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PAPER 66-49

UPPER CAMBRIAN FORMATIONS, SOUTHERN ROCKY MOUNTAINS OF ALBERTA, AN INTERIM REPORT

(Report, 4 figures, 7 plates and appendices)

J. D. Aitken and R. G. Greggs

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ABSTRACT

The revised Upper Cambrian sequence for the southern Rocky Mountains of Alberta is as follows:

Mistaya Formation (proposed) – a cliff-forming unit of carbonate rocks, overlying the Bison Creek Formation and underlying interbedded green-weathering shales and limestones with early Ordovician fossils. Age – Trempeleauan.

Bison Creek Formation (proposed) – a recessive-weathering unit of interbedded limestones, shales, and marlstones. Age – Franconian and Trempeleauan.

Lyell Formation (revised) – a thick, cliff-forming unit of carbonate rocks. Age – Dresbachian.

Sullivan Formation (revised) – a recessive-weathering unit of interbedded shales, limestones, and subordinate siltstones. Age – Dresbachian.

Waterfowl Formation (proposed) – a cliff-forming unit of carbonate rocks and siltstones. Age – partly Dresbachian; may be Middle Cambrian in part.

Arctomys Formation (restricted) – a recessive-weathering unit of red and green shales, thin-bedded siltstones, and minor carbonate rocks, overlying the late Middle Cambrian Pika Formation. Age – latest Middle (?) and earliest Upper (?) Cambrian.

The Upper Cambrian of the region comprises three cycles of deposition (Arctomys-Waterfowl, Sullivan-Lyell, and Bison Creek-Mistaya). Each cycle begins with the sudden appearance of shales above a thick interval of carbonate rocks. The interbedded shales, limestones and siltstones of the first half of the cycle grade upward into a sequence of carbonate rocks with minor siltstone and sandstone that forms the second half of the cycle. Evidence of deposition in very shallow water, such as mud-cracks, ripple-marks, algal stromatolites, pebble conglomerates, oolites and well-sorted calcarenites, is widespread in both shaly and carbonate half-cycles. The Upper Cambrian is up to 5,000 feet thick in the Main Ranges, thinning north-eastward toward the Plains.

The shaly Sullivan and Bison Creek Formations grade northward into carbonate intervals indistinguishable from the bounding Waterfowl, Lyell, and Mistaya Formations. The sequence Waterfowl-Sullivan-Lyell-Bison Creek-Mistaya thus passes into an equivalent, thick, undivided unit of carbonate rocks, the Lynx Group (elevated from Lynx Formation). The Lynx Group is divisible into Upper and Lower divisions in the region in which the Sullivan is present but the Bison Creek unrecognizable.

The Bosworth, Paget, and Sherbrooke Formations of the Kicking Horse Pass area, the Mons Formation of the Glacier Lake area, the Tangle Ridge Formation of the Sunwapta Pass area, and the Ghost River Formation of the eastern Front Ranges are considered obsolete and invalid.

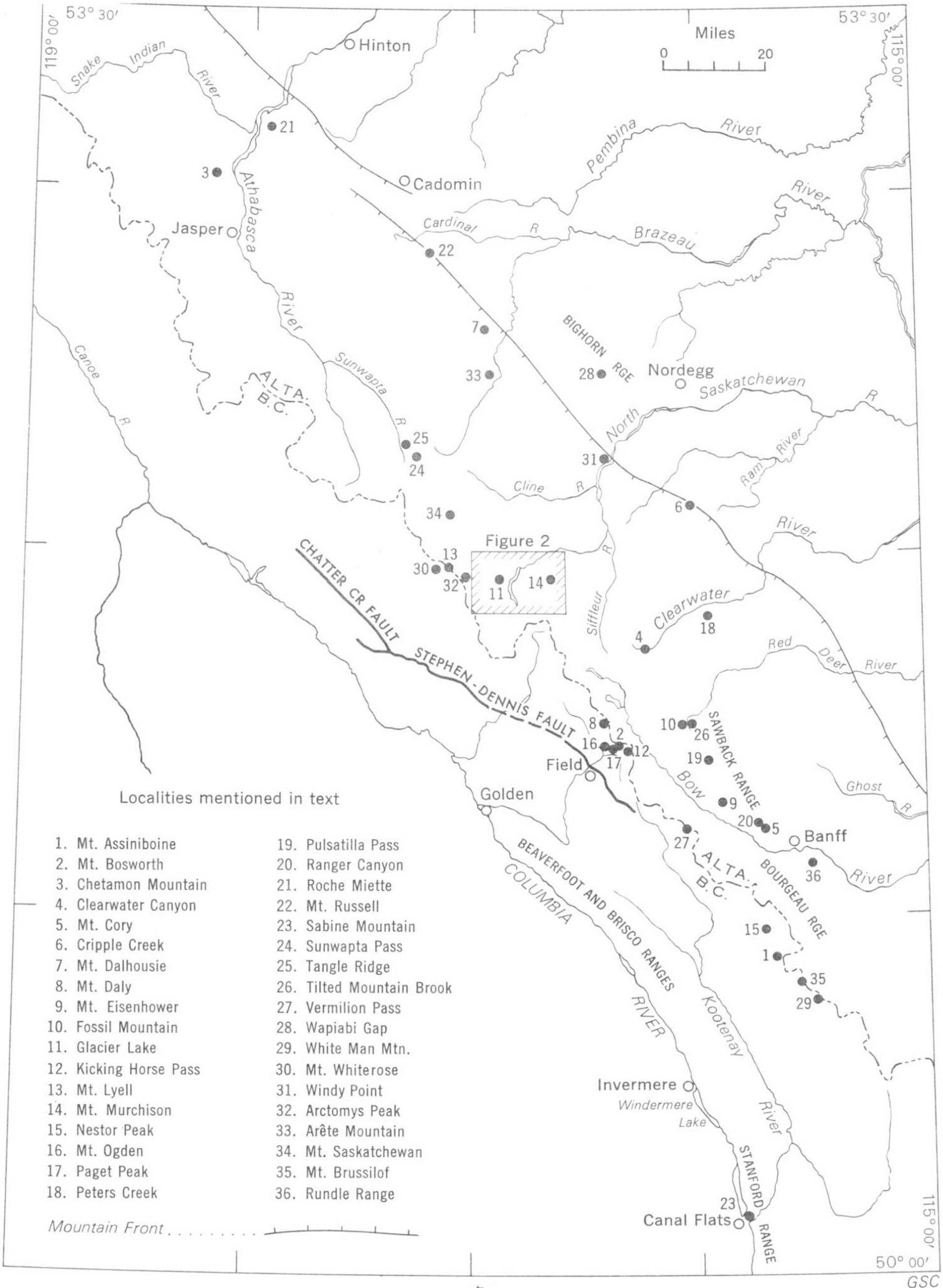

Figure 1. Index map

UPPER CAMBRIAN FORMATIONS, SOUTHERN ROCKY MOUNTAINS OF ALBERTA, AN INTERIM REPORT

INTRODUCTION

In the southern Rocky Mountains of Alberta, the Upper Cambrian Series is complete, or nearly so, and up to 5,000 feet thick. The series is represented by a wide variety of carbonate and clastic rocks, many highly fossiliferous. The structural style of the mountains permits the study of these rocks in well-exposed, structurally simple, unmetamorphosed sections. Although the region is thus an ideal one for the study of Upper Cambrian rocks and faunas, they have received little attention since the pioneering studies of C.D. Walcott in the early decades of this century.

PURPOSE OF THE INTERIM REPORT

Most Upper Cambrian formations of the southern Rocky Mountains of Alberta are, by modern standards, poorly defined in the literature. Ambiguities in the definitions of formations and the precise locations of type sections renders the published nomenclature almost useless for purposes of mapping and stratigraphic studies. Furthermore, the existence of two or more names for several of the clearly defined and widely recognizable Upper Cambrian rock units creates an impression of complexity and confusion in what is actually a simple stratigraphic situation.

C.D. Walcott erected these formations between 1908 and 1920, but since then detailed stratigraphic and faunal analysis of the type sections has not been undertaken. The purpose of this interim report is to redefine several Upper Cambrian formations, invalidate several others (on grounds of redundancy), and erect three new formations which in effect are not recognized by existing nomenclature. A framework of practical nomenclature will thus be made available for general use, pending publication of the details of the biostratigraphy and lithostratigraphy, now under study by the authors.

