, Pl. 16, figs. 1, 2, 5) has an anterior border that is shorter than the preglabellar field.

Alokistocare cleora (Walcott, 1917)

Pl. 19, figs. 1, 4-10.

Olenopsis cleora Walcott, 1917:74, pl. 13, fig. 3, 3a.
?Olenopsis crito Walcott, 1917:75, pl. 11, fig. 6, 6b.
Alokistocare cleora — Resser, 1935:9.
?Kochiella crito — Resser, 1935:39.
?Inglefieldia birdsalli Howell, 1936, pl. 1, fig. 1.
Amecephalus cleora — Rasetti, 1951:208, pl. 15, figs. 12-20.

HOLOTYPE

A cranidium from the Naiset Formation, near Mount Assiniboine, illustrated by Walcott (1917, Pl. 13, figs. 3, 3a).

DIAGNOSIS

Alokistocare with anterior border longer than preglabellar field, and long (exsag.), curved palpebral lobes.

MATERIAL

1 complete individual, 129 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 94 m, A 95 m, A 96 m, A 115 m, A 117 m), Mount Weed (H 114 m, H 115 m, H 116 m, H 150 m); Naiset Formation, Naiset Point (L float).

DESCRIPTION

See Rasetti 1951, p. 209-210.

DISCUSSION

With a relatively long anterior border, Alokistocare cleora most closely resembles A. subcoronatum (see Palmer 1954, Pl. 15, fig. 8), but can be distinguished from that species by its long, curved palpebral lobes.

Alokistocare? maxeyi (Rasetti, 1951)

Pl. 20, fig. 1.

Kochiella? maxeyi Rasetti 1951:228,pl. 13, figs. 5-8.
Kochiella? cf. K. maxeyi Rasetti 1951:229, pl. 13, fig. 9.
Kochiella? maxeyi — Rasetti 1957:961, pl. 120, figs. 1-3.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Eiffel Peak.

DIAGNOSIS

Alokistocare with prosopon of fine granules and coarse tubercles.

MATERIAL

2 cranidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 115 m), Mount Weed (A 150 m).

DESCRIPTION

See Rasetti, 1951, p. 228, 1957, p. 961.

DISCUSSION

Rasetti (1951) tentatively assigned this species to Kochiella Poulsen 1927, presumably on the basis of its prosopon. However, Poulsen (1927) stated that the cranidium of Kochiella was characterized by a medial posterior excursion of the 'paradoublural band' which the species under discussion lacks. Rasetti (1951) pointed out that if a small, featureless pygidium could be associated with the species, then it should be assigned to Amecephalus (= Alokistocare). Rasetti (1957, p. 961, Pl. 120, figs. 2, 3) tentatively assigned a pygidium to this species, primarily on the basis of its prosopon. No such pygidium was recovered in this study. Rasetti (1957) correctly noted that if this pygidium does indeed belong to the cranidia herein assigned to Alokistocare? maxeyi, then the species ought to be assigned to a new genus.

Genus Plagiura Resser, 1935

TYPE SPECIES

Ptychoparia? cercops Walcott, 1917, from the Mt. Whyte Formation, Ptarmigan Peak (by original designation).

DIAGNOSIS

Alokistocariidae with cephalon of very low relief, and small, anteriorly placed palpebral lobes located close to the glabella, adjacent to S4.

DISCUSSION

Plagiura Resser 1936 is generally regarded as a diagnostic "index fossil" for the earliest Middle Cambrian Plagiura-Poliella Zone of Lochman-Balk and Wilson (1958), and is represented by a single species, P. cercops (Walcott 1917) from the Mt. Whyte Formation of the Canadian Rocky Mountains. Palmer (1979) assigned three new species from the Carrara Formation of the Great Basin to Plagiura (see Palmer and Halley, 1979, p. 113-115, Pl. 6, figs. 17-21, 23-27), but detailed comparison of these species with P. cercops and Aphelotoxon Palmer 1965 (see Palmer 1965, p. 78-79, Pl. 19, figs. 1-14, 16), reveals that they likely belong to the latter genus and not Plagiura. Palmer's (1979) species do not resemble even juvenile Plagiura but are similar to Aphelotoxon in many features including shape of glabella and depth of glabellar furrows, size and shape of anterior border, and depth of anterior border furrow.

Although the ontogeny of P. cercops has been described by Hu (1985), the relationship of this species to other taxa in Ptychopariida remained unknown, and has never been discussed in the literature. Visual comparison of large holaspid cranidia of P. cercops (Pl. 20, Figs. 3, 4) with comparably sized cranidia of the Alokistocariid Alokistocare cleora (Pl. 19, Figs. 1, 4) reveals many similarities such as a long, relatively flat preglabellar field and anterior border, a paradoublural band, a relatively long, tapered glabella, and broad fixed cheeks of low relief. Further comparison of the ontogeny of *P. cercops* with ontogenies of *Alokistocare cleora*, and the Ptychopariid ?*Antagmus gibbosa* (see following discussion of *P. cercops*) suggests that *Plagiura* is more closely related to the Alokistocariidae than to the Ptychopariidae.

Plagiura cercops **Walcott, 1917**

Pl. 20, figs. 3-10.

Ptychoparia? cercops Walcott, 1917:81, pl. 12, fig. 1, 1a-d.
Ptychoparia? cleadas Walcott, 1917:83, pl. 12, fig. 2.
Plagiura cercops—Resser, 1935:43.
Plagiurella cleadas—Resser, 1937:23.
Plagiura cercops—Lochman, 1947:66.
Plagiura cleadas—Lochman, 1947:66.
Plagiura cercops—Rasetti, 1951:237, pl. 13, figs. 10-16.
Plagiura cercops—Hu, 1985:141, pl.4, figs. 1-28, pl. 5, figs. 1-26, Text-fig. 7, A-K.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Ptarmigan Peak, illustrated by Walcott, 1917, Pl. 12, fig. 1a.

MATERIAL

401 cranidia, 2 pygidia.

OCCURRENCE

Mt. Whyte Formation, Mount Weed (H 103 m, H 106 m, H 114 m, H 115 m, H 116 m).

DESCRIPTION

Very slightly convex, tapered glabella with nearly straight to somewhat convex sides, gently curved at front. Glabellar furrows nearly effaced. Axial and preglabellar furrows shallow and narrow. Occipital furrow slightly bowed forward, very shallow. Anterior border nearly flat, paradoublural band visible on largest holaspids; anterior border furrow narrow, straight, and shallow. Short, straight palpebral lobes extend from a point adjacent S4, and terminate adjacent to posterior portion of L3; palpebral area equal to just over one-half glabellar width between midlength of palpebral lobes. Palpebral ridges poorly defined. Posterior border defined by shallow border furrow. Anterior facial sutures nearly straight, slightly convergent to slightly divergent. Posterior facial suture nearly straight, angled backward at near 45° angle, defining wide post-ocular cheek. Surface of test smooth.

Pygidium gently convex, more than twice as wide as long (sag.), sub-triangular in outline. First two axial rings and pleural furrows well defined, third axial ring and terminal piece poorly defined. Axial furrows nearly parallel. Very narrow border defined by narrow and shallow border furrow.

DISCUSSION

Juveniles and adults of both Plagiura cercops and Alokistocare cleora share several morphologic characters, of which glabellar shape is primary, that serve to distinguish them from the ptychopariid ?*Antagmus gibbosa*. The main difference between *P*. *cercops* and *A*. *cleora* is the size and position of the eyes, which are small, anteriorly located, and close to the glabella in *P*. *cercops*, but large, posteriorly located, and distal from the glabella in *A*. *cleora*. This single character difference necessarily affects other features such as size and shape of the post-ocular cheek, the palpebral area, and width (tr.) of the frontal area. The following features are compared in similar growth stages for each of the above species.

A. Glabellar morphology. — Meraspids of both *Plagiura cercops* and *Alokistocare cleora* have a glabella which is wide at the base, and tapered anteriorly, while *Antagmus*? *gibbosa* meraspids have a narrow, parallel-sided glabella. It is worth noting that meraspids of the corynexochid *Fieldaspis* also have a parallel-sided glabella, but differ from the ptychopariid form in having a more strongly developed anterior lobe. An anteriorly tapered glabella is not present in Ptychopariidae meraspids. Holaspids of A? gibbosa develop a tapered glabella, but its features differ from those shared by holaspids of *P*. *cercops* and *A*. *cleora* in the following ways: the sides of the A? gibbosa glabella are concave, while those of *P*. *cercops* and *A*. *cleora* are straight or slightly convexed; the A? gibbosa glabella is much more inflated than the glabella of *P*. *cercops* and *A. cleora*; the glabellar furrows of A? gibbosa are relatively deep and bifurcated near the crest, whereas those of *P*. *cercops* and *A*. *cleora* are extremely shallow to effaced, and are not bifurcated.

B. Frontal area morphology. — In all three species, frontal area relative length increases throughout ontogeny. However, this increase is greater in P. cercops and A. cleora than in A? gibbosa. P. cercops and A. cleora adults have a rather flat, gently sloping preglabellar field, with a flat anterior border, a paradoublural band, and a broadly curved anterior margin; adults of A? gibbosa have a gently convex preglabellar field, an inflated anterior border with a plectrum which impinges on the preglabellar field, no paradoublural band, and a more sharply curved anterior margin.

C. Cranidial convexity. — Adults of P. cercops and A. cleora have cranidia with very low convexity, while the cranidium of A? gibbosa, and the glabella in particular, is quite convex.

From the above descriptions a close relationship between P. cercops and A. cleora can be seen, and thus there are reasonable grounds for assigning Plagiura to the Alokistocariidae.

Family uncertain

Genus Kochaspis Resser, 1935

TYPE SPECIES

Crepicephalus liliana Walcott 1886, from the Pioche shale, Nevada (by original designation).

DIAGNOSIS

Ptychoparioid having glabella that is about as wide as long, a short preglabellar field, and a flat (not convex) anterior border.

DISCUSSION

Kochaspis has traditionally been assigned to the Crepicephalidae on the basis of its associated pygidium which has a pair of marginal spines (see Pl. 21, Figs. 3, 5). Aside from the fact that it has a pair of spines, the pygidium of Kochaspis bears little resemblance to that of Crepicephalus (see Westrop 1992, Pl. 12, fig. 9). For these reasons, Kochaspis is removed from the Crepicephalidae. The shape of the glabella and the anterior border distinguish Kochaspis from the Ptychopariidae and the Alokistocariidae.

Kochaspis cecinna (Walcott, 1917)

Pl. 21, figs. 1-8.

Crepicephalus cecinna Walcott, 1917:99, pl. 11, figs. 1-1b.
Kochaspis eiffelensis Rasetti, 1951:226, pl. 14, figs. 14-10.
Kochaspis eiffelensis—Rasetti, 1957:960-961, pl. 119, figs. 5-8.

HOLOTYPE

A cranidium from the Mt. Whyte Formation, Ptarmigan Peak, illustrated by Walcott, 1917, Pl. 11, fig. 1.

DIAGNOSIS

Kochaspis with prosopon of fine granules and a few scattered coarse granules on the frontal and post-ocular cheeks.

MATERIAL

55 cranidia, 2 pygidia.

OCCURRENCE

Mt. Whyte Formation, Mount Field (A 96 m, A 112 m, A 115 m, A 117 m), Mount Weed (H 150 m).

DESCRIPTION

Convex, tapered glabella with slightly convex sides, curved at front. Glabellar furrows deep, S1 deepest, S4 shallow. Axial and preglabellar furrows deep and narrow. Occipital furrow straight, deep laterally, very shallow medially. Anterior border nearly flat; anterior border furrow narrow, moderately deep, shallower medially. Long, curved palpebral lobes extend from a point adjacent L3, and terminate adjacent to posterior portion of L1; palpebral area equal to just over one-half glabellar width between midlength of palpebral lobes. Palpebral ridges prominent. Posterior border narrow (exsag.), straight, convex; border furrow deep, as wide (exsag.) as border. Anterior facial sutures nearly straight, very slightly convergent. Prosopon of fine granules and a few scattered coarse granules on the frontal and post-ocular cheeks.

DISCUSSION

Walcott's (1917, p. 100) original description of this species from the Mt. Whyte Formation noted the prosopon of fine granules with a few scattered coarse granules "over the frontal limb and border". As the number, prominence, and distribution of coarser granules on the post-ocular cheek of this species is quite variable (see Pl. 21, Figs. 1, 2, 4, 7, 8), it is easy to see how these coarse granules could have been overlooked by Walcott. Other than this detail, Walcott's (1917) description and illustration matches both the specimens illustrated here, and those described and illustrated by Rasetti (1951) as _Kochaspis eiffelensis_. _K_. _eiffelensis_ Rasetti 1951 is therefore considered to be a junior synonym of *K. cecinna*. The pygidium associated with this species by Walcott (1917, Pl. 11, figs. 1a-b) differs from that assigned by Rasetti (1951, Pl. 14, figs. 9, 10, 1957, Pl. 119, figs. 5, 7), and there is presently no way to confidently assign a pygidium to *K. cecinna*. *K. liliana* (Walcott 1886) differs in having a more coarsely granular prosopon. The primary differences between this species and a Ptychopariid such as *Antagmus gibbosa*, for example, lie in the anterior border. *Kochaspis* has a relatively flat, gently inflated, and gently curved border, while *Antagmus* has a more strongly inflated, and strongly curved border.

REFERENCES

AITKEN, J. D.

1966 Middle Cambrian to Middle Ordovician cyclic sedimentation, southern Rocky Mountains of Alberta. Bulletin of Canadian Petroleum Geology, 14:405-441.

1967 Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta. Journal of Sedimentary Petrology 37:1163-1178.

1968 Cambrian sections in the easternmost southern Rocky Mountains and the adjacent subsurface, Alberta. Geological Survey of Canada, Paper 66-23:1-96.

1978 Revised models for depositional Grand Cycles, Cambrian of Western Canada. Bulletin of Canadian Petroleum Geology, 26:515-542.

1989a The Sauk Sequence — Cambrian to Lower Ordovician miogeocline and platform. In Ricketts, B. D., ed., Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, pp. 105-119.

1989b Birth, growth and death of the Middle Cambrian Cathedral carbonate lithosome, southern Rocky Mountains. Bulletin of Canadian Petroleum Geology 37:316-333.

in press Stratigraphy of the Middle Cambrian platformal succession, southern Rocky Mountain. Geological Survey of Canada, Bulletin 398.

AITKEN, J. D. and I. A. McILREATH

1990 Comment on "The Burgess Shale: not in the shadow of the Cathedral Escarpment". Geoscience Canada 17:111-116.

ANGELIN, N. P.

1854 Palaeontologia Svecicae. I: Iconographia crustaceorum formationis transitionis. Holmiae. Fasc. 1:1-24.

ARMIN, R. A. and L. MAYER

1983 Subsidence analysis of the Cordilleran miogeocline: implications for timing of late Proterozoic rifting and amount of extension. Geology, 11:702-705.

ARNOTT, R. W. and F. J. HEIN

1986 Submarine canyon fills of the Hector Formation, Lake Louise, Alberta: Late Precambrian deep-water syn-rift (?) deposits of the proto-Pacific miogeocline. Bulletin of Canadian Petroleum Geology X:x-y.

BALL, M. M.

1967 Carbonate sand bodies of Florida and the Bahamas. Journal of Sedimentary Petrology, 37:556-591.

BEECHER, C. E.

1897 Outline of a natural classification of the trilobites. American Journal of Science 153:89-106.

BOND G. C. and M. A. KOMINZ

1984 Construction of tectonic subsidence curves for early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implication for subsidence mechanisms, age of breakup, and crustal thinning. Geologcial Society of America, Bulletin 95:155-173.

BOND G. C., P. A. NICKESON and M. A. KOMINZ

1984 Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories. Earth and Planetary Science Letters, 70:325-345.

BOWRING, S. A., J. P. GROTZINGER, C. E. ISACHSEN, A. H. KNOLL, S. M. PELECHATY and P. KOLOSOV

1993 Calibrating rates of Early Cambrian evolution. Science 261:1293-1298.

BURKE, K. and J. F. DEWEY

1973 Plume generated triple junctions: Key indicators in applying plate tectonics to old rocks. Journal of Geology 81:406-433.

BURLING, L. D.

1916 Paedeumias and the Mesonacidae, with description of a new species, having at least 44 segments, from the Lower Cambrian of British Columbia. Ottawa Naturalist 30:53-58.

BYERS, C. W.

1977 Biofacies patterns in euxinic basins: a general model. In Cook, H. E., and P. Enos, eds., Deep-water carbonate environments. Society of Economic Paleontologists and Mineralogists, Special Publication 25:5-17.

CAMPBELL, L. D.

1971 Occurrence of "Ogygopsis shale" fauna in southeastern Pennsylvania. Journal of Paleontology 45:437-440.

CHANG W. T. and P. A. JELL

1987 Cambrian trilobites of north China - Chinese Cambrian trilobites housed in the Smithsonian Institution. Beijing, Science Press. 459 pp.

CHOW, N. and N. P. JAMES

1987 Facies-specific, calcitic and bimineralic ooids from Middle and Upper Cambrian platform carbonates, western Newfoundland, Canada. Journal of Sedimentary Petrology, 57: 907-921.

COOK, H. E. and H. T. MULLINS

1983 Basin margin environment. In Scholle, P. A., D. G. Bebout, and C. H. Moore, eds., Carbonate depositional environments. American Association of Petroleum Geologists, Memoir 33:540-617.

COOK, H. and M. E. TAYLOR

1977 Comparison of continental slope and shelf environments in the Upper Cambrian and Lowest Ordovician of Nevada. In Cook, H. E., and P. Enos, eds., Deep-water carbonate environments. Society of Economic Paleontologists and Mineralogists, Special Publication 25:51-81.

COWAN C. A. and N. P. JAMES

1993 The interactions of sea-level change, terrigenous-sediment influx, and carbonate productivity as controls on Upper Cambrian Grand Cycles of western Newfoundland, Canada. Geological Society of America Bulletin 105:1576-1590.

DAVIES G. R.

1977 Turbidites, debris sheets, and truncation structures in Upper Paleozoic deep-water carbonates of the Sverdrup Basin, Arctic Archipelago. In Cook, H. E., and P. Enos, eds., Deep-water carbonate environments. Society of Economic Paleontologists and Mineralogists, Special Publication 25:221-247.

DEISS, C.

1939 Cambrian formations of southwestern Alberta and southeastern British Columbia. Geological Society of America, Bulletin 50:951-1026.

1940 Lower and Middle Cambrian stratigraphy of southwestern Alberta and southeastern British Columbia. Geological Society of America, Bulletin 51:731-794.

DEVLIN, W. J. and G. C. BOND

1988 The initiation of the early Paleozoic Cordilleran miogeocline: evidence from the uppermost Proterozoic — Lower Cambrian Hamill Group of southeastern British Columbia. Canadian Journal of Earth Science, 25:1-19.

DICKINSON, W. R.

1977 Paleozoic plate tectonics and the evolution of the Cordilleran continental margin. In Stewart, J. H., C. H. Stevens and A. E. Fritsche, eds., Paleozoic paleogeography in the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1:137-155.

ENOS, P. and C. H. MOORE

1983 Fore-reef slope environment. In Scholle, P. A., D. G. Bebout, and C. H. Moore, eds., Carbonate depositional environments. American Association of Petroleum Geologists, Memoir 33:508-537.

ESTEBAN, M. and C. F. KLAPPA

1983 Subaerial exposure environment. In Scholle, P. A., D. G. Bebout, and C. H. Moore, eds., Carbonate depositional environments. American Association of Petroleum Geologists, Memoir 33:1-54.

FORTEY, R. A.

1975 Early Ordovician trilobite communities. Fossils and Strata 4:339-360.

FRITZ, W. H.

1968 Lower and early Middle Cambrian trilobites from the Pioche Shale, east-central Nevada, U.S.A. Paleontology 11:183-235.

1972 Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, northwestern

Canada. Geological Survey of Canada, Bulletin 212:1-90.

1975 Broad correlations of some lower and Middle Cambrian strata in the North American cordillera. Geological Survey of Canada, Paper 75-1, Part A, pp. 533-540.

1990 In defense of the escarpment near the Burgess Shale fossil locality. Geoscience Canada 17:106-110.

1991 Lower Cambrian trilobites from the Illtyd Formation, Wernecke Mountains, Yukon Territory. Geological Survey of Canada, Bulletin 409:1-77.

1992 Walcott's Lower Cambrian olenellid trilobite collection 61K, Mount Robson Area, Canadian Rocky Mountains. Geological Survey of Canada, Bulletin 432:1-65.

FRITZ, W. H. and E. W. MOUNTJOY

1975 Lower and early Middle Cambrian formations near Mount Robson, British Columbia and Alberta. Canadian Journal of Earth Sciences 12:119-131.

FRITZ, W. H., M. P. CECILE, B. S. NORFORD, D. MORROW, and H. H. J. GELDSETZER

1991 Cambrian to Middle Devonian assemblages. <u>In</u> Gabrielse, H., and C. J. Yorath, eds., Geology of the Cordilleran Orogen in Canada. Geological Survey of Canada, Geology of Canada, no. 4, pp. 151-218.

HALLEY, R. B., E. A. SHINN, J. H. HUDSON and B. H. LIDZ

1977 Pleistocene barrier bar seaward of ooid shoal complex near Miami, Florida. American Association of Petroleum Geologists Bulletin 61:519-526.

HALLEY, R. B., P. M. HARRIS and A. C. HINE

1983 Bank margin environment. In Scholle, P. A., D. G. Bebout, and C. H. Moore, eds., Carbonate depositional environments. American Association of Petroleum Geologists, Memoir 33:463-506.

HARRINGTON, H. J., ET AL.

1959 Arthropoda 1, part O (Moore, R. C., ed.), Treatise on invertebrate paleontology. University of Kansas Press.

HAWLE, I. and A. J. C. CORDA

1847 Prodrom einer Monographie der bohemischen Trilobiten. Prague, 176 pp. [In German]

HEIN, F. J.

1987 Tidal/littoral offshore shelf deposits—Lower Cambrian Gog Group, southern Rocky Mountains, Canada. Sedimentary Geology, 52:155-182.

HINE A. C.

1977 Lily Bank, Bahamas; history of an active oolite sand shoal. Journal of Sedimentary Petrology 47:1554-1581.

HOCKLEY, G. D.

1973 Stratigraphy and paleoenvironmental patterns of the Peyto-Mt. Whyte sediments (Lower-Middle Cambrian) of the southwestern Canadian Rocky Mountains. University of Calgary, unpublished M.Sc. thesis, xp.

HOFFMAN, X. Y,

1989 Precambrian geology and tectonic history of North America. In Bally, A. W. and A. R. Palmer, eds., The Geology of North America—An Overview. Geological Society of America, The Geology of North America, Vol. A, p.p. 447-512.

HU, C.-H.

1985 Ontogenetic development of Cambrian trilobites from British Columbia and Alberta, Canada (Part 1). Journal of the Taiwan Museum 38:121-158.

JAMES, N. P., R. K. STEVENS, C. R. BARNES and I. KNIGHT

1989 Evolution of a lower Paleozoic continental-margin carbonate platform, northern Canadian Appalachians. In Controls on Carbonate Platform and Basin Development, SEPM Special Publication No. 44, pp. x-y.

KENARD, J. M. and N. P. JAMES

1986 Thrombolites and stromatolites: Two distinct types of microbial structures. Paleos 1:492-503.

KOBAYASHI, T.

1935 The Cambro-Ordovician formations and faunas of South Chosen, Part 3. Journal of the Faculty of Science, Imperial University of Tokyo, section 2, 4:49-344.

KREISA, R. D.

1981 Storm-generated sedimentary structures in subtidal marine facies with examples from the Middle and Upper Ordovician of south-west Virginia. Journal of Sedimentary Petrology 51:823-848.

LERMONTOVA, E. V.

1940 Arthropoda-Class Trilobita. In Vologdin, A. ed., Atlas of the leading forms of fossil faunas of the USSR, vol. 1, Cambrian. VSEGEI, Moscow, pp. 1-193. [In Russian]

LOCHMAN, C.

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

1948 New Cambrian trilobite genera from northwest Sonora, Mexico. Journal of Paleontology 22:451-464.

1952 in Cooper, G. A., et al. Cambrian stratigraphy and paleontology near Caborca, north-western Sonora, Mexico. Smithsonian Miscellaneous Collections 119:

LOCHMAN-BALK, C. and J. L. WILSON

1958 Cambrian biostratigraphy in North America. Journal of Paleontology 32:312-350.

LONG, D. G. F.

1989 Ella Bay Formation: Early Cambrian shelf differentiation in the Franklinian basin, central eastern Ellesmere Island, Arctic Canada. Canadian Journal of Earth Science, 26:2621-2635.

LORENZ, T.

1906 Contribution to the geology and palaeontology of East Asia with special consideration of the Province of

Shantung in China. Z. dt. geol. Ges. 58:53-108. [In German]

LUDVIGSEN, R.

1979 A trilobite zonation of Middle Ordovician rocks, southwestern District of Mackenzie. Geological Survey of Canada Bulletin 312:1-99.

1989 The Burgess Shale: not in the shadow of the Cathedral Escarpment. Geoscience Canada 16:51-59.

LUDVIGSEN, R. and S. R. WESTROP

1983 Trilobite biofacies of the Cambrian-Ordovician boundary interval of northern North America. Alcheringa 7:301-319.

LUDVIGSEN, R., S. R. WESTROP, B. R. PRATT, P. A. TUFFNELL, and G. A. YOUNG.

1986 Paleoscene number 3. Dual biostratigraphy: zones and biofacies. Geoscience Canada 13:139-154.

MARKELLO, J. R. and J. F. READ

1981 Carbonate ramp-to-deeper shale shelf transitions of an Upper Cambrian intrashelf basin, Nolichucky Formation, southwest Virginia Appalachians. Sedimentology 28:573-597.

McILREATH, I. A.

1977 Accumulation of a Middle Cambrian, deep-water limestone debris apron adjacent to a vertical submarine carbonate escarpment, southern Rocky Mountains, Canada. In Cook, H. E., and P. Enos, eds., Deep-water carbonate environments. Society of

Economic Paleontologists and Mineralogists, Special Publication 25:113-124.

McKENZIE, D.

1978 Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters, 40:25-32.

McMECHAN, M. E.

1981 The Middle Proterozoic Purcell Supergroup in the southwestern Rocky and southeastern Purcell Mountains, British Columbia and the initiation of the Cordilleran miogeocline, southern Canada and adjacent United States. Bulletin of Canadian Petroleum Geology 29:583-621.

McNAMARA, K. J. and D. M. RUDKIN.

1984 Techniques of trilobite exuviation. Lethaia 17:153-173.

MEEK, F. B.

1874 In Preliminary Report Upon Invertebrate Fossils Collected by the Expeditions of 1871, 1872, 1873, With Descriptions of New Species, United States Geographical and Geological Explorations and Surveys West of the One Hundredth Meridian, C. A. White; Engineering Department, United States Army, pp. 5-27.

MILLER, K. B., C. E. BRETT and K. M. PARSONS

1988 paleoecological significance of storm generated disturbances within a Middle Devonian muddy epeiric sea. Paleos 3:35-52.

MONGER, J. W. H. and R. A. PRICE

1979 Geodynamic evolution of the Canadian Cordillera — progress and problems. Canadian Journal of Earth Sciences 16:770-791.

MONGER, J. W. H., J. G. SOUTHER and H. GABRIELSE

1972 Evolution of the Canadian Cordillera: A plate-tectonic model. American Journal of Science 272:577-602.

MOORE, R. C.

1959 Treatise on Invertebrate Paleontology. Part O. Arthropoda 1. Lawrence, Geological Society of America and University of Kansas Press. 560 pp.

MOUNTJOY, E. W.

1962 Mount Robson (southeast) map-area, Rocky Mountains of Alberta and British Columbia, 83E/SE. Geological Survey of Canada, Paper 61-31, pp. 1-114.

MOUNTJOY, E. W. and J. D. Aitken

1978 Middle Cambrian Snake Indian Formation (new) Jasper region, Alberta. Bulletin of Canadian Petroleum Geology, 26:343-361.

MYROW, P. M. and E. LANDING

1992 Mixed siliciclastic-carbonate deposition in an Early Cambrian oxygen-stratified basin, Chapel Island Formation, southeastern Newfoundland. Journal of Sedimentary Petrology, 62:455-473.

NARDIN, T. R., F. J. HEIN, D. S. GORSLINE, and B. D. EDWARDS

1979 Santa Cruz Basin, California borderland: dominance of slope processes in basin sedimentation. In Doyle, L. J., and O. H. Pilkey Jr., eds., Geology of continental slopes. Society of Economic Paleontologists and Mineralogists, Special Publication 27, p. 209-222.

NELSON, C. A.

1963 Stratigraphic range of Ogygopsis. Journal of Paleontology 37:244-248.

OLDOW, J. S., A. W. BALLY, H. G. AVE LALLEMANT and W. P. LEEMAN

1989 Phanerozoic evolution of the North American Cordillera; United States and Canada. In Bally, A. W. and A. R. Palmer, eds., The Geology of North America — An Overview. Geological Society of America, The Geology of North America, Vol. A, p.p. 139-232.

OPIK, A. A.

1982 Dolichometopid trilobites of Queensland, Northern Territory, and New South Wales. Australia Bureau of Mineral Resources, Geology and Geophysics Bulletin 175:1-85.

PALMER, A. R.

1954 An appraisal of the Great Basin Middle Cambrian trilobites described before 1900. United States Geological Survey, Professional Paper 264-D:1-86.

1957 Ontogenetic development of two olenellid trilobites. Journal of Paleontology 31:105-128.

1964 An unusual Lower Cambrian trilobite fauna from Nevada. United States Geological Survey, Professional Paper 483-F:1-13.

1965 Trilobites of the Late Cambrian Pterocephaliid Biomere in the Great Basin, United States. United States Geological Survey Professional Paper 493:1-105.

1968 Cambrian trilobites of east-central Alaska. United States Geological Survey, Professional Paper 559-B:1-115.

1981 On the correlatability of grand cycle tops. In Taylor, M. E., ed., Short Papers for the Second International Symposium on the Cambrian System, United States Geological Survey, Open-File Report 81-743:156-158.

PALMER, A. R. and R. B. HALLEY

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 1047:1-131.

PIPER, D. J. W. and D. A. V. STOW

1990 Fine-Grained Turbidites. In Einsele, G., W. Ricken, and A. Seilacher eds., Cycles and Events in Stratigraphy. Berlin, Springer-Verlag, pp. 360-376.

POULSEN, C.

1927 The Cambrian, Ozarkian and Canadian faunas of northwest Greenland. Meddelelser om Gronland 70:237-343.

PRICE, R. A.

1964 The Precambrian Purcell System in the Rocky Mountains of Southern Alberta and British Columbia. Bulletin of Canadian Petroleum Geology 12:399-426.

RASETTI, F.

1948a Lower Cambrian trilobites from the conglomerates of Quebec (exclusive of the Ptychopariidae). Journal of Paleontology 22:1-24.

1948b Middle Cambrian trilobites from the conglomerates of Quebec (exclusive of the Ptychopariidae). Journal of Paleontology 22:315-339.

1951 Middle Cambrian stratigraphy and faunas of the Canadian Rocky Mountains. Smithsonian Miscellaneous Collections 116:1-277.

1955 Lower Cambrian ptychopariid trilobites from the conglomerates of Quebec. Smithsonian Miscellaneous Collections 128:1-41.

1957 Additional fossils from the Middle Cambrian Mount Whyte Formation of the Canadian Rocky Mountains. Journal of Paleontology 31:955-972.

1959 in Harrington, H. J., et al.

1963 Middle Cambrian ptychoparioid trilobites from the conglomerates of Quebec. Journal of Paleontology 37:575-594.

RAYMOND, P. E.

1928 Two new Cambrian trilobites. American Journal of Science 15:309-315.

RESSER, C. E.

1935 Nomenclature of some Cambrian trilobites. Smithsonian Miscellaneous Collections 93:1-46.

1936 Second contribution to nomenclature of Cambrian trilobites. Smithsonian Miscellaneous Collections 95:1-29.

1937a Third contribution to nomenclature of Cambrian trilobites. Smithsonian Miscellaneous Collections 95:1-29

1937b Elkanah Billings' lower Cambrian trilobites and associated species. Journal of Paleontology 11:43-54.

1938a Middle Cambrian fossils from Pend Oreille Lake, Idaho. Smithsonian Miscellaneous Collections 97:1-12.

1938b Cambrian System (restricted) of the southern Appalachians. Geological Society of America, Special Paper 15:1-140.

1939a The Spence Shale and its fauna. Smithsonian Miscellaneous Collections 97:1-29.

1939b The Ptarmigania strata of the northern Wasatch Mountains. Smithsonian Miscellaneous Collections 98:1-72.

RESSER, C. E. and B. F. HOWELL

1938 Lower Cambrian Olenellus Zone of the Appalachians. Geological Society of America, Bulletin 49:195-248.

RHOADS, D. C. and J. W. MORSE

1971 Evolutionary and ecologic significance of oxygen-deficient marine basins. Lethaia, 4:413-428.

ROBISON, R. A.

1971 Additional Middle Cambrian trilobites from the Wheeler Shale of Utah. Journal of Paleontology 45:796-804.

1976 Middle Cambrian trilobite biostratigraphy of the Great Basin. Brigham Young University Studies 23:93-109.

RUDKIN, D. M.

1979 Healed injuries in _Ogygopsis klotzi_ (Trilobita) from the Middle Cambrian of British Columbia. Royal Ontario Museum, Life Sciences Occasional Papers 32:1-8.

SARG, J. F.

1988 Carbonate sequence stratigraphy. Sea-Level Changes—An Integrated Approach, SEPM Special Publication No. 42, pp. 155-181.

SHAW, A. B.

1962 Paleontology of northwestern Vermont IX. Fauna of the Monkton Quartzite. Journal of Paleontology 36:322-345.

STEWART, J. H.

1972 Initial deposits in the Cordilleran geosyncline: evidence of a late Precambrian (<850 m.y.) separation. Geological Society of America Bulletin 83:1345-1360.

1976 Late Precambrian evolution of North America: plate tectonics implication. Geology 4:11-15.

STEWART, J. H. and C. A. SUCZEC

1977 Cambrian and latest Precambrian paleogeography and tectonics in the western United States. In Stewart, J. H., et al., eds., Paleozoic paleogeography of the western United States. Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1:1-17.

STOW, D. A. V.

1986 Chapter 12 Deep clastic seas. In Reading, H. G., ed., Sedimentary Environments and Facies. Oxford, Blackwell Scientific Publications, pp. 399-412.

STRUIK, L. C.

1987 The ancient western North American margin: an Alpine rift model for the east-central Canadian Cordillera. Geological Survey of Canada Paper 87-15:1-19.

SWINNERTON, H. H.

1915 Suggestions for a revised classification of trilobites. Geological Magazine, new series, Decade 6, 2:487-496.

TREMBLAY, J. V. and S. R. WESTROP

1991 Middle Ordovician (Whiterockian) trilobites from the Sunblood Formation, District of Mackenzie, Canada. Journal of Paleontology 65:801-824.

VAN WAGONER, J. C., H. W. POSAMENTIER, R. M. MITCHUM, P. R. VAIL, J.F. SARG, T. S. LOUTIT, and J. HARDENBOL

1988 An overview of the fundamentals of sequence stratigraphy and the key definitions. Sea-Level Changes—An Integrated Approach, SEPM Special Publication No. 42, pp. 39-45.

VOGDES, A. W.

1925 Palaeozoic Crustacea. Pt. 2—A list of the genera and subgenera of the Trilobita. Transactions of the San Diego Society of Natural History 4:89-115.