Formations here redefined are the Arctomys, Sullivan, and Lyell, of the Glacier Lake area. The Bosworth, Paget, and Sherbrooke Formations of the Kicking Horse Pass area, the Mons Formation of the Glacier Lake area, the Tangle Ridge Formation of the Sunwapta Pass area, and the Ghost River Formation are considered invalid and obsolete. The new Waterfowl, Bison Creek, and Mistaya Formations are erected in the Glacier Lake-Mount Murchison area, and the Lynx Formation is raised to group rank.

PREVIOUS WORK

The first published reference to the existence of Cambrian fossils in the Canadian Rocky Mountains is that of H.H. Winwood (1885), who reported on a discovery made in Kicking Horse Pass by members of the visiting party of the British Association for the Advancement of Science. G.M. Dawson (1886, p. 119) made a further find of Cambrian fossils, but did not propose any formational names for the Cambrian units examined by him. The history of stratigraphic nomenclature for the Upper Cambrian of the Canadian Rocky Mountains begins with the Castle Mountain Group, erected by

R.G. McConnell (1887) to embrace the pre-Devonian part of the stratigraphic column dominated by limestones, that is, from the top of the Lower Cambrian clastic sequence up to, and including the Ordovician sequence.

C.D. Walcott, already a great authority on the Cambrian System of North America, first visited the Canadian Rocky Mountains in 1907, and commenced the studies that were to occupy him for much of the next two decades. He discovered in that year the Upper Cambrian strata of Mount Bosworth, and erected the Bosworth, Paget, and Sherbrooke Formations (Walcott, 1908a, 1908b). In 1913, he published the Cambrian stratigraphy of the Mount Robson area. In 1920, he published the first brief descriptions of the Arctomys, Sullivan, Lyell, and Mons Formations, which he erected in the Glacier Lake area, enlarging his descriptions in 1923. In 1927 he summarized his views on pre-Devonian sedimentation in the southern Rocky Mountains; the complex picture he presented – sedimentation taking place in several independent, only partly interconnected troughs – reflects the influence of Ulrich and explains in part the philosophy of Walcott in creating so many synonyms for units which later geologists have found to be recognizable over the entire region east of the Stephen-Dennis fault. In 1928, C.E. Resser completed the manuscript Walcott had been working on at the time of his death (Walcott, 1928). In this, the most comprehensive and perhaps the most widely available of Walcott's works on the Cambrian of the Canadian Rocky Mountains, are published the most complete descriptions of all of Walcott's measured sections and his final thoughts on correlations between them.

J.A. Allan (1912) named the Chancellor, Ottertail, and Goodsir Formations in the Field map-area, British Columbia. He recognized the Upper Cambrian age of the Chancellor and Ottertail, and placed the Cambrian-Ordovician boundary at the Ottertail-Goodsir contact. He also reported (op. cit., p. 181) the fault which he later named the Stephen-Dennis fault, that has come to be known as one of the great geological boundaries of the southern Rocky Mountains. In this and in further publications on the Field area, Allan considered the Chancellor and Ottertail to overlie the formations named by Walcott at Mount Bosworth, thus giving an enormous aggregate thickness for the Upper Cambrian. Allan's map (1913) was the first to distinguish Lower, Middle, and Upper Cambrian in any area of the Canadian Rocky Mountains.

In 1913, Allan proposed the name, Sawback Formation, for a thick section of strata in the Sawback Range, which he considered to be of Devonian age.

In 1916, L.E. Burling and E.M. Kindle reported the discovery of late Cambrian fossils from the Sawback Formation (Burling, 1916, p. 99). Later, Kindle (1924), by then having Walcott's Glacier Lake section available, a section more complete and representative of the Upper Cambrian than the Mount Bosworth section, recognized in the Sawback Formation equivalents of Walcott's Mons, Lyell and Sullivan Formations.

J.F. Walker (1926), provided evidence from the Windermere, British Columbia, and adjoining areas, that the Cambro-Ordovician contact lies within the Goodsir, rather than at its base.

P.S. Warren (1929), reviewing the stratigraphic section as then known, proposed the name Fieldian Series, for the Upper Cambrian succession in recognition of the very thick development of the Upper Cambrian near Field. This proposal was never adopted by other stratigraphers. Warren continued to support Allan's contention that the lower beds of the Chancellor represent the Sherbrooke, but reported a personal communication from Walcott expressing the latter's view that part of the Chancellor may represent a part or all of the Upper Cambrian succession of Mount Bosworth.

C.S. Evans (1933) erected the McKay Group in the Brisco range. This group is of Upper Cambrian age in its lower part and Ordovician age in its upper part. He recognized some degree of equivalence to the Goodsir "as a series", but having reviewed the by then confused history of the Goodsir, refrained from extending the latter term to the Beaverfoot and Brisco ranges. Evans also proposed the name, Jubilee Formation, for a thick unfossiliferous limestone formation continuous with the unit to the south which Walker (1926) had correlated with the Ottertail Formation.

P.E. Raymond (1930a) studied Cambrian strata exposed along Athabasca River, in connection with the activities of the 1929 Harvard Summer School of Field Geology. This work was preliminary and little attempt was made to correlate with the formations already established by Walcott. Accordingly, none of the Cambrian formations erected by Raymond have gained general acceptance. Raymond also contributed (1930b) to the question of the location of the Cambrian-Ordovician contact.

Field studies contributing to the understanding of the Upper Cambrian east of the Stephen-Dennis fault and its continuations, that is, the region dominated by thick carbonate formations in the Upper and Middle Cambrian, as recognized by McConnell in his erection of the Castle Mountain Group, entered a prolonged pause following Walcott's field work of 1922. The focus of original work then shifted southwest to a region wherein the Cambro-Ordovician is dominated by shales and argillaceous limestones, rocks whose correlation with the present area of study is still difficult and uncertain.

New stratigraphic tudies of the Upper Cambrian east of the Stephen-Dennis fault did not appear in print until 1939, when Deiss (1939) erected the Pika Formation in the upper part of Walcott's Eldon Formation, and reported its fauna as a "pre-Cedaria, Upper Cambrian fauna". He also measured and described the Arctomys and Bosworth Formations at Castle Mountain. The next year (Deiss, 1940), he recognized the confusion in Walcott's description of the Mount Bosworth Section, and published a redescription of that section up to the top of the Arctomys.

N.M. Denson (1942) examined and described fossils collected by Deiss from the Pika Formation, and found them to be of late Middle Cambrian age, rather than Upper Cambrian, as Deiss (1939) had stated. Denson also recognized that the Arctomys Formation (restricted) was probably of Middle Cambrian age.

F.K. North and G.G.L. Henderson (1954) published a synthesis of the Cambrian of the southern Rocky Mountains. Their application of the terms, Arctomys, Lyell and Mons reflects what had come to be informal usage among petroleum geologists interested in the Cambrian, and differs substantially from original definitions.

R.D. Hughes (1955) published a study of an area near Sunwapta Pass. He failed to establish correlations with most of the Middle and Upper Cambrian Formations of the Bow Anticline and Glacier Lake regions, and erected the Sunwapta Peak (Middle Cambrian) and Tangle Ridge (Upper Cambrian) Formations. R. deWit (1956) measured Upper Cambrian sections along Bow River from the Sawback Range to the Mountain Front, in connection with a study of the Ghost River Formation. He used a nomenclature based on Walcott's (1928) Ranger Brook section, except that he used Ottertail in place of Walcott's Lyell Formation. DeWit concluded that part of the Ghost River Formation could be correlated with the Arctomys Formation.

Rasetti (1956) reviewed the published material on the Middle and Upper Cambrian of the Canadian "Rockies", but made no changes in the nomenclature. J.L. Usher (1959) reported on the Cambrian and Ordovician sections of the Sawback-Bourgeau and Rundle Ranges, but refrained from applying formal names to the Upper Cambrian units because of the confused status of the nomenclature. His report on the Upper Cambrian and Ordovician faunas was an important contribution.