WALCOTT, C. D.

1886 Second contribution to the studies on the Cambrian faunas of North America. United States Geological Survey, Bulletin 30:

1889 Description of new genera and species of fossils from the Middle Cambrian. Proceedings of the United States National Museum, 11:441-446.

1890 The fauna of the Lower Cambrian or *Olenellus* Zone. United States Geological Survey, 10th Annual Report:511-774.

1908 Cambrian geology and paleontology no. 1.—Nomenclature of some Cambrian Cordilleran formations. Smithsonian Miscellaneous Collections 53:1-12.

1912 Group terms for the Lower and Upper Cambrian series of formations. Smithsonian Miscellaneous Collections 57:305-307.

1916 Cambrian trilobites. Smithsonian Miscellaneous Collections 64:305-307.

1917a Fauna of the Mount Whyte Formation. Smithsonian Miscellaneous Collections 67:61-114.

1924 Cambrian geology and paleontology, part 5, number 2, Cambrian and lower Ozarkian trilobites. Smithsonian Miscellaneous Collections 75:53-60.

1928 Pre-Devonian Paleozoic formation of the Cordilleran provinces of Canada. Smithsonian Miscellaneous Collections 75(5):1-368.

WALKER, R. G.

1984 Turbidites and associated coarse clastic deposits. In Walker, R. G., ed., Facies models: Geological Association of Canada, Geoscience Canada Reprint Series 1, pp. 171-188.

1990 Facies modeling and sequence stratigraphy. Journal of Sedimentary Petrology, 60:777-786.

WESTROP, S. R.

1986 Trilobites of the Upper Cambrian Sunwaptan Stage, southern Canadian Rocky Mountains, Alberta. Palaeontographica Canadiana 3:1-179.

1989 Facies anatomy of an Upper Cambrian grand cycle: Bison Creek and Mistaya formations, southern Alberta. Canadian Journal of Earth Sciences 26:2292-2304.

WESTROP, S. R.

1992 Upper Cambrian (Marjuman-Steptoan) trilobites from Port au Port, Western Newfoundland. Journal of Paleontology, 66:228-255.

WESTROP, S. R., J. V. TREMBLAY and E. LANDING

1995 Declining importance of trilobites in Ordovician nearshore communities: displacement or dilution? Paleos:x-y.

WHITTINGTON, H. B.

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

WIGNALL P. B. and K. J. MEYERS

1988 Interpreting benthic oxygen levels in mudrocks: a new approach. Geology, 16:452-455.

WILSON, J. L., and C. JORDAN

1983 Middle shelf environment. In Scholle, P. A., D. G. Bebout, and C. H. Moore, eds., Carbonate depositional environments. American Association of Petroleum Geologists, Memoir 33:298-343.

WINSTON, D.

1986 Sedimentation and tectonics of the Middle Proterozoic Belt basin and their influence on Phanerozoic compression and extension in western Montana and northern Idaho. In Peterson, J. A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States. American Association of Petroleum Geologists, Memoir 41:87-118.

YOUNG, F. G.

1979 The lowermost Paleozoic McNaughton Formation and equivalent Cariboo Group of eastern British Columbia:

Piedmont and tidal complex. Geological Survey of Canada, Bulletin 288:1-.

YOUNG, G. A. and R. LUDVIGSEN.

1989 Middle Cambrian trilobites from the lowest part of the Cow Head Group, western Newfoundland. Geological Survey of Canada Bulletin 392:1-49.

PLATE 1, figs. 1-7.

Figs. 1,2. *Olenellus* sp. 1, Peyto Formation, Banff National Park.

1,2. Cephalon, dorsal and anterior views, Mount Weed (29 m), ROM 52498, x 5.5.

Fig. 3. *Olenellus* sp. 2, Peyto Formation, Banff National Park.

3. Cephalon, dorsal view, Mount Weed (0.3 m), ROM 52499, x 2.

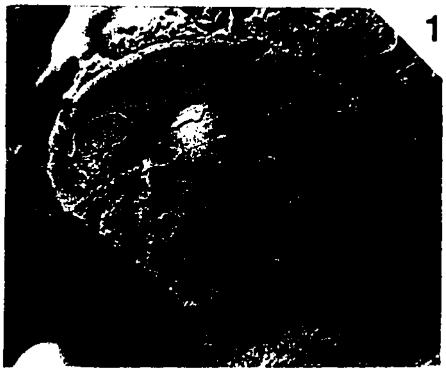
Figs. 4-7. *Olenellus gilberti* Meek, Peyto Formation, Banff National Park.

4. Small cephalon, dorsal view, Mount Weed (29 m), ROM 52500, x 9.

5. Cephalon, dorsal view, Mount Jimmy Simpson (24 m), ROM 52501, x 1.

6. Cephalon, dorsal view, Mount Jimmy Simpson (10 m), ROM 52502, x 0.8

7. Cephalon, dorsal view, Mount Jimmy Simpson (10 m), ROM 52503, x 2.5.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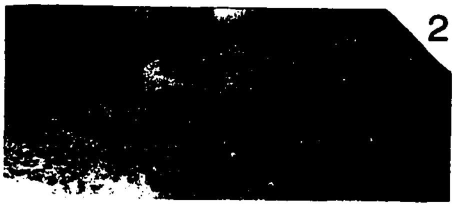
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PLATE 2, figs. 1-7.

Figs. 1-4. *Olenellus romensis* Resser and Howell, Peyto and Mt. Whyte formations, Banff and Yoho national parks.

1,2. Cephalon, dorsal and lateral views, Park Boundary (6 m), ROM 52504, x 0.8.

3. Cephalon, latex impression, dorsal view, Pope's Peak (3 m), ROM 52505, x 2.

4. Coquina with large glabellar fragment, Pope's Peak (3 m), ROM 52506, x 0.8.

Figs. 5-7. *Olenellus* sp. 3, Mt. Whyte Formation, Yoho National Park.

5. Cephalic fragment, dorsal view, Monarch Creek (B 26 m), ROM 52507, x 3.

6. Cephalic fragment, dorsal view, Monarch Creek (B 26 m), ROM 52508, x 3.

7. Cephalic fragment, dorsal view, Monarch Creek (B 26 m), ROM 52509, x 2.5.


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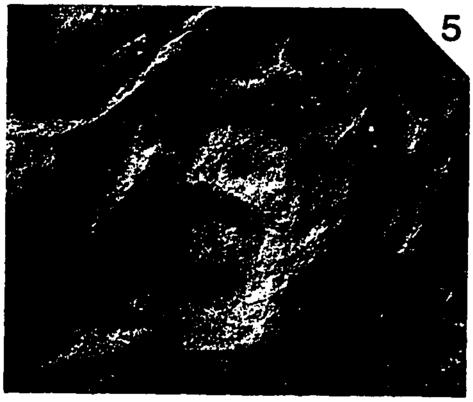
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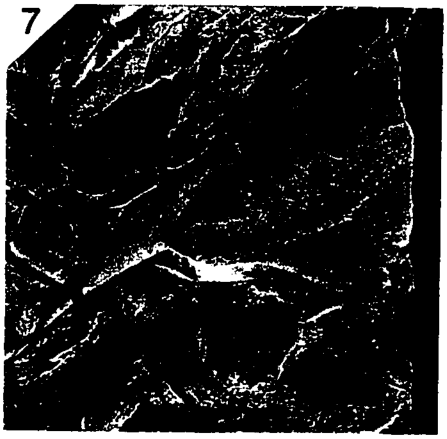
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PLATE 3, figs. 1-10.

Figs. 1-10. *Olenoides fieldensis* (Walcott), Peyto Formation, Banff and Yoho national parks.

1-3. Cranidium, dorsal, anterior and lateral views, Mount Weed (29 m), ROM 52510, X 5.5.

4-6. Cranidium, dorsal, anterior and lateral views, Mount Weed (29 m), ROM 52511, X 5.5.

7. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52512, X 5.5.

8,9. Pygidium, dorsal and lateral views, Mount Weed (29 m), ROM 52513, X 5.5.

10. Cranidium, dorsal view, Mount Weed (3.5 m), ROM 52514, X 14.5.


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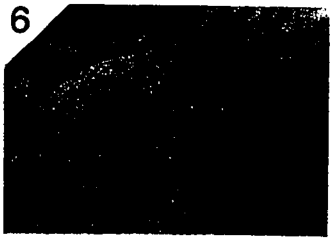
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PLATE 4, figs. 1-6.

Figs. 1-2. *Olenoides fieldensis* (Walcott), Peyto Formation, Yoho National Park.

1. Cranidium, dorsal view, Snow Shed (1 m), ROM 52515, x 5.5.

2. Pygidium, dorsal view, Monarch Creek (26 m), ROM 52516, x 2.5.

Figs. 3-5. *Ogygopsis klotzi* (Rominger), Naiset Formation, Yoho National Park.

3. Cranidium, dorsal view, North Gully (81 m), ROM 52517, x 2.5.

4. Cranidium, dorsal view, North Gully (81 m), ROM 52518, x 2.

5. Hypostome, ventral view, North Gully (81 m), ROM 52519, x 4.

Fig. 6. *Oryctocephalites* sp. indet. 2 Rasetti, Naiset Formation, Yoho National Park.

6. Thorax with attached pygidium, dorsal view, Fossil Gully (lower), ROM 52520, x 4.

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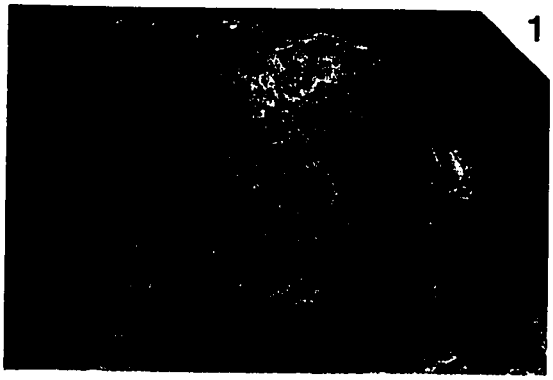

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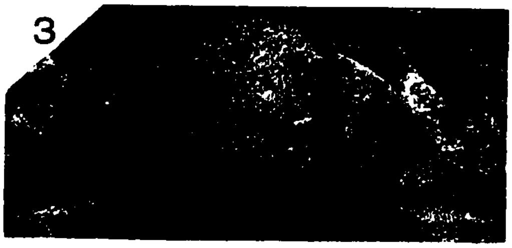

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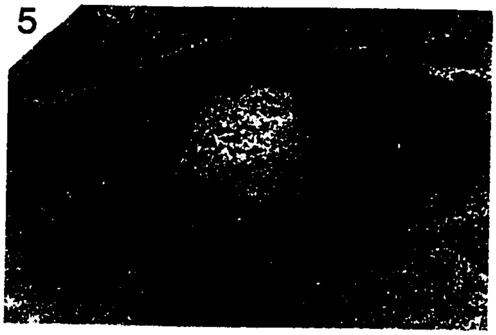

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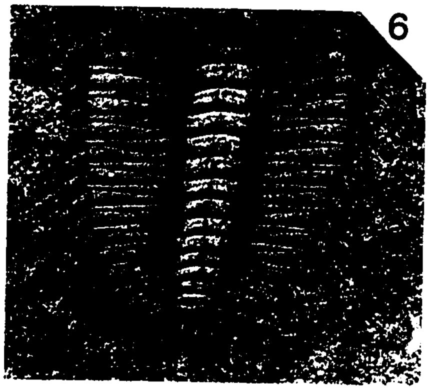


PLATE 5, figs. 1-8.

Figs. 1-3. *Poliella prima* (Walcott), Naiset Formation, Banff National Park.

1. Nearly complete individual, dorsal view, Pope's Peak (12 m), ROM 52521, x 7.5.

2. Cranidium, dorsal view, Pope's Peak (12 m), ROM 52522, x 4.

3. Pygidium, dorsal view, Pope's Peak (12 m), ROM 52523, x 7.

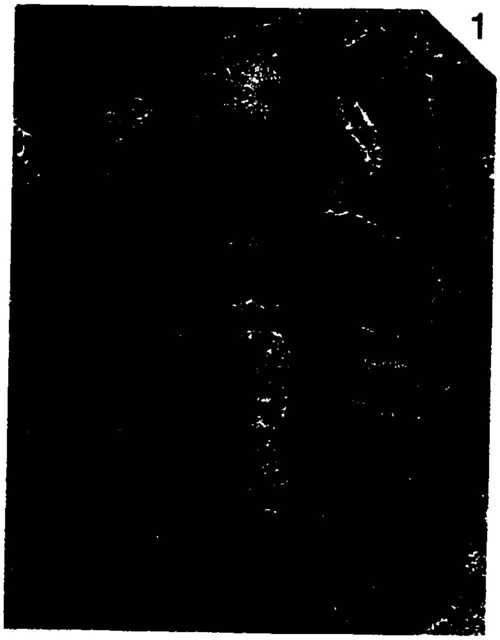
Figs. 4-8. *Poliella denticulata* Rasetti, Naiset Formation, Yoho National Park.

4-5. Cranidium, lateral and dorsal views, North Gully (78 m), ROM 52524, x 10.

6. Cranidium, dorsal view, Fossil Gully, ROM 52525, x 3.5.

7. Cranidium, dorsal view, Fossil Gully, ROM 52526, x 5.5.

8. Cranidium, dorsal view, Fossil Gully, ROM 52527, x 5.5.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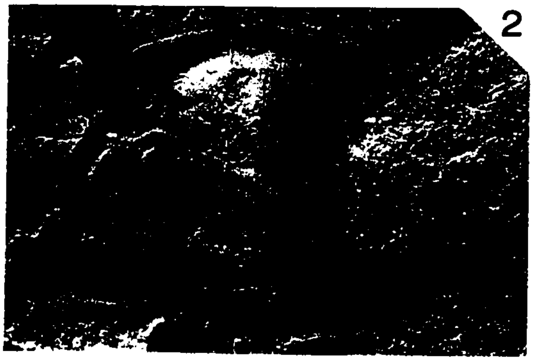
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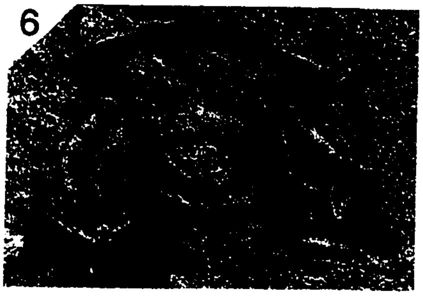
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PLATE 6, figs. 1-4.

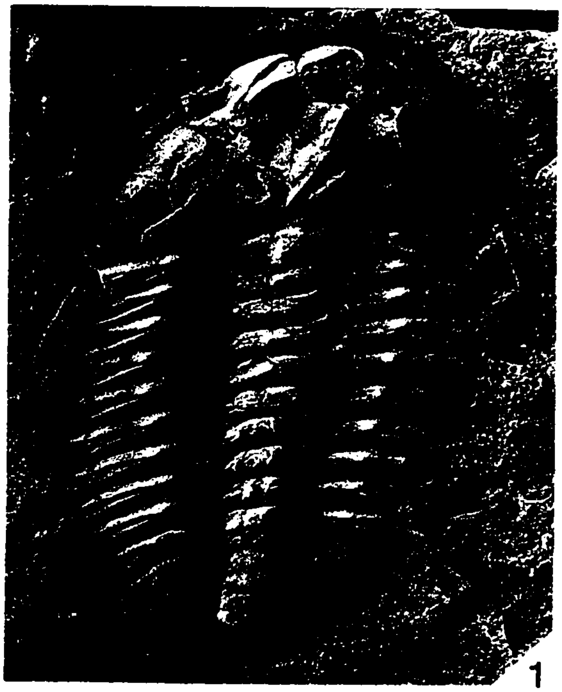
Figs. 1-4. *Wenkchemnia walcotti* Rasetti, Naiset Formation, Yoho National Park.

1. Complete individual, dorsal view, North Gully (87 m), ROM 52528, x 3.5.

2. Nearly complete individual, dorsal view, North Gully (88 m), ROM 52529, x 5.5.

3. Nearly complete individual, dorsal view, North Gully (88 m), ROM 52530, x 4.5.

4. Complete individual, dorsal view, North Gully (float), ROM 52531, x 5.5.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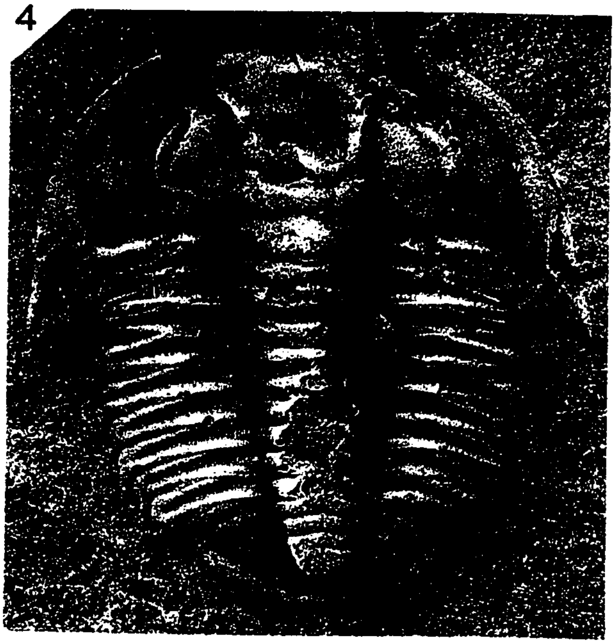
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PLATE 7, figs. 1-8.

Figs. 1-7. *Wenkchemnia walcotti* Rasetti, Naiset Formation, Banff and Yoho national parks.