E.W. Mountjoy (1962, 1963) studied the regional geology of a large area north of Jasper, that includes a thick Upper Cambrian succession. He outlined four major stratigraphic units in the late Middle Cambrian to Lower Ordovician sequence and applied the names Pika, Arctomys, Lynx and Chushina Formations to them. The former two terms originated at Mount Eisenhower and Glacier Lake respectively, and the latter two near Mount Robson. J.O. Wheeler concurrently investigated the regional geology of the area southwest of Glacier Lake. Initially (Wheeler, 1961) he applied the names Arctomys, Sullivan and Lyell Formations to units he had established in the Upper Cambrian sequence east of the Stephen-Dennis and Chatter Creek faults. Subsequently (1963) he used an informal numbering system for Upper Cambrian and Lower Ordovician units, but the complete sequence of stratigraphic units described in this report was clearly outlined by him. These recent studies of the regional geology in parts of the southern Rocky Mountains emphasize the need for clarification of Upper Cambrian rock-stratigraphic nomenclature.

FIELD WORK

The field work of Greggs, undertaken as the foundation for a doctoral dissertation submitted to the University of British Columbia in 1962, began in 1957 with financial assistance from the National Research Council of Canada, and continued while Greggs was employed by Shell Canada Limited in 1959 and 1960. The field work of Aitken, an officer of the Geological Survey of Canada, was part of a study of the pre-Devonian formations of the southern Rocky Mountains, and occupied the summers of 1961, 1962 and 1963.

The author responsible for the detailed description of the type sections is indicated in each instance. Data on the regional distribution and behaviour of the Upper Cambrian formations is provided by Aitken, while the palaeontological data are drawn from the dissertation of Greggs (1962), with minor subsequent additions.

ACKNOWLEDGMENTS

The writers are grateful to the many wardens and officials of the National Parks service, whose cooperation in the course of field work was indispensable. Dr. G.O. Raasch, consultant palaeontologist for Shell Canada, provided guidance and an unparalleled wealth of experience with Upper Cambrian faunas, which greatly promoted the early stages of the faunal studies. Dr. J.L. Usher, of the Department of Geological Sciences, Queen's University, contributed field data and valuable counsel. Drs. E.W. Mountjoy, J.O. Wheeler, and G.B. Leech, of the Geological Survey of Canada helped to demonstrate the suitability of the present nomenclature for mapping purposes, and provided information on the geographic limits of its applicability. Dr. B.S. Norford, Geological Survey of Canada, cooperated in all phases of the work, and identified Ordovician fossils. Dr. V.J. Okulitch, formerly head of the Department of Geology, University of British Columbia, provided valued aid and counsel. Thanks are expressed to the National Research Council of Canada, for financial assistance received by Greggs during the 1957-1958 university term.

The manuscript was critically read by Drs. R.A. Price and B.S. Norford, who made many worthwhile suggestions for its improvement.

STRATIGRAPHY

BOUNDARIES OF THE UPPER CAMBRIAN SERIES

Clarification of the positions of the Upper Cambrian time-rock boundaries in the southern Rocky Mountains has resulted from this study. Some formation boundaries appear to approximate time lines in the area under study, thus permitting generalizations regarding the position of the series boundaries with reference to lithologic boundaries.

Walcott and most workers following him have placed the base of the Upper Cambrian series at the lower boundary of the Arctomys Formation. This was based on discoveries of a few fragmental fossils from the Arctomys at its type section and at Mount Eisenhower (Castle Mountain). Deiss (1939) lowered the base of the Upper Cambrian series with his report of a "pre-Cedaria, Upper Cambrian fauna" from the Pika Formation, which underlies the Arctomys. Denson (1942), however, showed that the Pika faunas belong to the second-youngest Middle Cambrian zone present in Montana, Wyoming, and Utah, and on this basis suggested that the Arctomys was probably also of Middle Cambrian age. Denson's thesis was never published, and his conclusions were generally ignored by Canadian workers.

The discovery, in the course of the present study, of faunas assignable to the earliest Upper Cambrian, lower Cedaria subzone, in the Sullivan Formation and the top of the underlying Waterfowl Formation (proposed), tends to confirm Denson's suggestion as to the age of the Arctomys. Although the Middle-Upper Cambrian boundary has not been located, even approximately, because of the generally barren nature of the sequence containing it, it may be concluded that the boundary lies within the original type section of the Arctomys Formation (Arctomys and Waterfowl Formations of this report)..

Walcott also placed the upper limit of the Upper Cambrian series too low in the sequence. In 1928, he considered the lower Mons or Sabine (here Bison Creek Formation, proposed) to be Upper Cambrian in age, and the upper Mons (Mistaya Formation, proposed, and la of the type Mons) to be Ozarkian. Although Walcott discusses the Ozarkian System and its boundaries (1928, p. 233), a clear definition of the faunas of this system is lacking, and it is not possible to compare Walcott's use of Ulrich's Ozarkian System with the Upper Cambrian and Lower Ordovician series as currently defined in North America. As applied by Walcott, the system straddles the Upper Cambrian-Lower Ordovician boundary as presently recognized.

Raymond (1930b) placed the base of the Ordovician System at the base of the Chushina Formation, on the basis of his own collections and those of Burling, and in a review of Walcott's work, placed it at the base of the stratigraphically equivalent Mons Formation. His understanding of the Mons Formation, in this context, clearly corresponds not to the type section, but to the concept of the Mons Formation held by North and Henderson (1954), deWit (1956), and Usher (1959) (see pp. 53, 54).

North and Henderson (1954, p. 62) also placed the base of the Ordovician series at the base of the Mons Formation, but, because in their usage the term Mons was apparently restricted to Walcott's unit la of the type Mons (less than a fifth of the type section), their contact approximates that arrived at in this study.