1. Complete individual, dorsal view, North Gully (float), ROM 52532, x 4.5.

2. Cranidium, dorsal view, Pope's Peak (12 m), ROM 52533, x 4.

3. Complete individual, dorsal view, North Gully (float), ROM 52534, x 3.5.

4. Pygidium, dorsal view, Pope's Peak (12 m), ROM 52535, x 5.5.

5. Pygidium, dorsal view, Pope's Peak (12 m), ROM 52536, x 4.

6. Cranidium, dorsal view, North Gully (88 m), ROM 52537, x 5.5.

7. Cranidium, dorsal view, North Gully (88 m), ROM 52538, x 4.

Fig. 8. Albertella?, Cathedral Formation, Banff National Park.

8. Pygidium, dorsal view, Park Boundary (140 m), ROM 52539, x 7.


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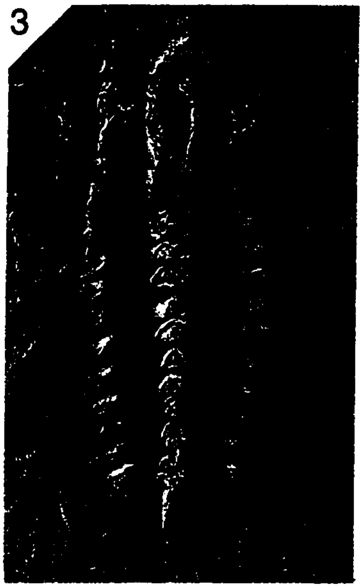
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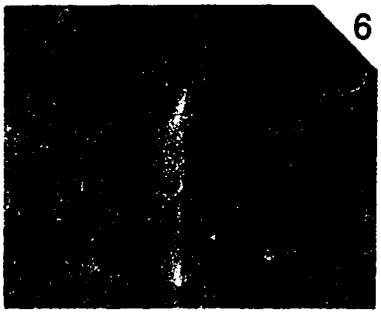
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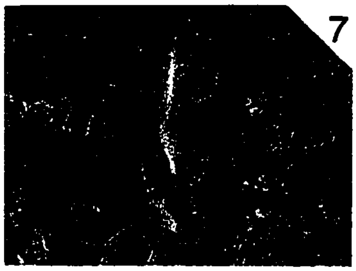
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PLATE 8, figs. 1-9.

Figs. 1-9. *Fieldaspis celer* (Walcott), Mt. Whyte Formation, Yoho National Park.

1,2. Cranidium, dorsal and oblique views, Mount Field (115 m), ROM 52540, x 5.

3. Pygidium, dorsal view, Mount Field (115 m), ROM 52541, x 7.

4. Hypostome, ventral view, Mount Field (115 m), ROM 52542, x 5.5.

5. Hypostome, ventral view, Mount Field (115 m), ROM 52543, x 12.

6. Cranidium, dorsal view, Mount Field (115 m), ROM 52544, x 5.5.

7. Cranidium, dorsal view, Mount Field (115 m), ROM 52545, x 6.

8. Cranidium, dorsal view, Mount Field (115 m), ROM 52546, x 12.

9. Cranidium, dorsal view, Mount Field (115 m), ROM 52547, x 5.

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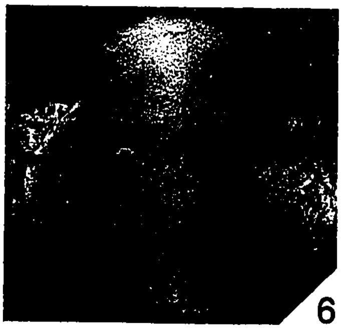

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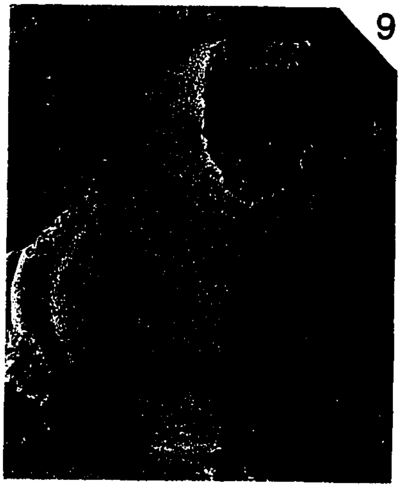

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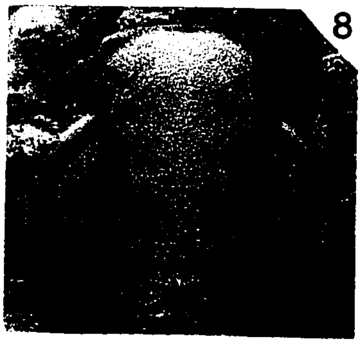

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PLATE 9, figs. 1-13.

Figs. 1-9. *Fieldaspis celer* (Walcott), Mt. Whyte Formation, Yoho National Park.

1. Protaspid, dorsal view, Mount Field (115 m), ROM 52548, X 40.

2. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52549, X 29.

3. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52550, X 24.

4. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52551, X 24.

5. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52552, X 26.

6. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52553, X 24.

7. Cranidium, dorsal view, Mount Field (115 m), ROM 52554, X 24.

8. Cranidium, dorsal view, Mount Field (115 m), ROM 52555, X 24.

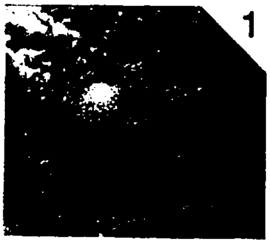
9. Cranidium, dorsal view, Mount Field (115 m), ROM 52556, X 24.

10. Hypostome, ventral view, Mount Field (115 m), ROM 52557, X 5.

11. Pygidium, dorsal view, Mount Field (115 m), ROM 52558, X 7.

12. Pygidium, dorsal view, Mount Field (115 m), ROM 52559, X 7.

13. Pygidium, dorsal view, Mount Field (115 m), ROM 52560, X 5.5.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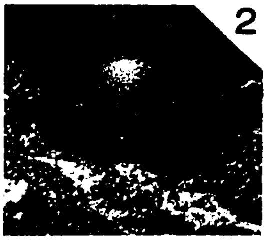
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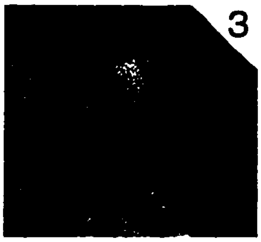
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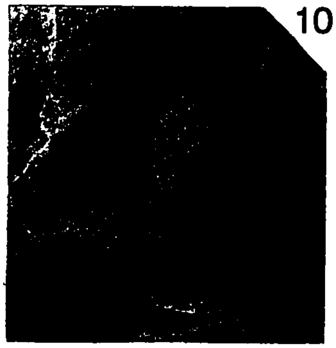
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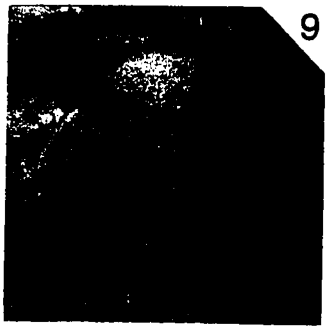
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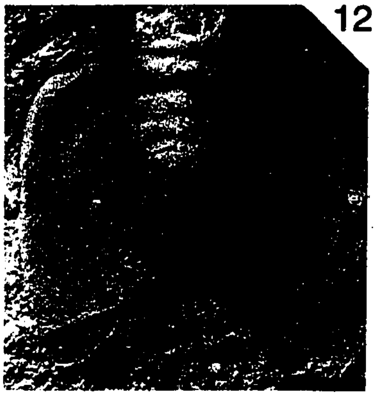
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PLATE 10, figs. 1-8.

Figs. 1-5. *Fieldaspis bilobata* Rasetti, Mt. Whyte Formation, Yoho National Park.

1. Cranidium, dorsal view, Mount Field (115 m), ROM 52561, X 24.

2. Cranidium, dorsal view, Mount Field (115 m), ROM 52562, X 7.

3. Cranidium, dorsal view, Mount Field (115 m), ROM 52563, X 7.

4. Cranidium, dorsal view, Mount Field (115 m), ROM 52564, X 5.5.

5. Cranidium, dorsal view, Mount Field (115 m), ROM 52565, X 16.

Figs. 6-8. *Fieldaspis bispinosa* (Rasetti), Naiset Formation, Yoho National Park.

6. Cranidium, dorsal view, Fossil Gully, ROM 52566, X 4.

7. Nearly complete individual, dorsal view, Fossil Gully, ROM 52567, X 4.

8. Pygidium, dorsal view, Fossil Gully, ROM 52568, X 5.5.

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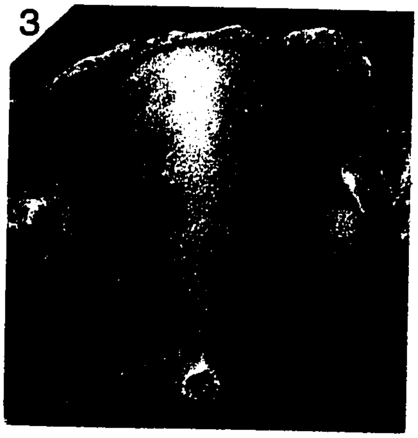

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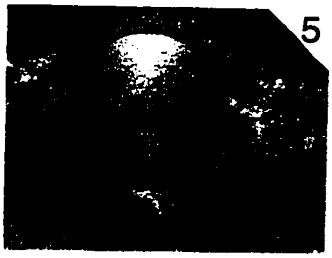

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PLATE 11, figs. 1-10.

Figs. 1-5. *Antagmus fieldensis* (Rasetti), Mt. Whyte Formation, Yoho National Park.

1-3. Cranidium, anterior, lateral and dorsal views, Mount Field (117 m), ROM 52569, X 12.

4. Cranidium, dorsal view, Mount Field (115 m), ROM 52570, X 13.

5. Cranidium, dorsal view, Mount Field (117 m), ROM 52571, X 14.

Fig. 6. *Antagmus tuberculata* (Rasetti), Naiset Formation, Yoho National Park.

6. Cranidium, dorsal view, North Gully (79 m), ROM 52572, X 10.

Figs. 7-9. *Antagmus depressus* (Rasetti), Mt. Whyte Formation, Yoho National Park.

7. Cranidium, dorsal view, Mount Field (94 m), ROM 52573, X 13.

8. Cranidium, dorsal view, Mount Field (94 m), ROM 52574, X 13.

9. Cranidium, dorsal view, Monarch Creek (53 m), ROM 52575, X 7.5.

Fig. 10. *Antagmus* sp., Mt. Whyte Formation, Yoho National Park.

10. Hypostome, ventral view, Mount Field, ROM 52576, X 35.


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PLATE 12, figs. 1-11.

Figs. 1-5. *Antagmus* cf. *A.* sp. 1 Fritz, Mt. Whyte Formation, Yoho National Park.

1,2. Cranidium, dorsal and anterior views, Mount Weed (29 m), ROM 52577, x 14.

3,4. Cranidium, lateral and dorsal views, Mount Weed (29 m), ROM 52578, x 14.

5. Cranidium, dorsal view, Mount Weed (29 m), ROM 52579, x 30.

Figs. 6-11. *Antagmus buttsi* (Resser), Mt. Whyte Formation, Banff National Park.

6,7. Cranidium, dorsal and lateral views, Mount Weed (150 m), ROM 52580, x 14.

8. Cranidium, dorsal view, Mount Weed (150 m), ROM 52581, x 12.

9. Cephalon, dorsal view, Mount Weed (150 m), ROM 52582, x 12.

10,11. Cranidium, anterior and dorsal views, Mount Weed (150 m), ROM 52583, x 14.

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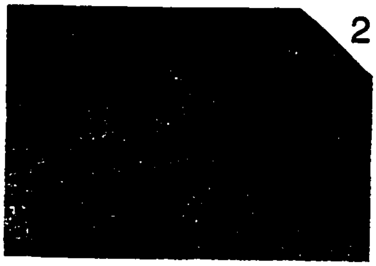

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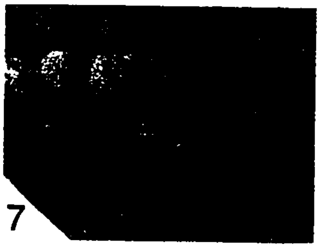

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PLATE 13, figs. 1-10.

Figs. 1-10. *Antagmus maior* (Rasetti), Mt. Whyte Formation, Yoho National Park.

1,2. Cranidium, lateral and dorsal views, Mount Field (115 m), ROM 52584, x 10.

3-5. Cranidium, lateral, anterior and dorsal views, Mount Field (117 m), ROM 52585, x 12.

6. Cranidium, dorsal view, Mount Field (115 m), ROM 52586, x 14.

7. Cranidium, dorsal view, Mount Field (117 m), ROM 52587, x 8.

8. Cranidium, dorsal view, Mount Field (117 m), ROM 52588, x 12.

9. Cranidium, dorsal view, Mount Field (115 m), ROM 52589, x 24.

10. Meraspid cranidium, dorsal view, Mount Field (115 m), ROM 52590, x 30.

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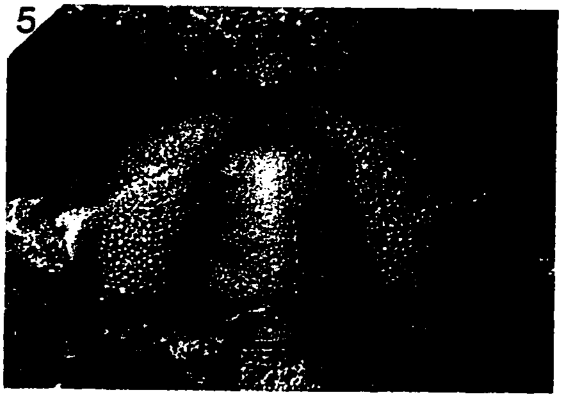

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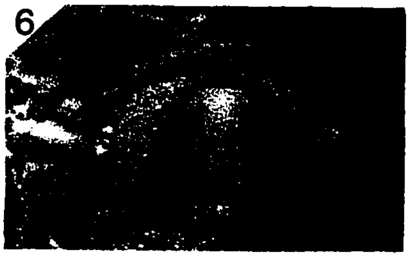

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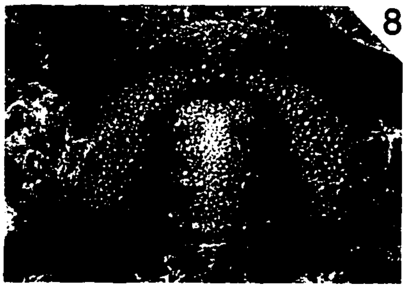

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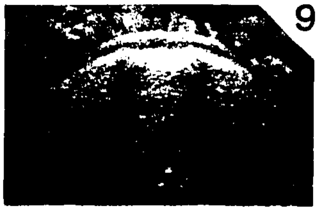

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PLATE 14, figs. 1-10.

Figs. 1-9. *Antagmus? gibbosa* (Rasetti), Mt. Whyte Formation, Yoho National Park.

1. Cranidium, dorsal view, Mount Field (117 m), ROM 52591, x 12.

2. Cranidium, dorsal view, Mount Field (115 m), ROM 52592, x 8.

3. Cranidium, dorsal view, Mount Field (115 m), ROM 52593, x 8.

4. Cranidium, dorsal view, Mount Field (115 m), ROM 52594, x 8.

5. Cranidium, dorsal view, Mount Field (115 m), ROM 52595, x 13.

6. Cranidium, dorsal view, Mount Field (115 m), ROM 52596, x 12.

7. Cranidium, dorsal view, Mount Field (115 m), ROM 52597, x 16.

8. Cranidium, dorsal view, Mount Field (115 m), ROM 52598, x 26.

9. Cranidium, dorsal view, Mount Field (115 m), ROM 52599, x 26.

Fig. 10. *Antagmus?* sp., Mt. Whyte Formation, Yoho National Park.

10. Cranidium, dorsal view, Mount Field (117 m), ROM 52600, x 10.


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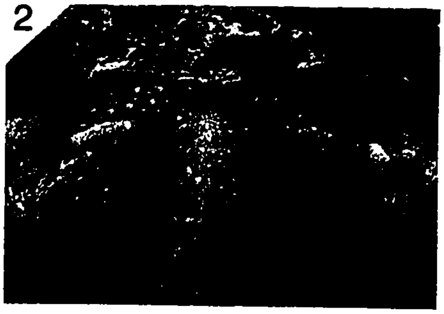
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PLATE 15, figs. 1-8.

Figs. 1-3. *Syspacephalus perola* (Walcott), Naiset Formation, Banff National Park.

1. Cranidium, dorsal view, Pope's Peak (12 m), ROM 52601, x 8.

2. Cranidium and thorax, dorsal view, Pope's Peak (12 m), ROM 52602, x 7.

3. Cranidium, dorsal view, Pope's Peak (12 m), ROM 52603, x 10.

Figs. 4,5. *Syspacephalus charops* (Walcott), Peyto Formation, Yoho National Park.

4. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52604, x 14.

5. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52605, x 13.

Figs. 6-8. *Syspacephalus laticeps* Rasetti, Naiset Formation, Banff and Yoho national parks.

6. Complete individual, dorsal view, North Gully (79 m), ROM 52606, x 7.

7. Cranidium, dorsal view, North Gully (81 m), ROM 52607, x 7.

8. Cranidium, dorsal view, North Gully (81 m), ROM 52608, x 7.


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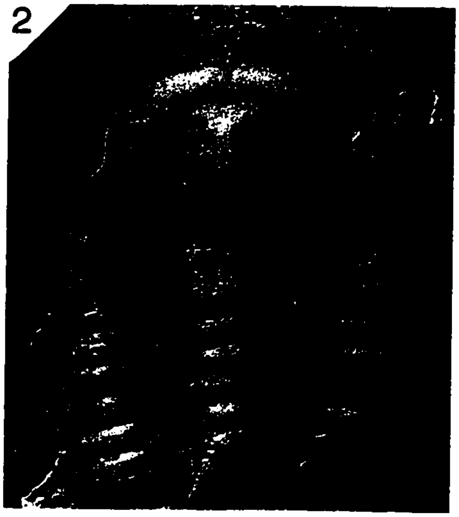
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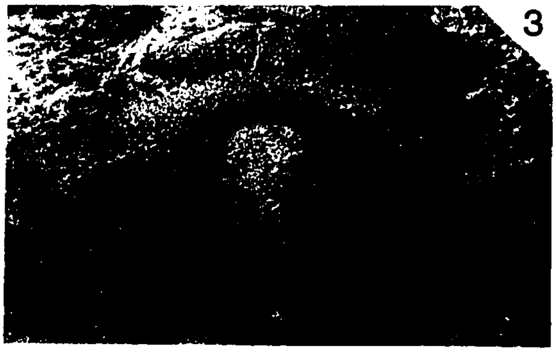
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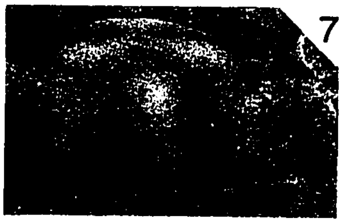
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PLATE 16, figs. 1-10.