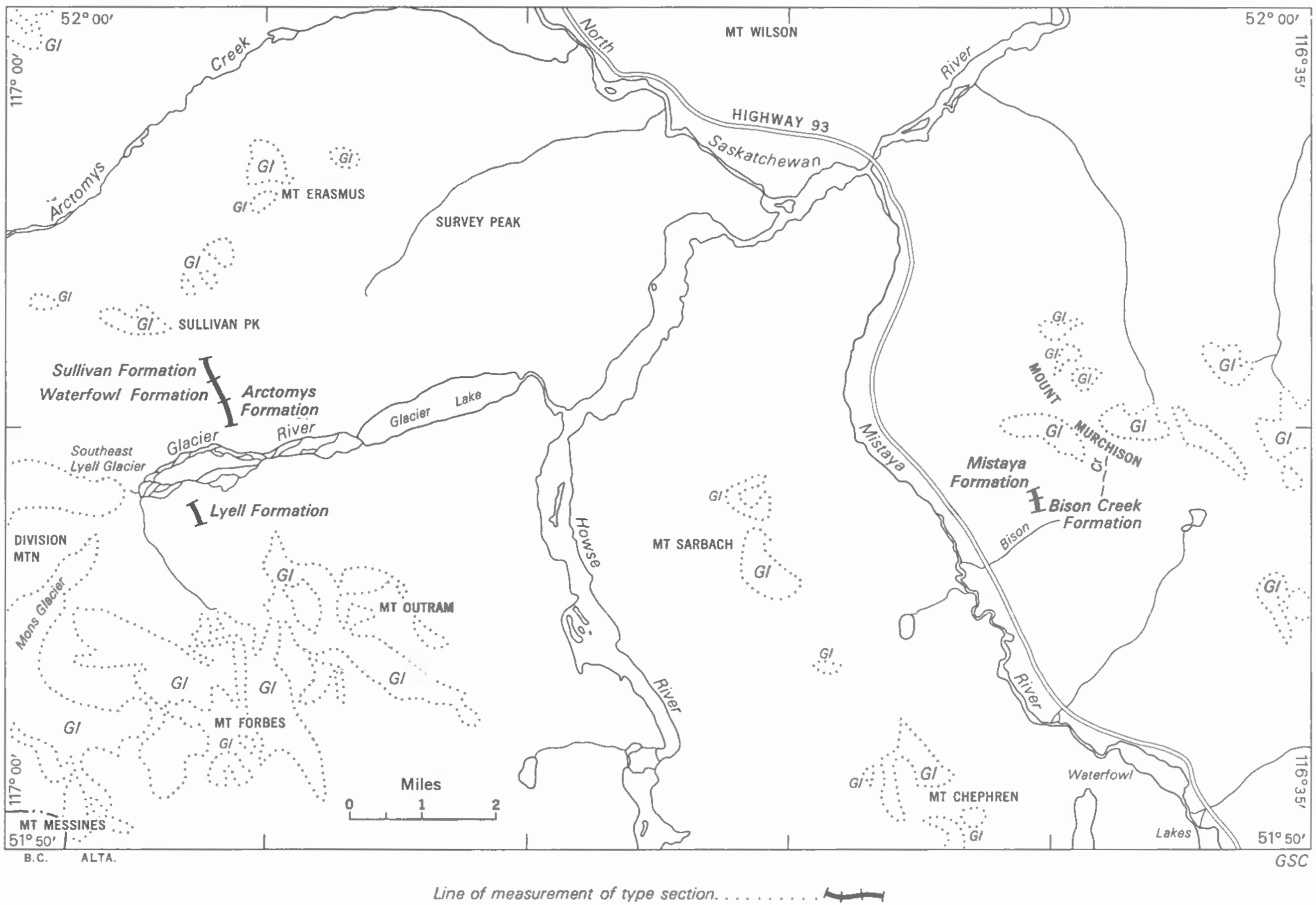

Figure 2. Location of type sections

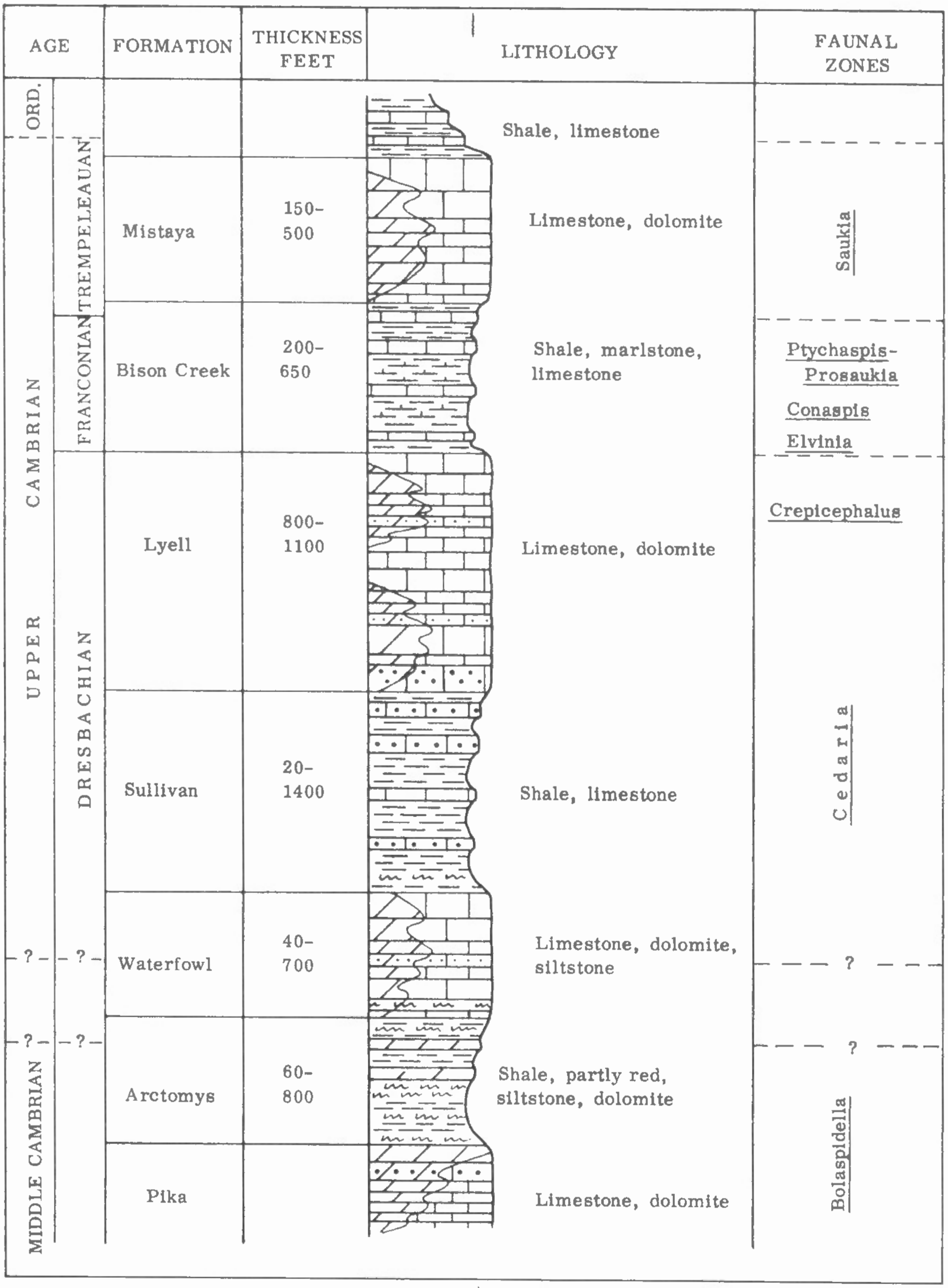

Figure 3. Upper Cambrian sequence, southern Rocky Mountains, Alberta

In the present study the major break between Cambrian and Ordovician faunas is placed slightly above the top of the unit here named the Mistaya Formation, in the lower part of the widespread shaly unit designated by Walcott as unit 1a of the type Mons. This result confirms Usher's (1959) conclusions. The boundary has not, however, been located with precision. Saukia zone fossils have been found at the top of the Mistaya Formation by the writers, and 25 feet higher by Usher (op. cit., p. 30). Symphysurina zone fossils have been found higher in the section, but still within Walcott's unit 1a, by Walcott, Usher, B.S. Norford (personal communication), the writers, and others. The base of the Ordovician System therefore lies within the aforementioned shaly unit, and probably near its base, but determination of its exact position will require further study.

DEPOSITIONAL CYCLES IN THE UPPER CAMBRIAN

The Middle Cambrian, Upper Cambrian, and Lower Ordovician strata of a large area of the southern Rocky Mountains display a striking, large-scale cyclical repetition of lithologies and lithological associations. It is appropriate to provide at least a brief description of this cyclical deposition, because all of the formational boundaries the writers propose fall either at the beginning or at the mid-point of cycles.

A typical depositional cycle of the Upper Cambrian begins with shales, normally accompanied by platy, shaly siltstones, that overlie a thick sequence of carbonate beds unbroken except by very minor beds of very calcareous or dolomitic siltstone and sandstone. The change from essentially carbonate deposition to predominantly shaly deposition is so abrupt that it strongly suggests the possibility of a disconformity, but in most sections, careful inspection fails to provide confirmatory evidence. Formational contacts have been placed at the beginning of each of the Upper Cambrian cycles, in recognition of the important and easily traced stratigraphic discontinuities at these levels. Interbedded in almost any proportion with the shales and siltstones of the lower part of the shaly half-cycle are thin to very thick beds of limestone, mainly coarsely particulate types such as biocalcarenites and oolites; and minor amounts of conglomerate. The limestone beds commonly serve as the foundations for hemispherical to subspherical stromatolites. Very thin to thick intervals of dense limestones also occur. These are thin-bedded calcisiltites, and less commonly, micrites, with partings and mottlings of dolomite and argillaceous dolomite. Nodules of dense argillaceous limestone also occur within the shales of certain intervals of the typical shaly half-cycle. As the cycle is followed upward, shales continue dominant over interbedded limestones, but siltstones generally disappear a short distance above the base.

Limestones of the shaly half-cycle display ample evidence of shallow-water to intermittently emergent conditions, not only in their coarsely clastic and commonly crossbedded character, but also in the stromatolites rooted in them, types which Logan, et al. (1964, p. 77) attribute to an intertidal origin. Further evidences of intermittent non-deposition or emergence are found in the solution-etched and glauconite-coated tops of many limestone beds.

In contrast to the abrupt base of the depositional cycle, the transition at mid-point from the shaly to the carbonate half-cycle is so gradational as to render indefinite the formational contacts generally placed at this level. Even if the contact is consistently placed above the highest shale bed, the problem is not completely resolved because the difficulty remains of deciding whether a very thin "highest shale", or a "highest shale" overlying many feet of carbonates, should be assigned to the shaly formation below or the carbonate formation above. As the transition between shaly and carbonate half-cycles is approached from below, the proportion of limestone increases, and the individual limestone beds, commonly oolitic at this level, thicken greatly. Subspherical stromatolites up to five feet in diameter, embedded in the thick massive limestone beds, are also characteristic of this level. Oolites, biocalcarenites, and large stromatolites may or may not persist into the basal part of the overlying carbonate half-cycle.

The carbonate half-cycle is dominated by dense limestones (micrites and calcisiltites, in part argillaceous) and their dolomitized equivalents. These carbonates are characterized by thin, locally lenticular to nodular bedding, and by partings and mottlings of very fine crystalline dolomite and argillaceous dolomite. These distinctive bedding features are easily recognized in the completely dolomitized rocks. Biocalcarenite and oolite are present in medium to very thick massive beds, but are not as prominent as in the shaly half-cycle. Conglomerates of the round-pebble, flat-pebble, and edgewise types are generally present, at least as thin or medium beds occurring at wide intervals, and locally are prominent. Thin and medium beds composed of sand-sized carbonate rock-fragments, which might be called lithocalcarenite or microconglomerate, are characteristic, though minor, constituents of the carbonate half-cycle. Quartz and feldspar silt, abundantly present in certain of the carbonate half-cycles, is sparse to absent in others. Quartz and feldspar sand, uncommon in carbonate beds of the shaly half-cycle, and present only in the easternmost outcrops, is widespread in certain zones of particular carbonate half-cycles, and is apparently lacking in other carbonate half-cycles. The silty and sandy carbonates intergrade with calcareous and dolomitic siltstones and sandstones, which are minor constituents of certain of the carbonate half-cycles.

Inasmuch as both shaly and carbonate half-cycles of deposition contain evidence of very shallow-water conditions, such as conglomerates, oolites, and algal stromatolites, it appears probable that water depth was not the fundamental control of the depositional cycle.

Close study of the Upper Cambrian depositional cycles throughout a wide region reveals that although the formational contacts placed at mid-cycle are almost certainly interdigitating and therefore diachronous to some degree, those placed at the beginning of a cycle are almost certainly not interdigitating, and may closely approximate time-planes. For these reasons, maps derived from stratigraphic measurements, such as isopach maps and lithofacies maps, will be most significant if based not on formations (half-cycles), but on complete cycles, as represented by the pairs Arctomys-Waterfowl, Sullivan-Lyell, and Bison Creek-Mistaya.

REGIONAL RELATIONSHIPS OF THE UPPER CAMBRIAN, AND GEOGRAPHIC LIMITS OF THE PRESENT NOMENCLATURE

The nomenclature proposed by the writers is applicable only within a region which throughout Upper Cambrian time was a shelf area of carbonate deposition, interrupted by cyclical incursions of muddy sediments. In areas where the described cycles cannot be recognized, the present nomenclature is inapplicable.

The formations described in this report are best developed in the Glacier Lake-Mount Murchison area and are generally recognizable eastward to the easternmost Front Ranges[1] and in wells drilled in the Foothills[1], except that the Bison Creek Formation ceases to be recognizable due to a facies change into a carbonate unit. Where the Bison Creek is unrecognizable, the underlying Lyell and overlying Mistaya Formations are no longer separable, and the sequence Lyell-Bison Creek-Mistaya becomes a single thick carbonate unit. Beneath the western plains, the formations change eastward through a pronounced decrease in the proportion of carbonates to a shale-siltstone-sandstone-limestone sequence in which the depositional cycles of the mountain area are not recognized.

Northward from the type sections, the shaly formations intertongue with and grade laterally into carbonate rocks; thus along the line of the Athabasca River, neither the Sullivan nor the Bison Creek Formation is recognizable. The Arctomys Formation is thus overlain by a very thick, monotonous, mainly carbonate unit, the Lynx Formation (Walcott, 1913, p. 334, restricted by Mountjoy, 1962, p. 13), which is equivalent to the sequence Waterfowl-Sullivan-Lyell-Bison Creek-Mistaya.

Southeastward from the type sections, the formations are recognizable as far as White Man Mountain, but immediately to the south and west of that point, the strongly cyclical character of the Upper Cambrian sequence cannot be recognized at all. Even the easily recognized Arctomys Formation disappears without structural cause, when traced from White Man Mountain down Cross River.

Between the latitudes of White Man Mountain and Yellowhead Pass, a normal development of the formations discussed in this report is encountered westward to the Stephen-Dennis fault, but no farther (Allan, 1914, pp. 9, 67; North and Henderson, 1954, pp. 30-31; Wheeler, 1963, map). No doubt contemporaneous strata are present west of that line, but they are unrecognizable in terms of the nomenclature presented in this report.

DISCUSSION OF FORMATIONS

<u>Bosworth Formation (Walcott, 1908, obsolete)</u>

The Bosworth Formation, erected by Walcott (1908a, p. 3) for the oldest Upper Cambrian formation on Mount Bosworth, was defined as follows:

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[1] Subprovinces are named according to the designations of Douglas (1957, pp. 343-346).

Type Locality - Ridge extending northeast from Mount Bosworth, and southeast base of Paget Peak and Mount Daly.
Derivation - From Mount Bosworth, the type locality.
Character - Arenaceous, dolomitic limestones, massive, thin bedded, and shaly, with bands of purple and grey siliceous shales.
Thickness - At Mount Bosworth, 1,855 feet.
Organic remains - None observed; formation referred to Upper Cambrian.

Later, Walcott (1908b) published a further description of the Bosworth Formation and subdivided it into five units. The lowest of these five units, 268 feet of "variable arenaceous shales with alternating bands of colour - greenish, deep red, buff, yellow, and grey" (op. cit. p. 208), was later removed (1928) from the basal beds of the Bosworth Formation and correlated with the Arctomys of Glacier Lake valley.

As far as the writers are aware, the only published field investigations of the Upper Cambrian of Mount Bosworth-Paget Peak subsequent to Walcott's work and prior to their own are brief reports by Deiss (1940) and North and Henderson (1954). These authors recognized the confusion embodied in Walcott's Mount Bosworth section, but did not establish valid correlations with the formations erected by Walcott at Glacier Lake.

Numerous references to the Bosworth Formation appear in the literature, but rarely have authors treated it in the same manner. Many authors have attempted to correlate it with the Upper Cambrian of Glacier Lake, but none has arrived at a satisfactory solution, the main reason being the difficulty of establishing precisely which strata of Mount Bosworth-Paget Peak were intended by Walcott to be included in the type Bosworth Formation.

Almost certainly, Walcott did not intend to include any beds below the "variable arenaceous shales with alternating bands of colour" (1908b, p. 208), despite the annotation of Plate 67 (1928), that indicates the base of the Bosworth far below the base of the Arctomys, and may have been added many years after the photo was taken. The "Eldon-Bosworth" contact shown in Plate 67 corresponds to the Eldon-Pika contact, as pointed out by Deiss (1940, p. 753). Deiss further notes that in Walcott's concept of 1928, the Arctomys Formation, and not the Bosworth, overlies the Eldon Formation. Furthermore, the beds assigned by Deiss and the writers to the Pika Formation are clearly identifiable as Units 1a to 1d and Unit 2 of Walcott's description of the Eldon Formation (1928, p. 311). It is therefore clear that Plate 67 is mis-annotated, and does not contribute to the question of the identity of the Bosworth Formation. This seems to have been generally recognized, because the writers know of no published correlation of the Bosworth Formation with sub-Arctomys strata.

It is sufficiently clear that Walcott originally placed the base of the Bosworth at the base of the Arctomys Formation, and subsequently (1928), on recognizing that the original Bosworth included beds correlative with (part of) the type Arctomys Formation, raised the base of the type Bosworth to exclude the "Arctomys". Here, however, he miscorrelated, in assigning to the Arctomys only the beds correlative with his units 2a to 2n of the type Arctomys, thus overlooking the fact that beds correlative with 1a of the type Arctomys, "bluish grey, irregularly laminated limestone", thereby remained in the emended type Bosworth.