Figs. 1-3. *Syspacephalus laticeps* Rasetti, Naiset Formation, Yoho National Park.

1. Nearly complete individual, dorsal view, North Gully (81 m), ROM 52609, X 4.

2. Nearly complete individual, dorsal view, North Gully (81 m), ROM 52610, X 5.

3. Cranidium, dorsal view, North Gully (81 m), ROM 52611, X 7.

Figs. 4,5. *Syspacephalus laevigatus* Rasetti, Naiset Formation, Banff and Yoho national parks.

4. Nearly complete individual, dorsal view, Pope's Peak (12 m), ROM 52612, X 5.5.

5. Nearly complete individual, dorsal view, North Gully (47 m), ROM 52613, X 5.5.

Figs. 6-9. *Syspacephalus tardus* Rasetti, Naiset Formation, Yoho National Park.

6. Cranidium, dorsal view, Park Boundary (140 m), ROM 52614, X 10.

7. Cranidium, dorsal view, Park Boundary (140 m), ROM 52615, X 10.

8. Cranidium, dorsal view, Park Boundary (140 m), ROM 52616, X 10.

9. Cranidium, dorsal view, Park Boundary (140 m), ROM 52617, X 10.

Fig. 10. *Syspacephalus crassus* Rasetti, Naiset Formation, Yoho National Park.

10. Cranidium, dorsal view, North Gully, (79 m) ROM 52618, x 10.


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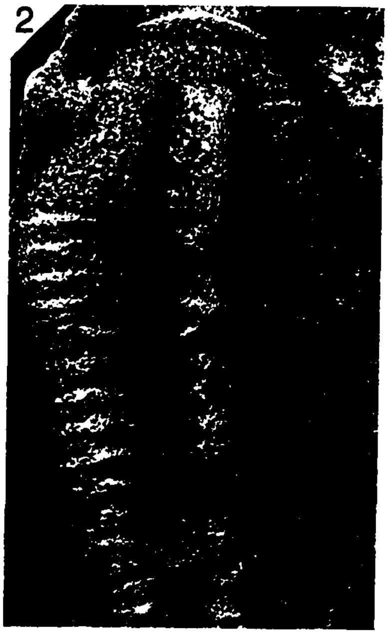
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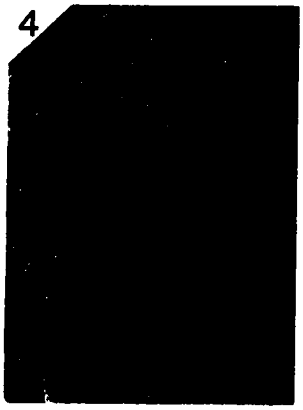
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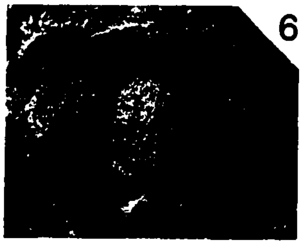
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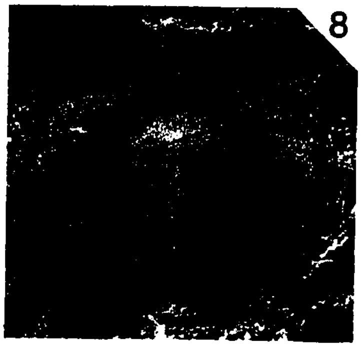
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PLATE 17, figs. 1-10.

Figs. 1-10. *Periomma walcotti* (Resser), Mt. Whyte Formation, Yoho National Park.

1. Cranidium, dorsal view, Mount Weed (29 m), ROM 52619, X 9.

2. Cranidium, dorsal view, Mount Jimmy Simpson (45 m), ROM 52620, X 7.

3. Cranidium, dorsal view, Mount Weed (3.5 m), ROM 52621, X 7.

4. Cranidium, dorsal view, Mount Weed (29 m), ROM 52622, X 12.

5-6. Cranidium, dorsal and lateral views, Mount Weed (3.5 m), ROM 52623, X 10.

7. Cranidium, dorsal view, Mount Weed (0.3 m), ROM 52624, X 19.

8. Cranidium, dorsal view, Mount Weed (3.5 m), ROM 52625, X 10.

9. Cranidium, dorsal view, Mount Weed (3.5 m), ROM 52626, X 10.

10. Cranidium, dorsal view, Mount Weed (0.3 m), ROM 52627, X 14.


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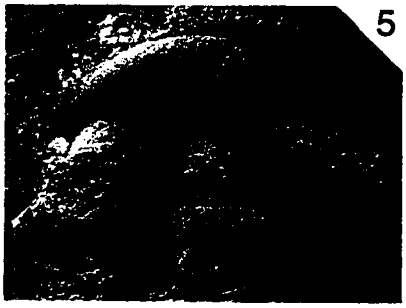
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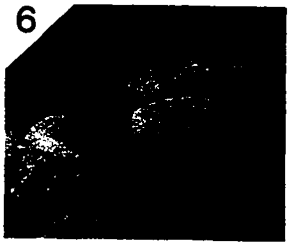
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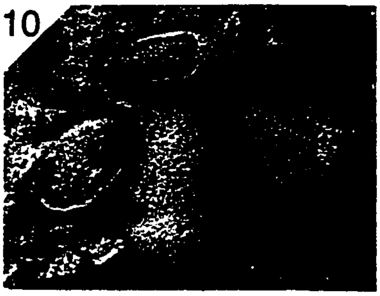
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PLATE 18, figs. 1-14.

Figs. 1-5. *Onchocephalites laevis* Rasetti, Mt. Whyte Formation, Yoho National Park.

1. Cranidium, dorsal view, Mount Field (111 m), ROM 52628, x 10.

2-4. Cranidium, dorsal, anterior and lateral views, Mount Field (111 m), ROM 52629, x 10.

5. Cranidium, dorsal view, Mount Field (111 m), ROM 52630, x 10.

Figs. 6-14. *Onchocephalites unca* (Walcott), Peyto Formation, Banff and Yoho national parks.

6. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52631, x 14.

7. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52632, x 14.

8-9. Cranidium, dorsal and anterior views, Mount Weed (29 m), ROM 52633, x 14.

10. Cranidium, dorsal view, Mount Schaffer (29 m), ROM 52634, x 10.

11-13. Cranidium, anterior, lateral and dorsal views, Mount Schaffer (29 m), ROM 52635, x 14.

14. Cranidium, dorsal view, Mount Weed (29 m), ROM 52636, x 17.


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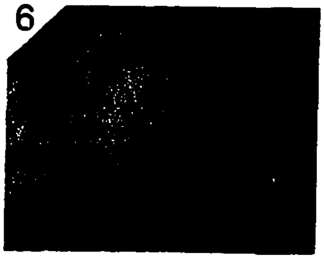
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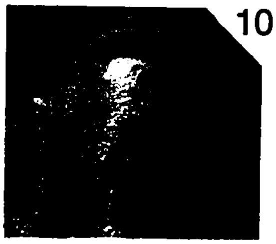
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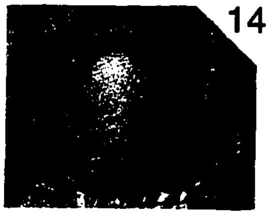
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PLATE 19, figs. 1-10.

Figs. 1, 4-10. *Alokistocare cleora* (Walcott), Naiset Formation, Yoho National Park, Mount Assiniboine Provincial Park.

1. Complete individual, dorsal view, Mount Assiniboine (float), ROM 52637, x 1.5.

4. Cranidium, dorsal view, Mount Field (115 m), ROM 52638, x 13.

5. Cranidium, dorsal view, Mount Field (115 m), ROM 52639, x 14.

6. Cranidium, dorsal view, Mount Field (115 m), ROM 52640, x 16.

7. Cranidium, dorsal view, Mount Field (115 m), ROM 52641, x 26.

8. Cranidium, dorsal view, Mount Field (115 m), ROM 52642, x 24.

9. Cranidium, dorsal view, Mount Field (115 m), ROM 52643, x 19.

10. Cranidium, dorsal view, Mount Field (115 m), ROM 52644, x 19.

Figs. 2-3. *Alokistocare agnesensis* (Walcott), Naiset Formation, Banff and Yoho national parks.

2. Cranidium, dorsal view, Pope's Peak (12 m), ROM 52645, x 5.5.

3. Complete individual, dorsal view, Fossil Gully (float), ROM 52646, x 3.


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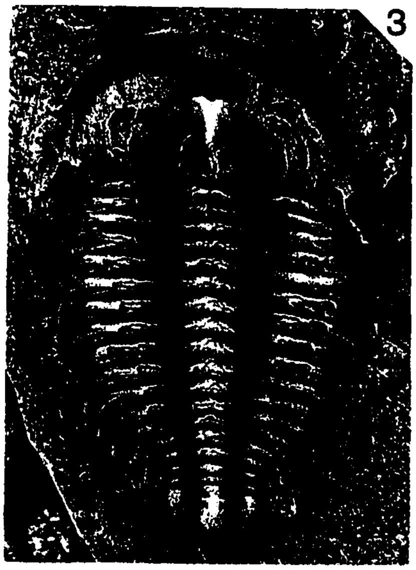
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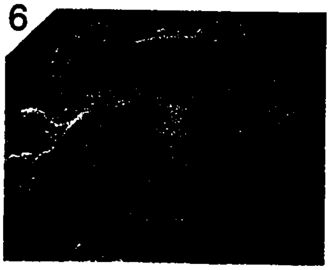
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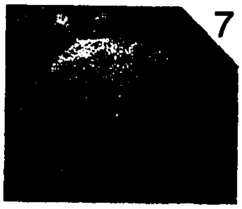
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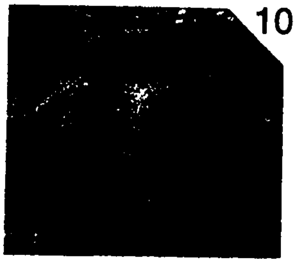
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PLATE 20, figs. 1-10.

Fig. 1. *Alokistocare*? *maxeyi* (Rasetti), Mt. Whyte Formation, Yoho National Park.

1. Cranidium, dorsal view, Mount Field (115), ROM 52647, x 5.

Fig. 2. *Alokistocare cleora* (Walcott), Mt. Whyte Formation, Banff National Park.

2. Cranidium, dorsal view, Mount Weed (106 m), ROM 52648, x 5.

Figs. 3-10. *Plagiura cercops* Walcott, Mt. Whyte Formation, Banff National Park.

3. Cranidium, dorsal view, Mount Weed (106 m), ROM 52649, x 5.

4. Cranidium, dorsal view, Mount Weed (106 m), ROM 52650, x 5.

5. Cranidium, dorsal view, Mount Weed (106 m), ROM 52651, x 5.

6. Pygidium, dorsal view, Mount Weed (114 m), ROM 52652, x 5.

7. Pygidium, dorsal view, Mount Weed (106 m), ROM 52653, x 3.

8. Cranidium, dorsal view, Mount Weed (114 m), ROM 52654, x 12.

9. Cranidium, dorsal view, Mount Weed (114 m), ROM 52655, x 12.

10. Cranidium, dorsal view, Mount Weed (114 m), ROM 52656, x 18.

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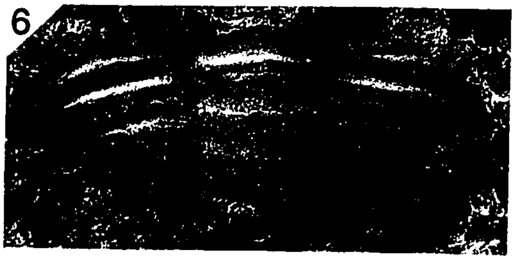

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PLATE 21, figs. 1-9.

Figs. 1-8. *Kochaspis ceccina* (Walcott), Mt. Whyte Formation, Banff and Yoho national parks.

1. Cranidium, dorsal view, Mount Field (115), ROM 52657, x 5.5.

2. Cranidium, dorsal view, Mount Field (115), ROM 52658, x 10.

3. Pygidium, dorsal view, Mount Weed (150 m), ROM 52659, x 10.

4. Cranidium, dorsal view, Mount Weed (150 m), ROM 52660, x 14.

5-6. Pygidium, dorsal and lateral views, Mount Field (112 m), ROM 52661, x 9.

7. Cranidium, dorsal view, Mount Weed (115 m), ROM 52662, x 16.

8. Cranidium, dorsal view, Mount Weed (115 m), ROM 52663, x 20.

Fig. 9. *Solenopleurella minor* Rasetti, Mt. Whyte Formation, Yoho National Park.

9. Cranidium, dorsal view, Mount Field (115 m), ROM 52664, x 19.


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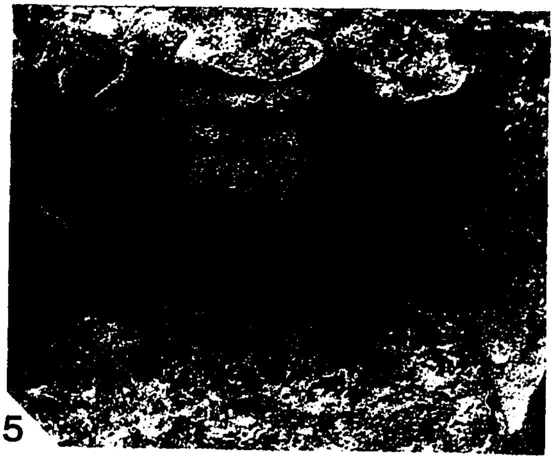
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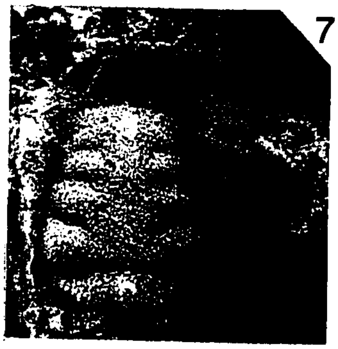
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APPENDIX 1

TRILOBITE SPECIES COUNTS FOR COLLECTIONS

MOUNT FIELD

A 94	*Antagmus fieldensis*	58 cranidia
	A. depressus	2 cranidia
	Alokistocare cleora	26 cranidia
	Plagiura cercops	1 cranidium
A 95	*Antagmus fieldensis*	77 cranidia
	Alokistocare cleora	2 cranidia
	Fieldaspis celer	1 cranidium
A 96	*Kochaspis cecinna*	16 cranidia
	Alokistocare cleora	13 cranidia
	Antagmus fieldensis	11 cranidia
	Fieldaspis celer	2 cranidia
A 115	*Fieldaspis celer*	70 cranidia, 8 pygidia
	F. bilobata	5 cranidia
	Alokistocare cleora	74 cranidia
	A? maxeyi	1 cranidium
	Kochaspis ceccina	24 cranidia
	Antagmus maior	11 cranidia
	A? gibbosa	9 cranidia
	A. fieldensis	1 cranidium

	Solenopleurella *minor*	4 cranidia
A 117	*Antagmus* *maior*	90 cranidia
	A. *fieldensis*	2 cranidia
	A? *gibbosa*	1 cranidium
	A? sp.	1 cranidium
	Fieldaspis *celer*	10 cranidia
	Solenopleurella *minor*	7 cranidia
	Kochaspis *ceccina*	2 cranidia
	Alokistocare *cleora*	2 cranidia

MOUNT STEPHEN

B 26	*Olenellus* sp.	fragments
	Olenoides *fieldensis*	fragments
B 28	*Olenellus* sp.	fragments
B 58	*Antagmus* *depressus*	1 cranidium
	Syspachephalus *perola*	1 cranidium
C 47	*Syspacephalus* *laticeps*	50 complete, 6 cranidia
	Syspacephalus *laevigatus*	1 complete
	Wenkchemnia *walcotti*	4 cranidia
C 78-79	*Syspacephalus* *laticeps*	28 complete, 5 cranidia
	S. *crassus*	2 cranidia

	Poliella denticulata	11
	Antagmus tuberculata	1 cranidium
C 81	*Syspacephalus laticeps*	75 complete, 13 cranidia
	Ogygopsis klotzi	14 pygidia, 7 cranidia, 1 hypostome
	Wenkchemnia walcotti	2 cranidia
C 85-88	*Wenkchemnia walcotti*	30 cranidia, 3 complete
	Fieldaspis bispinosa	3 cranidia
	Poliella prima	2 cranidia
	Syspacephalus perola	2 cranidia
	Ogygopsis klotzi	1 pygidium

POPE'S PEAK

F 12	*Syspacephalus perola*	63 cranidia
	S. laevigatus	2 cranidia
	Poliella prima	1 complete, 4 cranidia, 1 pygidium
	Alokistocare agnesensis	24 cranidia
	Wenkchemnia walcotti	8 cranidia, 3 pygidia

MOUNT WEED

H 0.3	*Periomma* cf. *walcotti*	50 cranidia
	Olenellus cf. *puertoblancoensis*	1 cephalon