Walcott's intent as to the top of the type Bosworth remains uncertain. It appears most likely, from Plate 19 (1908b) that he recognized the normal fault immediately west of "Buff Point" at the time of his original measurement. Assuming this, the top of the type Bosworth is located at the fault, within or at the top of beds correlative with 1a of Walcott's type Arctomys, strata assigned by the authors to the Waterfowl Formation (proposed). Walcott's description of the uppermost unit of the type Bosworth, "massive-bedded, gray and bluish-gray arenaceous dolomitic limestone (with) several bands of steel-gray, yellowish-buff-weathering ... strata ... in the lower half" (600 feet or more), is consistent with this interpretation. If this interpretation is correct, then Walcott's thickness for the Bosworth plus Arctomys at Mount Bosworth-Paget Peak (1,855 feet) is grossly in error. The figure cannot be determined with precision anywhere on Mount Bosworth-Paget Peak, but in perfect exposures on Mount Ogden, 1.9 miles to the west, in the west limb of the syncline whose east limb passes through Mount Bosworth, the total thickness of Arctomys plus Waterfowl is 985 feet, of which 478 feet can be assigned to the Arctomys (restricted). In the light of our knowledge of the regional behaviour of Arctomys and Waterfowl thicknesses, the thicknesses on Mount Ogden may be assumed comparable to those at Mount Bosworth. A suggestion as to the source of Walcott's apparent error in measurement is found in the fact that the sequence of lithologic units described by him cannot be duplicated on the Mount Bosworth-Paget Peak connecting ridge, and furthermore that Units 1, 2a and 2c are similar in appearance and thickness. These facts suggest that Walcott may have unwittingly measured the same unit more than once, on different parts of the mountain. If, as seems most likely, Walcott placed the top of the type Bosworth Formation at the fault west of "Buff Point", the Bosworth Formation corresponds to the upper part (1a) of the type Arctomys, that is, to the Waterfowl Formation of this report.

If Walcott did not recognize the fault west of "Buff Point" at the time of measurement, it is possible that he extended the type Bosworth Formation beyond the fault, including in the type Bosworth the northward continuation of his type Sherbrooke Formation. This, however, seems most unlikely, because of the close correspondence between his description of the uppermost unit (1) and the beds exposed on "Buff Point".

In summary, the emended Bosworth Formation of 1928 apparently corresponds more or less to the upper part (1a) of the type Arctomys of Walcott (Waterfowl Formation of this report). The thickness reported by Walcott was greatly exaggerated, apparently because certain units were measured in different places and shown more than once in the description of the type section. The type section was poorly specified and is structurally complicated and bounded at the top, not by a formation contact, but by a fault. The strata present at the type locality can be readily correlated with the much better exposures at Glacier Lake. For these reasons, it is recommended that the name be considered invalid and obsolete, as recommended (although on different grounds) by North and Henderson in 1954.

Arctomys Formation (Walcott, 1920, restricted)

The Arctomys Formation was first named and very briefly described by Walcott (1920, p. 15) from the Glacier Lake section on the southern slopes of Sullivan Peak. The original description of this formation is:

"Upper Cambrian Arctomys Unit 1a Laminated limestones...520 feet
Unit 1b Purple, green and grey shale with layers of laminated limestone..........866 feet
Total thickness..............1,386 feet"

In 1923, Walcott amplified the description of the type section but omitted any mention of the maroon and green shales, the most characteristic feature of the formation. Part of this description of the Arctomys is given below:

"Character - Bluish grey irregularly laminated cliff-forming limestones which are more or less magnesian in some layers. This limestone is underlain by a series of arenaceous and siliceous shales with bands of hard, finely laminated, dove-coloured limestone.
Thickness - Upper cliff-forming limestone 520 feet (158.5m.). The siliceous shales and limestone below have a thickness of 866 feet (263.9m.) which gives 1,386 feet (422.4m.) for the entire formation.
Organic Remains - The character of the sedimentation appears to have been unfavourable for the presence and preservation of vegetable and animal life. The few fossils found indicate the Upper Cambrian fauna" (Walcott, 1923, p. 462).

In Walcott's (1928) summation of the pre-Devonian geology of the Canadian "Rockies", the Arctomys Formation from various Upper Cambrian sections in the Front and Main Ranges of the Rocky Mountains is described. It is important to note that by this date, Walcott's conception of the Arctomys had changed significantly. Only in the Siffleur River section (1928, pp. 335, 336) did he correlate with his type Arctomys of Glacier Lake. In all other sections, he placed the top of his Arctomys at the top of the lithological correlatives of the lower, shaly part (Units 2a to 2n) of his 1928 description of the type section. In all sections but one, he placed the base of the Arctomys correctly at the base of the brightly coloured shales, but at Cotton Grass cirque (op. cit., pp. 286, 287) he extended the Arctomys downward to include the Pika Formation. Walcott thus laid the foundation for the practice followed, almost without exception, by later geologists, of applying the name Arctomys only to beds correlative with the shaly part of the type section.

Deiss (1939) remeasured the Castle Mountain (now Mount Eisenhower) section, and reported 270 feet of Arctomys from the ridge near the top of the section. He discovered poorly preserved Obolus sp. 133 feet below the top of the formation. With reference to the correlation of the Arctomys of Castle Mountain with the type section near Glacier Lake, Deiss observed (op. cit. p. 974) that:

> "The correlation of these rocks with those of the Arctomys in its type section 65 miles to the northwest is based upon the lithologic similarity and stratigraphic position of these rocks in the two areas but not upon fossils. Only Obolus sp. and Lingulella isse (Walcott) are known from the lower part of the formation near Glacier Lake (Walcott, 1928, p. 374)."

Deiss assigned the overlying 430 feet of beds to the "Bosworth limestone". In a note (op. cit., p. 964), he explains his placing of the Arctomys-Bosworth contact:

> "Walcott may have drawn his Arctomys-Bosworth boundary lower in section, but this is the only natural boundary between the dominantly maroon shaly beds of the upper Arctomys and the limestone and dolomite of the Bosworth and is the only useful boundary for mapping."

The beds assigned to the "Bosworth limestone" by Deiss are also straightforward lithological correlatives of Walcott's Unit 1a of the type section of the Arctomys.

Few additional observations of importance were made concerning the Arctomys Formation until the publication in 1954 of North and Henderson's summary of Southern Rocky Mountain geology. They stated (1954, p. 62) that:

> "The Arctomys is characterized by thin beds and bright colours. It is dominated by shales, usually siliceous or calcareous and containing beds of limestone or dolomite or both. The shales are of all colours - maroon, red, yellow, and buff - and frequently bear mud-cracks and casts of salt crystals..... The formation is now best seen around the lower slopes of the peaks in the Glacier Lake region, south of the Icefields. It thins northward and southward and thickens for a short distance westward, from this central area."

DeWit, reporting in 1956 on a study of the relationship between the Ghost River and Arctomys Formations as exposed in the Bow Valley, described four sections in which he reported the presence of the Arctomys Formation. In each section, the Arctomys is designated as a unit of siltstones, shales, and thin platy dolomites coloured red, maroon, yellow, and buff. The immediately overlying Cambrian limestones and dolomites have generally been assigned to the Bosworth Formation by deWit. Usher (1959) assigned the same limits as deWit to the Arctomys of Mount Rundle and the Sawback-Bourgeau Range.

From the foregoing summary, it is apparent that Walcott, in his last publication, and later authors have more or less consistently restricted the Arctomys Formation to correlatives of the lower part of the type section, characterized by green and maroon shales, although there is nothing to suggest that they were aware that they were not correlating with the full type section. It is therefore proposed formally to restrict the Arctomys Formation to the lower, recessive part of the original type section, a distinctive and readily mappable rock-unit characterized by brightly coloured shales

(Units 2a to 2n of Walcott, 1928), and to elevate the overlying, cliff-forming carbonate part (1a of Walcott) to formation rank as the Waterfowl Formation (see below).

Origin of Name

The Arctomys Formation is named for Arctomys Peak, 2 3/4 miles west of Sullivan Peak.

Type Locality and Type Section

The type locality of the Arctomys Formation (restricted) is unchanged from that chosen by Walcott, namely, the southern slopes of Sullivan Peak, near Glacier Lake, in Banff National Park.

The type section is the lower part of Walcott's original type section, illustrated, but inaccurately annotated, in Walcott's (1928) Plate 92, that is, in a gully tributary to Glacier River, 1.7 miles west of the west end of Glacier Lake, and between altitudes of 5,500 and 6,200 feet. The approximate geographic coordinates of the section are: Lat. 51°55'30"N; Long. 116°56'W. The type section is well exposed and reasonably accessible. It is cut by a normal fault with a throw of some tens of feet, but beds on either side of the fault can easily be correlated, permitting accurate measurement. A detailed description of the type section is included in the Appendix.

Summary of Lithology

The Arctomys Formation (restricted) is most readily distinguished from other late Middle and Upper Cambrian formations of the region by its brightly coloured shales and mudstones. These rocks, mainly weaklv fissile to non-fissile, are characteristically deep maroon, green, or mottled although grey to black shales occur in many sections, especially the thinner, more easterly ones. Thin lenticles and laminae of siltstone normally accompany the shales. Equally characteristic of the Arctomys Formation, and normally constituting a greater proportion than the shales, are very well-sorted siltstones, white to deep orange-buff in colour, less commonly green. The siltstones are commonly cemented by silica or dolomite, but a most distinctive variety, of earthy aspect, is calcareous and highly porous. Very small vugs, generally lined with calcite crystals are an extraordinary and common characteristic of the Arctomys siltstones. The siltstones are almost invariably thin-bedded and flaggy, laminated and cross-laminated. They commonly display oscillation ripple-marks, and at certain horizons casts of halite crystals, preserved in their bases project into the underlying shale. "Polygonal stromatolites", presumably formed by algal colonization of mud-cracks, are found in many beds. The buff[1] to yellow-orange, weathered surfaces of siltstone beds and talus give a characteristic colour to Arctomys exposures.

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[1] Buff here refers to colours ranging from about 10 YR 7/4 to about 5 Y 6/4.

Dolomite beds, grey to yellow in colour, dense, and generally argillaceous, silty, or siliceous, are found in most sections. Dense, argillaceous and silty thin-bedded grey limestones occur in many Arctomys sections, and in some, such as the type section, form important intervals. In the middle parts of many sections there are one or more horizons of large, pillow-shaped stromatolites of limestone or dolomite.

The Arctomys Formation, forming brightly coloured, recessive outcrops, locally punctuated by one or two minor cliffs of dolomite and/or limestone, stands in marked topographic contrast to the cliff-forming Pika Formation below and Waterfowl Formation above.

Contacts

The contact of the Arctomys with the underlying Pika Formation is sharp and planar and is drawn where dolomitic siltstones overlie dolomitized, dense and particulate limestones of the Pika Formation. The sharp topographic break occurs when the first shales outcrop and lies a few feet higher than the base of the siltstones. The abrupt lithologic change at the base of the Arctomys prompted a search for evidence of disconformity, but none has been found.

The contact of the Arctomys with the overlying Waterfowl Formation is gradational in every section studied. Comparison of sections across the sedimentary strike shows that intertonguing takes place between typical Arctomys and typical Waterfowl lithologies. The contact is most easily located in the type section; in all directions from Glacier Lake, it becomes increasingly gradational and indefinite. The upper contact is placed above the highest interval in which shales, especially brightly coloured shales, or flaggy siltstones with shale partings, are prominent. Minor, isolated beds of shale and/or siltstone, interrupting intervals of dolomite or limestone higher in the section, are included in the Waterfowl Formation. In many parts of the Front Ranges, and in the Vermilion Pass-Mount Assiniboine region (where the Arctomys assumes a cliff-forming character), the contact is so indefinite that it is advisable to map an undifferentiated unit, the Arctomys-Waterfowl.

Thickness and Distribution

At the type section the Arctomys Formation is fully developed and is 771 feet thick. Westward, it thins slightly to 729 feet at Mount Whiterose (51°58'N; 117°16'W). Mountjoy (1962, 1963) has mapped the Arctomys Formation from the Main and Front Ranges to the upper reaches of the Snake Indian River, near latitude 53°30'N. He reports that the formation is 700 feet thick in the Mount Robson (SE) map-area, thickening to 1,100 feet near Mount Robson. Southeastward along strike from the type section, the formation thins to 230 feet at Vermilion Pass, and the contact with the overlying Waterfowl Formation becomes indefinite. It continues to thin southeastward to Mount Assiniboine, where the best choice of an Arctomys-Waterfowl contact gives only 132 feet of Arctomys, then thickens to 335 feet at White Man Mountain, beyond which it disappears abruptly. The Arctomys Formation is identifiable along the Mountain Front from Bow River to Athabasca River.

Only 55 to 60 feet thick at Ghost River, it thickens gradually northwestward to 86 feet at Wapiabi Gap, and plunges from view a short distance beyond. In the next structural panel to the west, the formation thickens to 240 feet in the vicinity of Mount Dalhousie, on Brazeau River, and to 283 feet at Roche Miette.

Fauna and Age

No fossils have been found in the Arctomys Formation by the writers, but some fragmental, unidentifiable trilobites, and lingulid brachiopods were found by Walcott at the type section, and Obolus ? sp. by Deiss at Mount Eisenhower (Castle Mountain).

The Waterfowl Formation, which overlies the Arctomys, is also predominantly unfossiliferous, but identifiable trilobites occur widely in the Pika Formation underlying the Arctomys. The fossil collections made by Deiss, and identified by Denson (1942) from the type Pika Formation on Mount Eisenhower are correlated with the second youngest Middle Cambrian zone of Utah, Montana, and Wyoming. Denson concluded that the overlying Arctomys Formation must be Middle Cambrian in age. The writers have reached the same conclusion on evidence provided by a collection of trilobites from the upper 100 feet of the Waterfowl Formation, at Mount Whiterose, twelve miles west of Sullivan Peak. Preliminary study of this collection (G.S.C. No. 57659) indicates that it is from the basal Cedaria zone of the Dresbachian thus confirming Denson's conclusion that the Arctomys is Middle Cambrian in age. Geologists in the United States accepted Denson's (1942) view but Canadian geologists persisted in considering the Arctomys to be Upper Cambrian until the early 1960's (Lochman-Balk, personal communication, 1962).

Environment of Deposition

The Arctomys Formation displays, throughout its entire areal extent, abundant evidence of shallow-water deposition and intermittent emergence, features noted by North and Henderson (1954, p. 62), and Mountjoy (1962, p. 12). Evidence of shallow-water deposition is found in oscillation ripple-marks and widespread crossbedding and cross-lamination. Evidence of intermittent emergence is found in the widespread mud-cracks and shale-chip breccias, and in algal stromatolites of a sort known to be forming to-day in the intertidal zone of certain shorelines (Logan, et. al., 1964, Plate 3). The common red coloration of the Arctomys shales may be due to subaerial oxidation subsequent to deposition.

The widespread casts of salt crystals ("salt-hoppers") are evidence of an evaporitic environment. In the evaporation of sea water, gypsum or anhydrite or both precipitate from sea water before halite, thus one or other of these sulphates must have been deposited during Arctomys time, although neither gypsum nor anhydrite is known to occur in the Arctomys. The peculiar vugs of the siltstone beds may be evidence of the prior presence of soluble sulphate minerals. Similar vugs occur in certain thin beds of a peculiar breccia of shale chips set in a secondary calcite matrix, which can be found in most Arctomys sections.

It is worth emphasizing that Arctomys lithologies change very little within the sixty-mile-wide belt in which the formation occurs, and that the pre-Laramide distribution of the formation may have been twice the present width. No matter how rapidly the shoreline of the times may have migrated back and forth across the belt of occurrence, it is obvious that at any given moment extremely shallow-water and intermittently emergent conditions persisted over a belt extending many miles seaward from the line of highest high tide.

The Arctomys Formation probably accumulated on a stable and very slowly subsiding shelf, with a variable influx of terrigenous clastics. When terrigenous influx was strong, shales with siltstone lenticles and laminae were deposited. When terrigenous influx was moderate, the clay particles were borne seaward, and clean, well-sorted silts were laid down. When terrigenous influx was slight, carbonate-depositing mechanisms dominated.

The suggestion of North and Henderson (1954, pp. 60-62), that the Arctomys was laid down in a "starved basin" enclosed by "Eldon reefs" is completely untenable for several reasons, chiefly: (a) The reefs in the Eldon-Pika are limited to the Eldon proper, at least 300 to 900 feet lower in the section than any part of the Arctomys Formation, and entirely predating the Arctomys; (b) The supposed relationship that suggested the above hypothesis, namely, that the Arctomys Formation is thick where the Eldon-Pika is thin or absent, is entirely due to Walcott's failure to recognize the Eldon Formation in his Siffleur River section (1928, p. 336) and his miscorrelation of the "Murchison Formation" (Stephen) of Siffleur River with the "Murchison Formation" (Pika) of Glacier Lake, which led to the erroneous conclusion that the Pika-Eldon is absent at Siffleur River and Glacier Lake. The Pika-Eldon in fact is coextensive with the Arctomys in the region covered by this report.