H 3.5	*Periomma* cf. *walcotti*	67 cranidia
	Olenoides fieldensis	4 cranidia
	Antagmus sp.	4 cranidia
H 3.7	*Periomma* cf. *walcotti*	91 cranidia
	Olenellus sp	3 cephalic fragments
	Olenoides fieldensis	1 cranidium
H 29	*Onchocephalites unca*	52 cranidia
	Periomma cf. *walcotti*	3 cranidia
	Antagmus cf. sp. 1 Fritz	3 cranidia
	Olenoides fieldensis	3 cranidia, 1 pygidium
	Olenellus gilberti	2 cephala
	O. *puertoblancoensis*	1 cranidium
H 103	*Plagiura cercops*	99 cranidia
	Alokistocare agnesensis	5 cranidia
H 106	*Plagiura cercops*	61 cranidia, 1 pygidium
	Alokistocare agnesensis	5 cranidia
H 114	*Plagiura cercops*	50 cranidia, 1 pygidium
	Alokistocare cleora	1 cranidium
H 115	*Plagiura cercops*	110 cranidia
	Alokistocare cleora	1 cranidium

H 116	*Plagiura cercops*	81 cranidia
	Alokistocare cleora	1 cranidium
H 150	*Antagmus* cf. *buttsi*	29 cranidia
	Kochaspis cecinna	12 cranidia, 1 pygidium
	Alokistocare cleora	8 cranidia
	Fieldaspis celer	5 cranidia
	F. bilobata	4 pygidia
	Onchocephalites laevis	1 cranidium
	Alokistocare? *maxeyi*	1 cranidium

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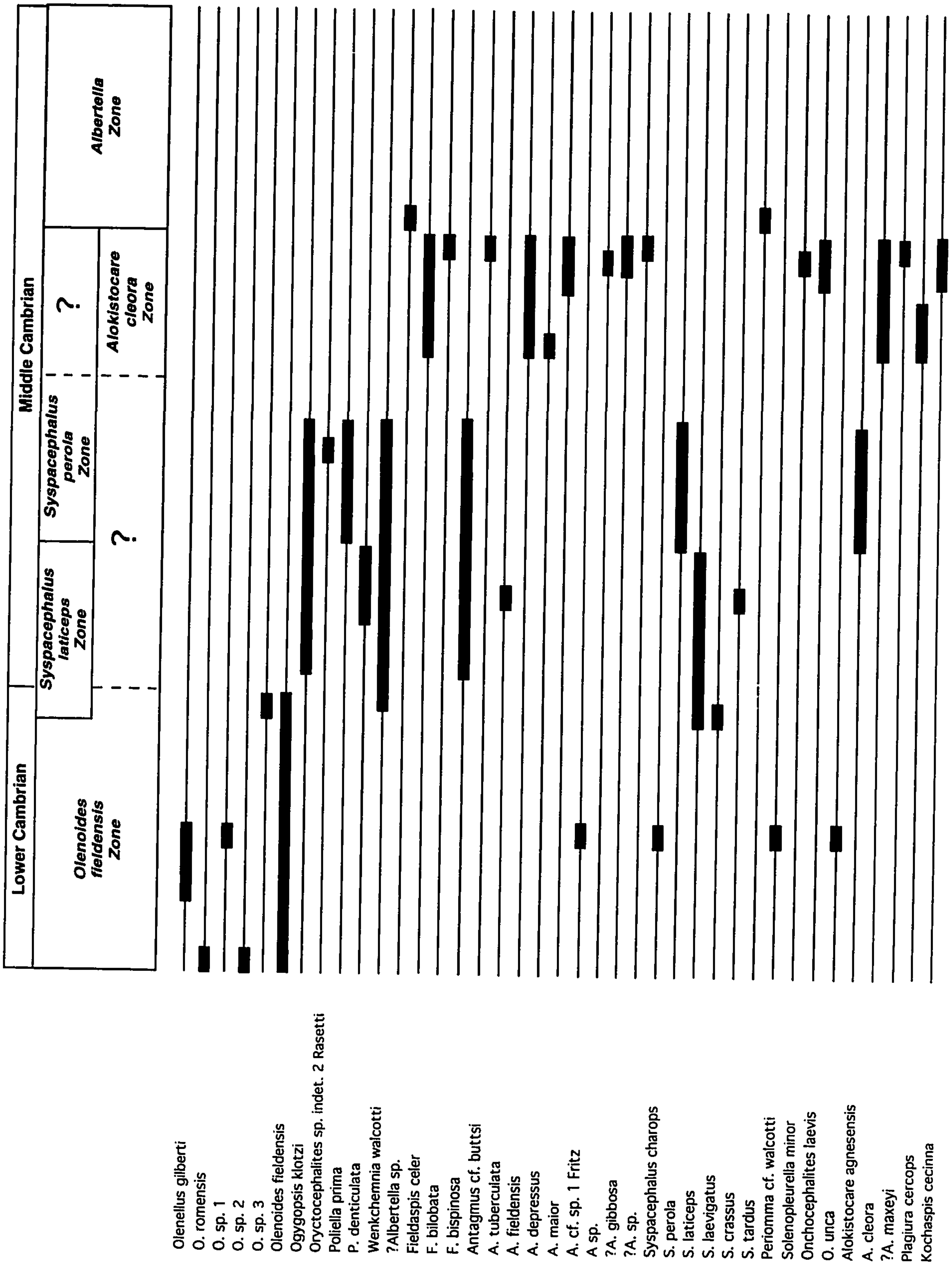
K 29	*Onchocephalites unca*	34 cranidia
	Olenoides fieldensis	7 pygidia, 4 cranidia
	Antagmus sp.	7 cranidia
	Syspacephalus charops	2 cranidia
	Olenellus puertoblancoensis	1 cephalon
	O. gilberti	1 cephalon

APPENDIX 2

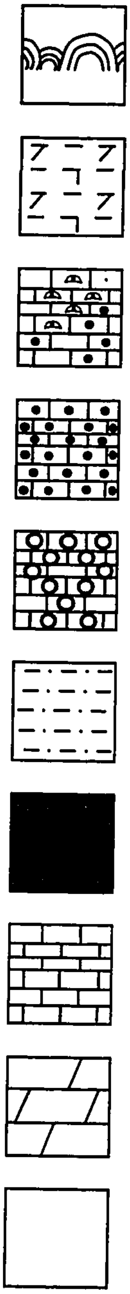
COMPOSITE SPECIES RANGE CHART


Lower Cambrian
Middle Cambrian
Olenoides fieldensis Zone
Syspacephalus laticeps Zone
Syspacephalus perola Zone
?
?
Alokistocare cleora Zone
Albertella Zone
Olenellus gilberti
O. romensis
O. sp. 1
O. sp. 2
O. sp. 3
Olenoides fieldensis
Ogygopsis klotzi
Oryctocephalites sp. indet. 2 Rasetti
Poliella prima
P. denticulata
Wenkchemnia walcotti
?Albertella sp.
Fieldaspis celer
F. bilobata
F. bispinosa
Antagmus cf. buttsi
A. tuberculata
A. fieldensis
A. depressus
A. maior
A. cf. sp. 1 Fritz
A sp.
?A. gibbosa
?A. sp.
Syspacephalus charops
S. perola
S. laticeps
S. laevigatus
S. crassus
S. tardus
Periomma cf. walcotti
Solenopleurella minor
Onchocephalites laevis
O. unca
Alokistocare agnesensis
A. cleora
?A. maxeyi
Plagiura cercops
Kochaspis cecinna

APPENDIX 3

LITHOLOGIC LOGS OF MEASURED STRATIGRAPHIC SECTIONS

LEGEND FOR STRATIGRAPHIC SECTION LOGS



Algal boundstone
(lithofacies A)

Interbedded wackestone-mudstone
(Lithofacies B, J)

Bio-oolitic, wackestone/packstone
(Lithofacies C, E)

Oolitic grainstone
(Lithofacies D)

Oncolitic rudstone
(Lithofacies F)

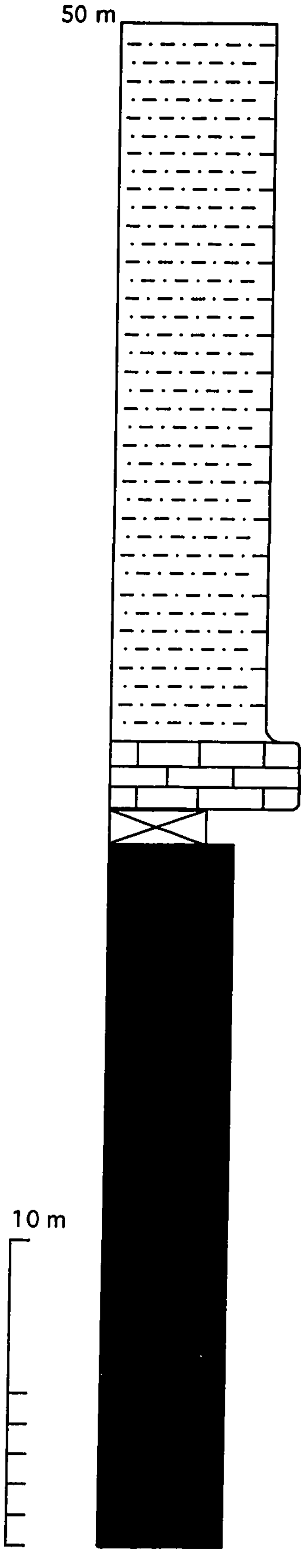
Laminated, green-grey siltstone
(Lithofacies G, I)

Green/grey/black shale
(Lithofacies K, L)

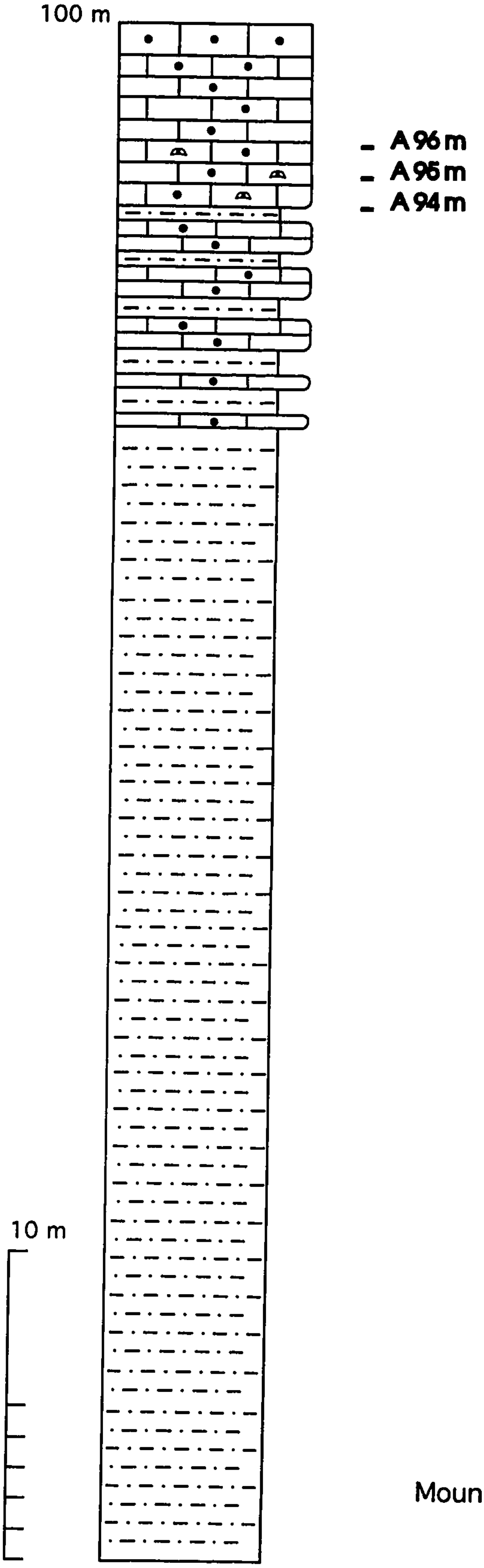
Grey/black lime mudstone
(Lithofacies M)

Thin-bedded to massive dolostone
(Lithofacies N)

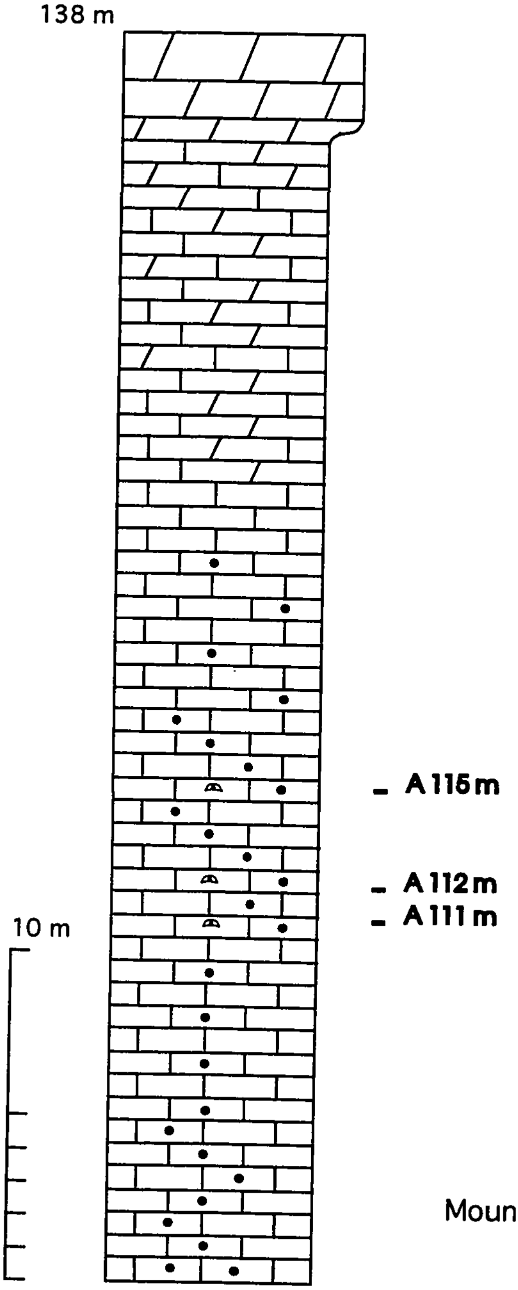
Quartz sandstone
(Lithofacies O)



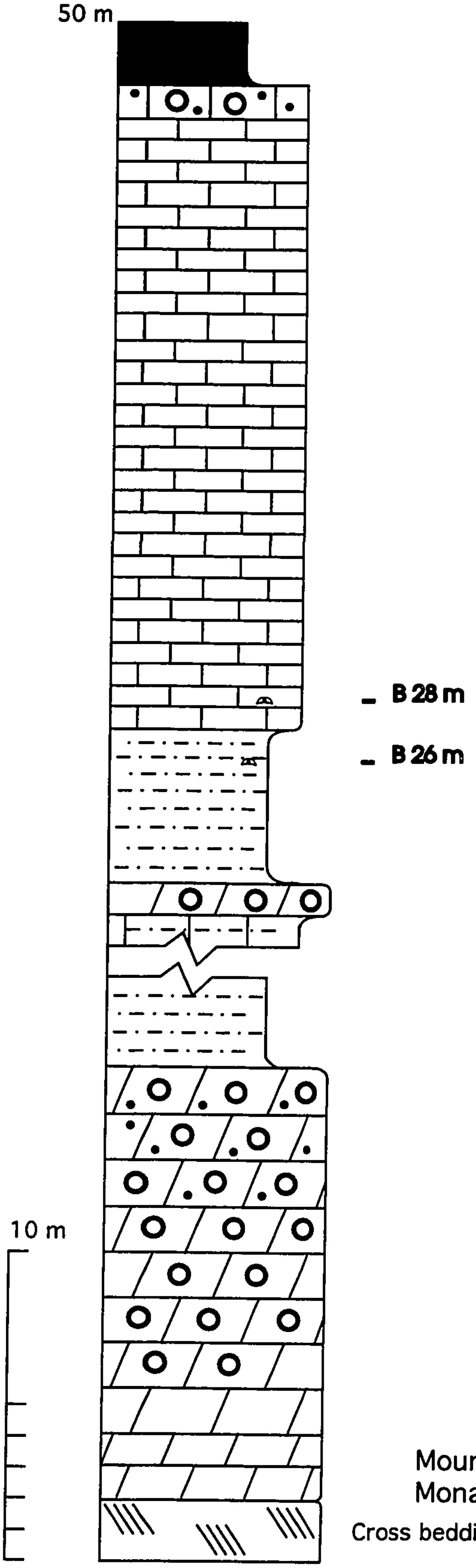
Mount Field, 1



Mount Field, 2

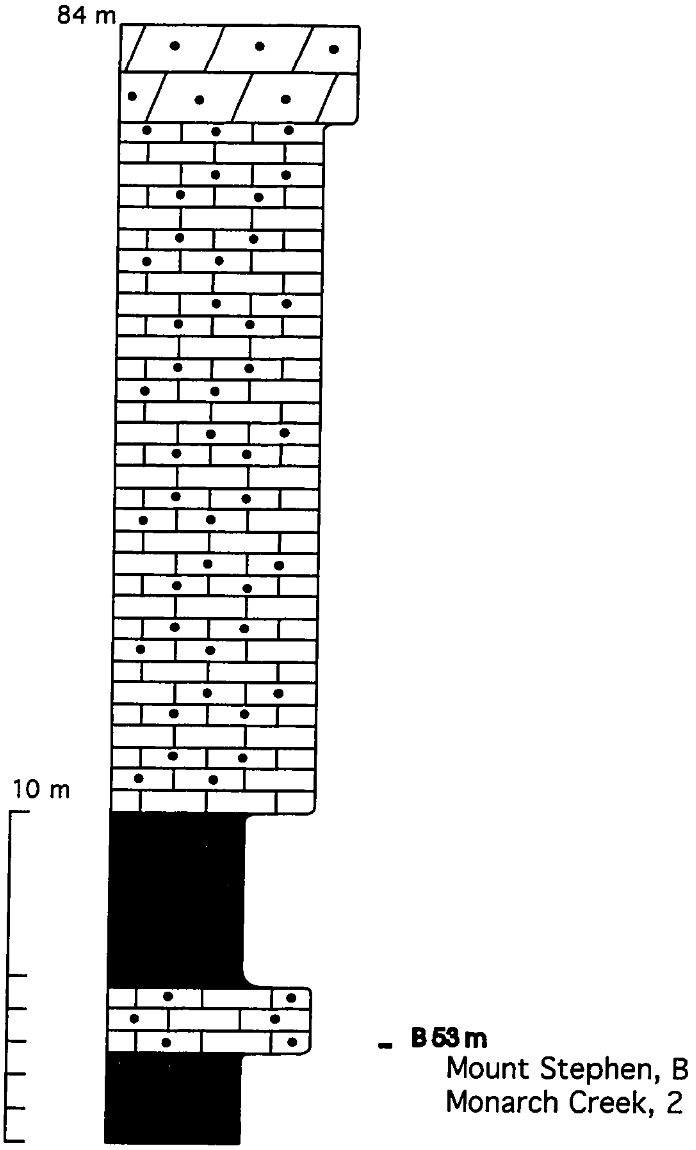


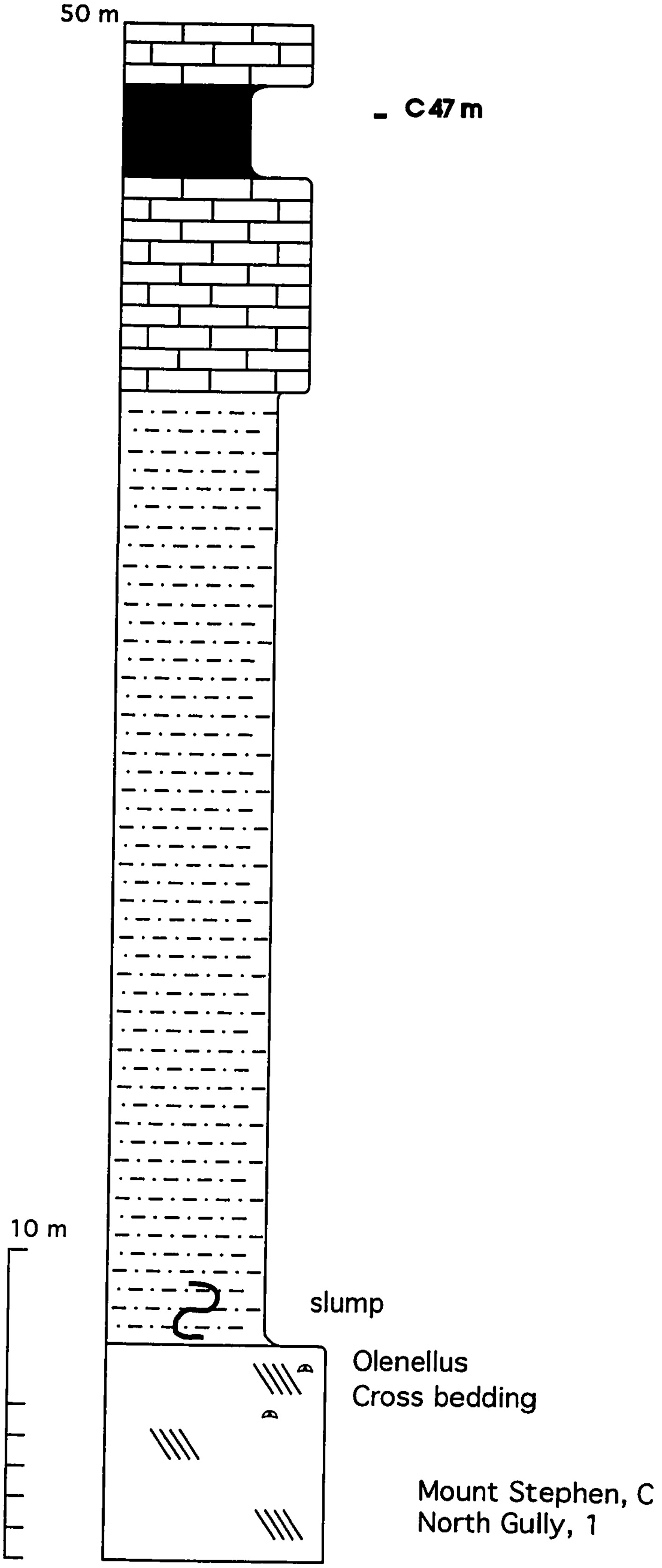
Mount Field, 3

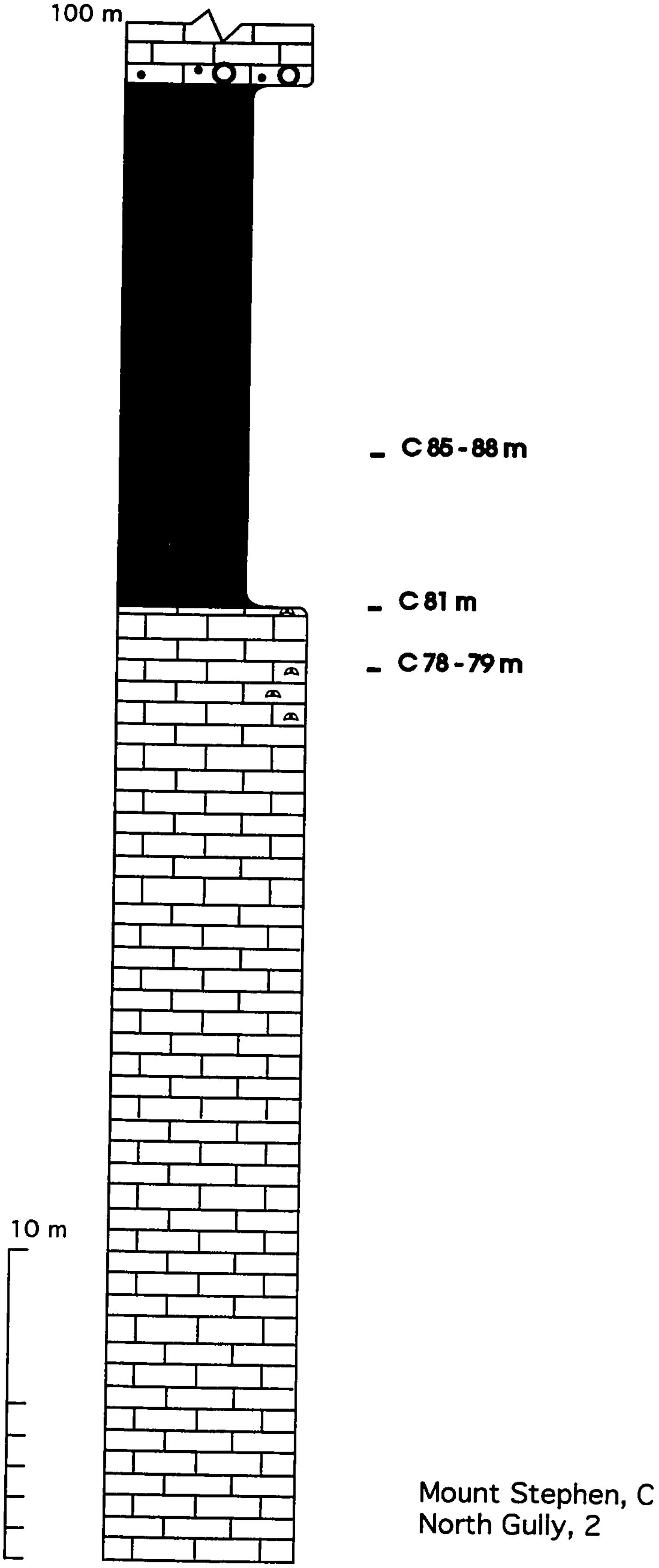


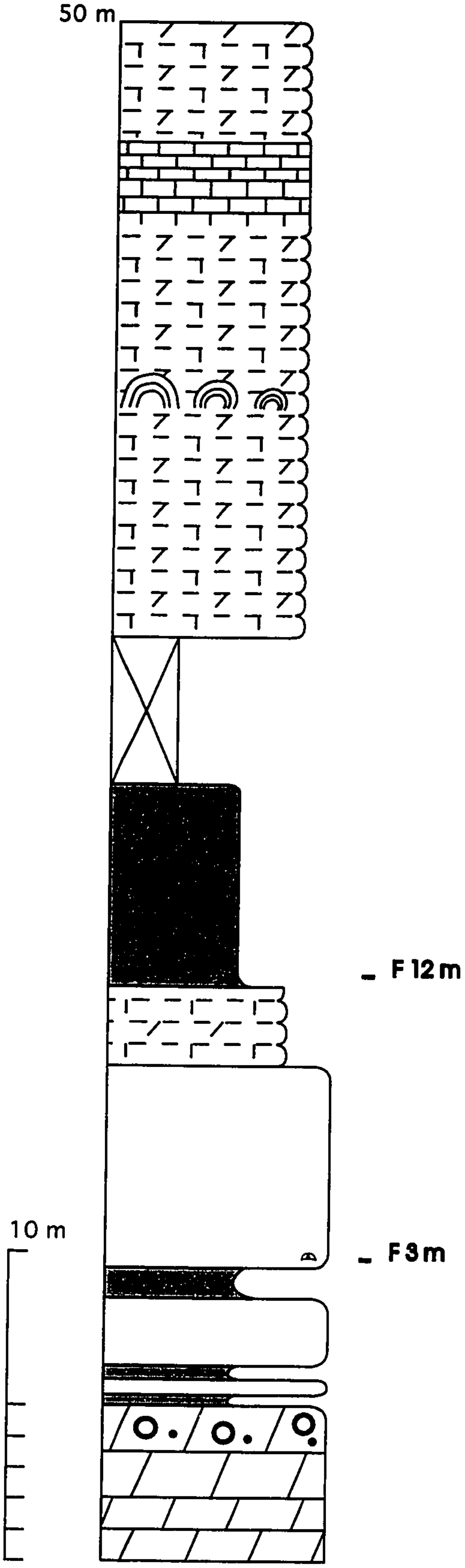
Mount Stephen, B,
Monarch Creek, 1

Cross bedding

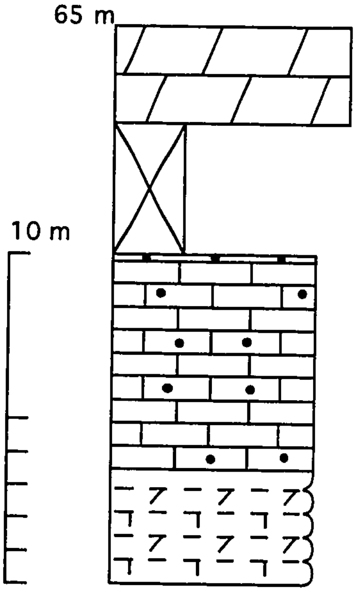

84 m
10 m
B 53 m
Mount Stephen, B
Monarch Creek, 2


50 m
C 47 m
10 m
slump
Olenellus
Cross bedding
Mount Stephen, C
North Gully, 1

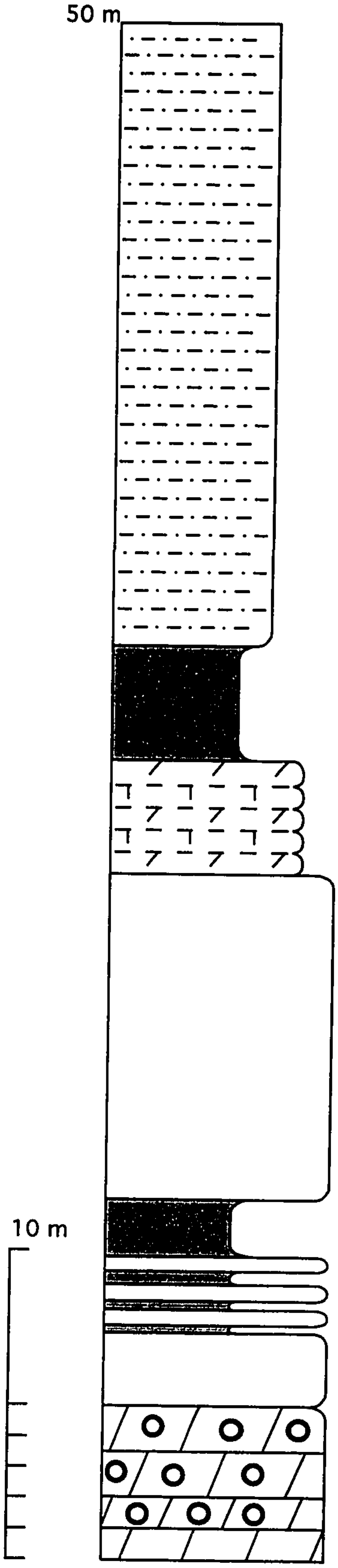

100 m
C 85-88 m
C 81 m
C 78-79 m
10 m
Mount Stephen, C
North Gully, 2



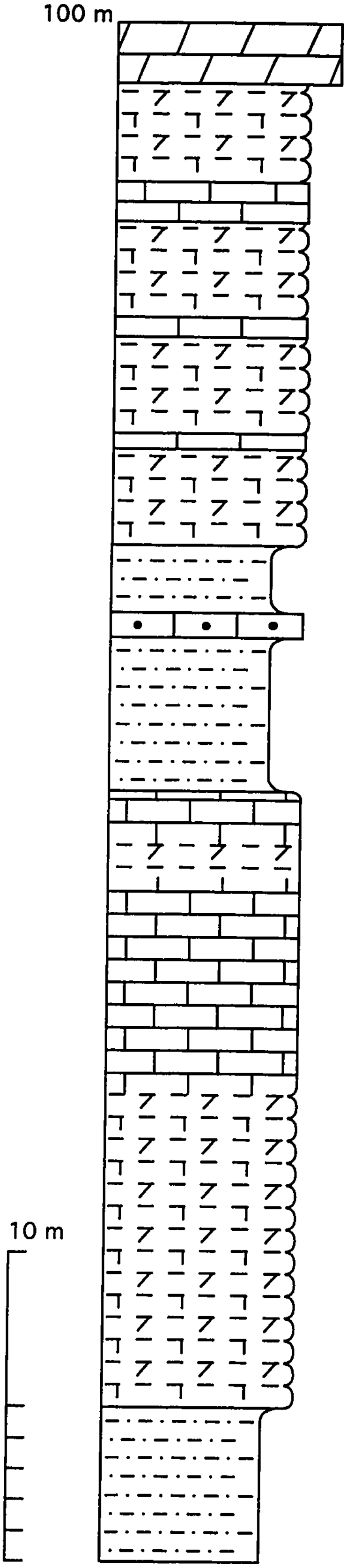
Pope's Peak, 1



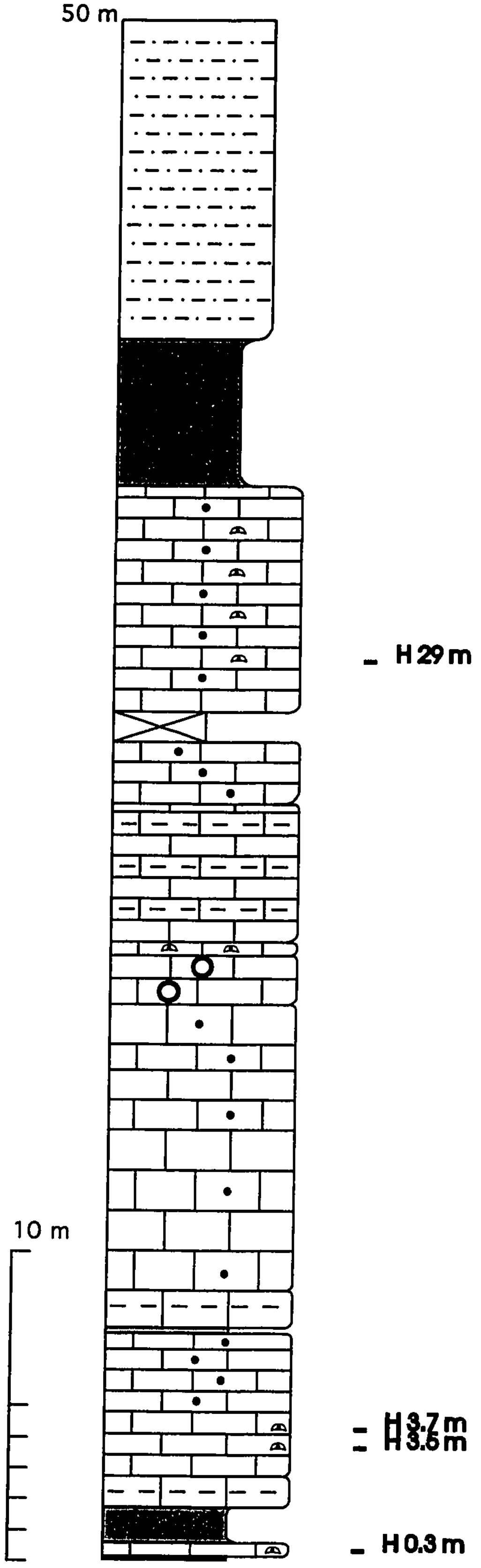
Pope's Peak, 2



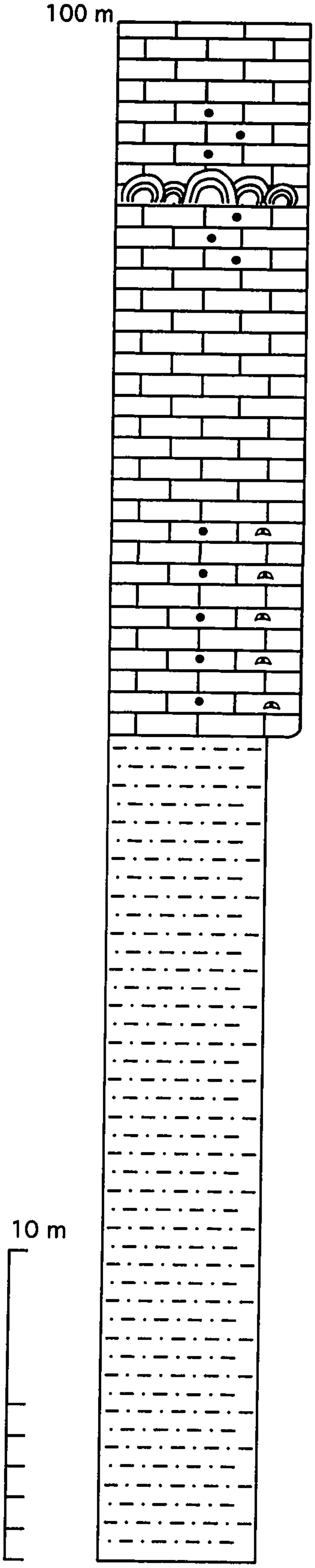
Mount Niblock, 1



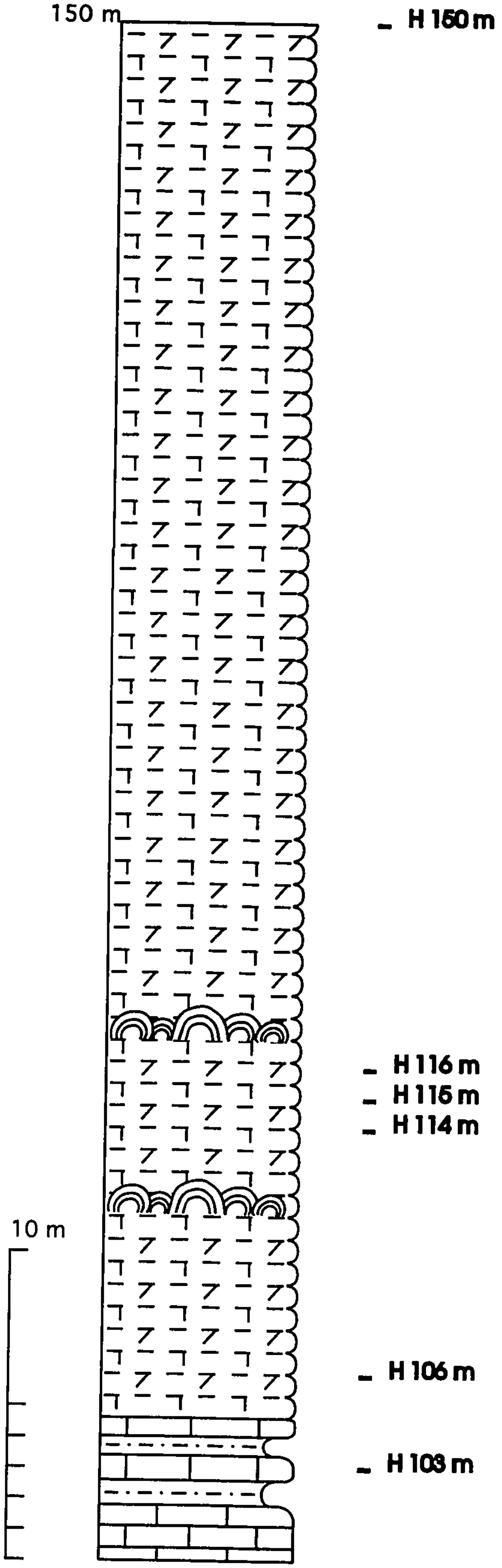
Mount Niblock, 2



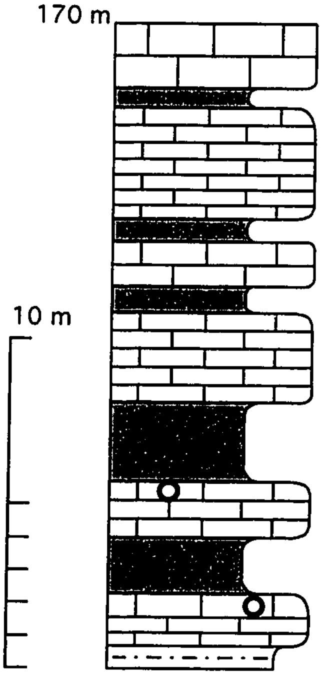
Mount Weed, 1



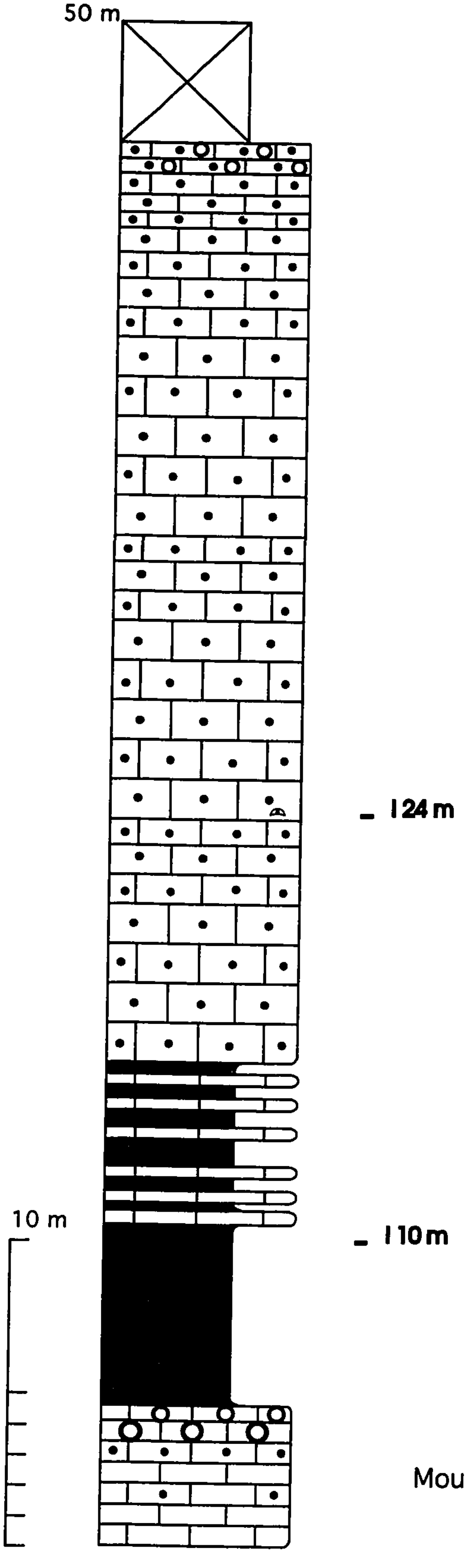
Mount Weed, 2



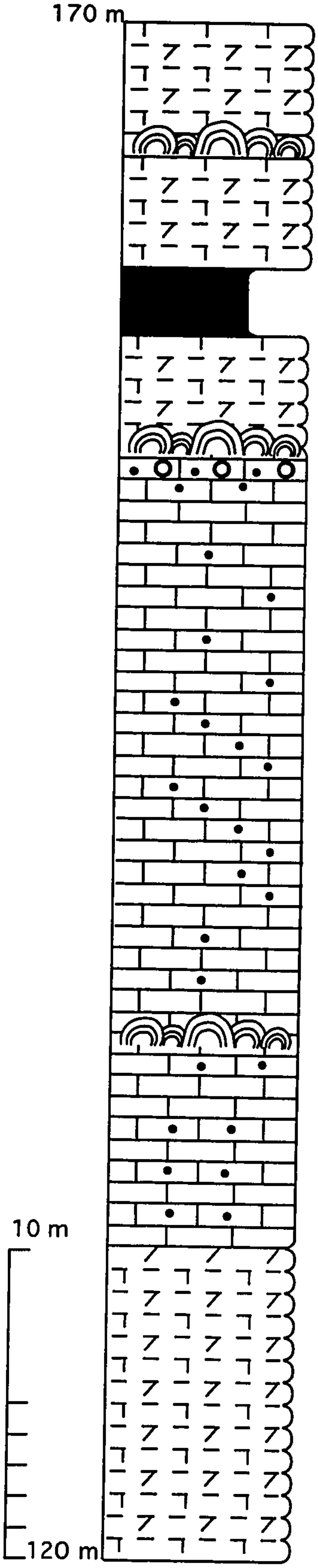
Mount Weed, 3



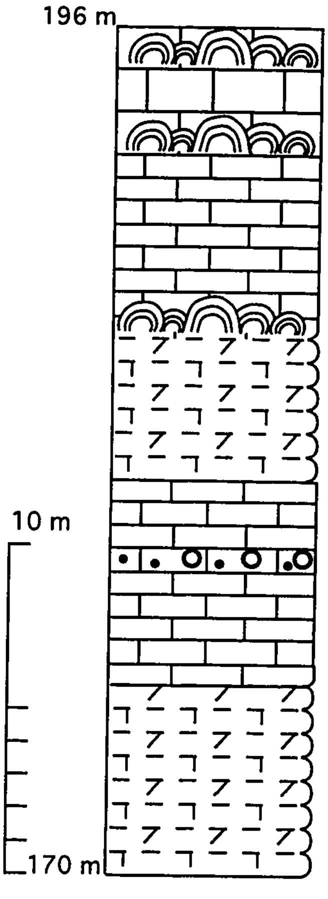
Mount Weed, 4



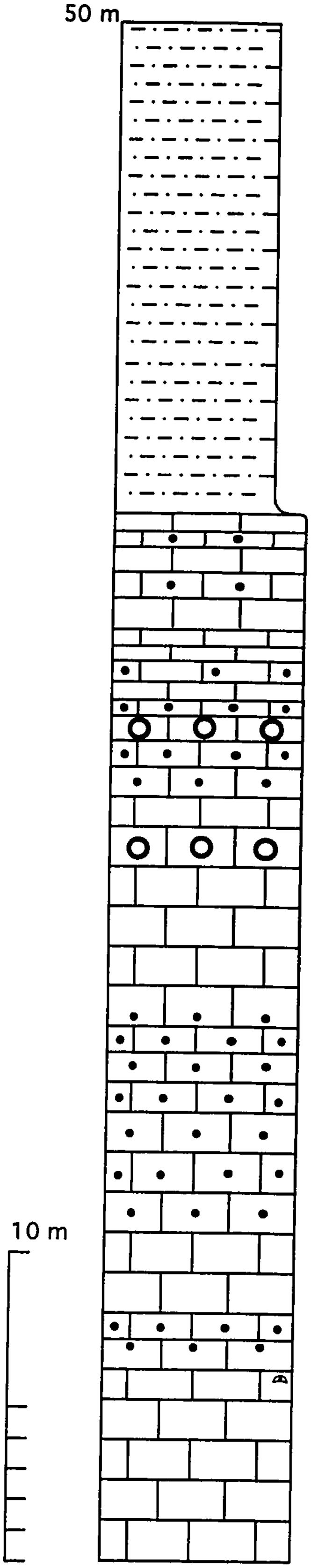
Mount Jimmy Simpson, 1



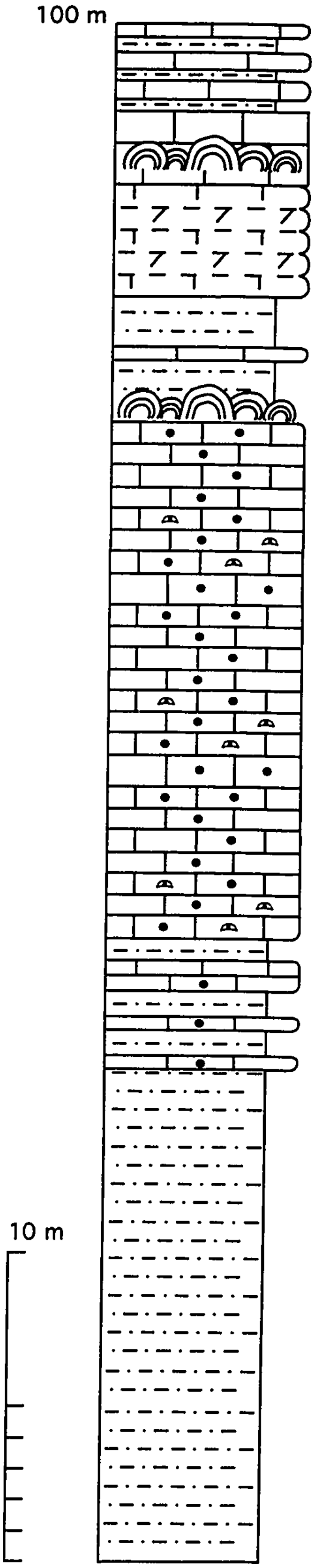
Mount Jimmy Simpson, 2



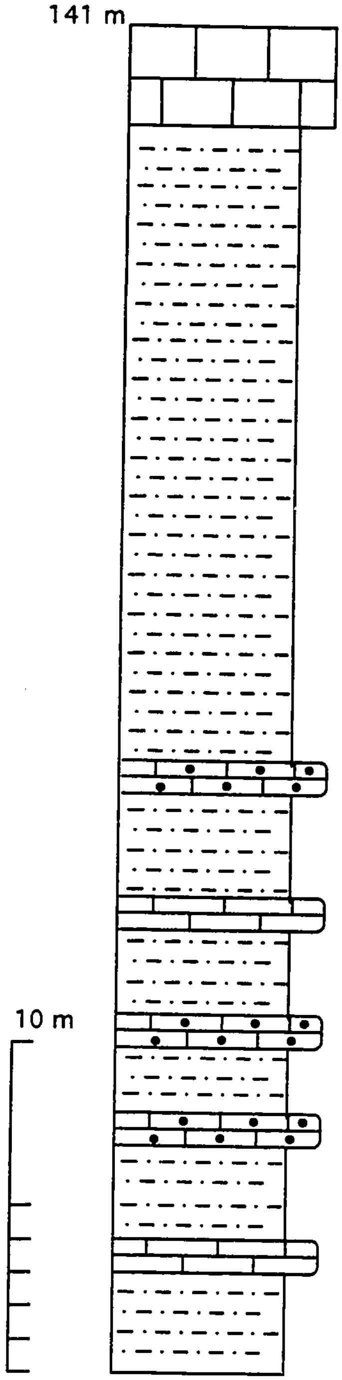
Mount Jimmy Simpson, 3



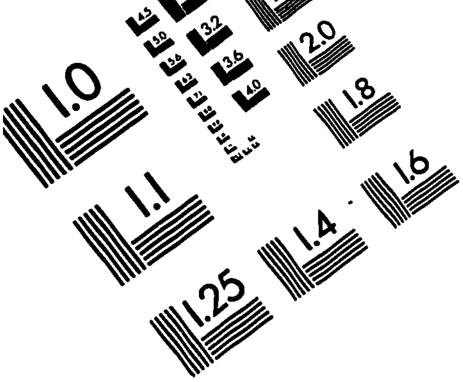
Park Boundary, 1

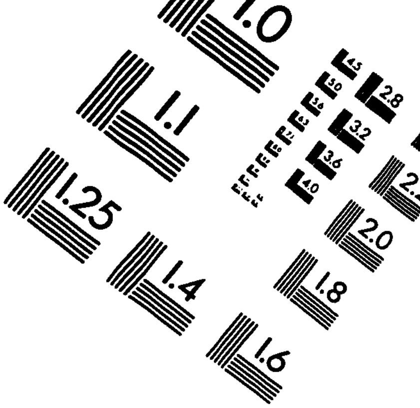


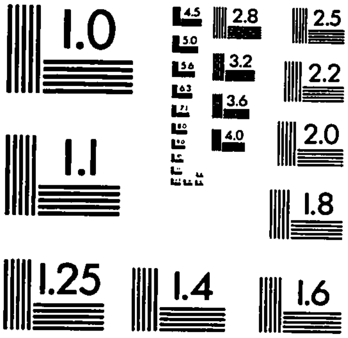
Park Boundary, 2

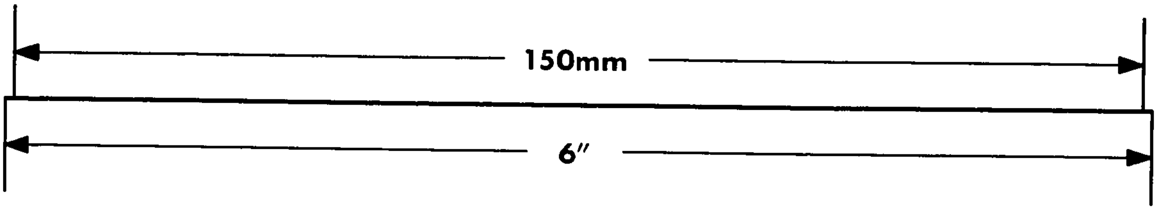


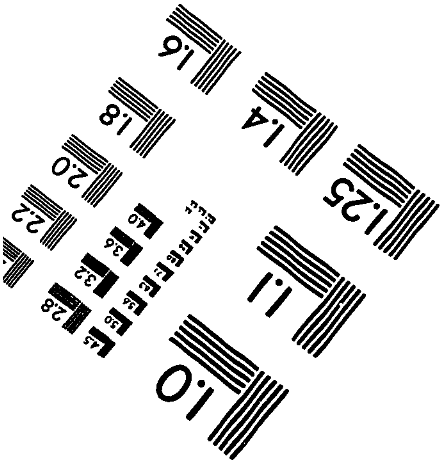
Park Boundary, 3

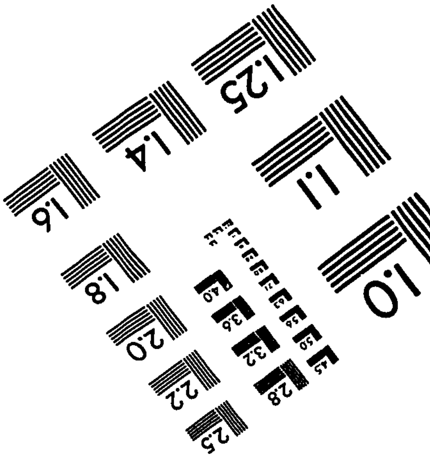












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