Waterfowl Formation (proposed)

The name Waterfowl Formation is proposed for a resistant unit of carbonate rocks and minor siltstones, that overlies the Arctomys Formation and underlies the Sullivan Formation.

Origin of Name

The name is derived from Waterfowl Lakes, situated in Mistaya River valley, ten miles south of the summit of Mount Murchison. The formation is present on the east wall of the valley, high above the lakes.

Type Locality and Type Section

The type locality of the Waterfowl Formation is on the southern slopes of Sullivan Peak, near Glacier Lake, in Banff National Park.

The type section coincides with the upper part (1a) of Walcott's type section of the Arctomys Formation, illustrated but inaccurately annotated in his Plate 92 (1928), and is continuous with the type section of the

Arctomys Formation (restricted), described on pages 16 and 17 of this report, extending between altitudes of 6,200 and 7,200 feet. The type section is well exposed and reasonably accessible. Normal faults of some tens of feet displacement flank the type section to the east and west, but were avoided in measuring the section. A detailed description of the type section is included in the Appendix.

Summary of Lithology

The Waterfowl Formation, a resistant succession dominated by carbonate rocks, stands in sharp lithological contrast to overlying and underlying formations. In many sections in the Main Ranges, and notably at the type section, the Waterfowl carbonates are largely limestones. In the Front Ranges, however, the Waterfowl is mainly dolomite, most of which has inherited sufficient details of fabric and bedding style to reveal its relationship to pre-existing limestones. For this reason, descriptive emphasis will be placed on the limestones, as revealing more of the conditions of deposition than do the derived dolomites.

The Waterfowl carbonates, which make up some 90 per cent of the formation, are dominated by dense limestones, that is, by brown micrites and grey calcisiltites not always separable from one another in the field. These strata are generally dolomitic, but here and there are argillaceous, commonly silty to very silty, and in many places contain a scattering of intraclasts and trilobite fragments. They display two distinct types of bedding. One consists of dense limestone in thin and very thin, lenticular to nodular beds and laminae, separated by partings of dolomite that is buff, very finely crystalline, generally argillaceous and locally silty. The parting material is tan-weathering[1], in contrast to the intervening grey-weathering limestone. It commonly "invades" the limestone beds and laminae along sharp-walled cracks and burrows, and in some beds the limestone appears as fragments of a breccia, with the parting material as matrix. The second type consists of thick to very thick, massive beds of dense limestone, mottled with irregular, amoeba-shaped blotches of dolomite similar to that of the partings described above. The dolomitized equivalents of these dense limestones can be recognized by their characteristic bedding style and the relict mottling that is still recognizable, especially on weathered surfaces, in the completely dolomitized, light grey to light brown, fine- and very fine-crystalline rock.

Medium and thick beds of intraclast-sparite and pellet-sparite limestones commonly form minor constituents of the Waterfowl Formation and usually interrupt intervals of dense limestones. Relict fabrics clearly indicate that some dolomites were derived from limestones of these types. Biocalcarenites are not abundant and are generally found near the top of the formation. Oolitic limestones are minor constituents of the Waterfowl Formation at most localities, and are most common near the base or top. One or more beds largely composed of algal pisolites are found near the base in many sections. Flat-pebble conglomerates, although nowhere prominent,

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1 Tan here refers to colours near 10 YR 6/6.

are scattered throughout the formation, and tend to be associated with dense limestones. The latter three rock types are easily recognizable in their dolomitized equivalents.

Hemispherical to pillow-shaped stromatolites are present at one or more levels in nearly all sections of the formation and tend to be best developed near the base and top of the formation, and to increase in prominence toward the south and west. Polygonal stromatolites of low relief are common in the flaggy siltstones and argillaceous dolomites described below.

The Waterfowl Formation contains more silty carbonates and siltstones than the other two Upper Cambrian carbonate units, the Lyell and Mistaya Formations. The siltstones appear to be of two types, the first and least important being thin beds that intergrade with the very silty dense limestones and derived dolomites. The second type, essentially identical with the typical, flaggy, yellow-weathering siltstones of the Arctomys Formation, and like them is associated with mud-cracks, ripple-marks, and cross-lamination. These siltstones form intervals two to twenty feet thick, in the predominantly carbonate succession. The proportion of siltstones in the Waterfowl increases eastward, and siltstone dominates many of the thin sections along the Mountain Front.

Sandstone, fine grained, calcareous or dolomitic and commonly carrying pebbles of various carbonates, is found in one or more thin intervals in most Waterfowl sections and is generally associated with dense limestones or derived dolomites, rather than with intervals dominated by flaggy siltstone.

Non-fissile, non-laminated, yellow-weathering, grey to yellow, calcareous or dolomitic mudstone or claystone, and very argillaceous dense dolomite, form thick, discrete beds in most Waterfowl sections, and are associated with intervals dominated by flaggy siltstones. Grey and brown fissile shales occur in rare isolated beds rarely exceeding two feet in thickness.

The strata of the Waterfowl Formation are predominantly resistant and cliff-forming. In the thicker sections, the formation forms two, three or four steep cliffs, interrupted by recessive ledges underlain by flaggy siltstones and argillaceous carbonates. At Vermilion Pass and Mount Assiniboine, the individual cliffs disappear, and the formation forms a single steep, ledgy slope. In the western Front Ranges, the formation generally forms a double cliff, while along the Mountain Front it forms a single cliff.

Contacts

The base of the Waterfowl Formation is gradational, as indicated in the discussion of the Arctomys Formation (pp. 17, 18). The contact is designated as the top of the highest interval in which shales, especially brightly coloured shale, or flaggy siltstones with shale partings, are prominent. Isolated beds of shale and siltstone, intercalated within carbonate rocks, are included in the Waterfowl.

The top of the formation is placed at an abrupt change from limestone or dolomite below to shales and interbedded siltstones with minor limestone beds above. Although the abruptness of the change prompted a search for evidence of disconformity, none has been found. The uppermost unit of the Waterfowl Formation in the Front Ranges commonly is a massive biocalcarenite and is overlain by similar beds alternating with subordinate shales. Although the massive biocalcarenite is more typical of Sullivan than Waterfowl limestones, it forms the top of an unbroken carbonate sequence, and accordingly is included in the Waterfowl Formation.

Thickness and Distribution

The Waterfowl Formation is 544 feet thick at the type locality, and thickens westward to 602 feet at Mount Whiterose. At Tangle Ridge, near Sunwapta Pass, to the north, it has thinned to 453 feet. Between Sunwapta Pass and Chetamon Mountain, near Jasper, the Sullivan Formation disappears as a mappable unit, and the Waterfowl Formation passes into the lower part of the Lynx Group.

Traced southeastward along the tectonic strike, from the type section, the Waterfowl is 520 feet thick at Mount Ogden, 675 feet thick at Vermilion Pass, and 492 feet thick at Mount Assiniboine. It is worth noting that the Waterfowl maintains or increases its thickness at the expense of the underlying Arctomys Formation, which undergoes pronounced thinning in this direction. This, and the difficulty of separating the Arctomys from the Waterfowl at the latter two sections, supports the conclusion that the base of the Waterfowl is an intertongued, diachronous contact. The Waterfowl Formation is clearly recognizable and 415 feet thick at White Man Mountain, but cannot be delimited a short distance to the south and west of that point.

The Waterfowl Formation thins rapidly northeastward toward the Mountain Front. At Ghost River, at the Mountain Front, it is only 40-45 feet thick. It thickens very slowly northwestward in the easternmost outcrops to 88 feet at Wapiabi Gap (52°30'N; 116°25'W), beyond which the Upper Cambrian plunges from view. The northward thickening continues in the next structural panel to the west, from 96 feet at Windy Point on North Saskatchewan River, to 118 feet at Mount Russell, near the head of Cardinal River. At Roche Miette, the formation is incomplete through sub-Devonian erosion.

Fauna and Age

As previously noted (p. 18), only one fossil collection has been obtained by the writers from the Waterfowl Formation. Preliminary study of this collection (G.S.C. Cat. No. 57659) from the uppermost 100 feet of the Waterfowl Formation at Mount Whiterose (51°58'N; 117°16'W) suggests a basal Dresbachian age. The small fauna reported by Hughes (1955, p. 90) from beds assigned by the writers to the top of the Waterfowl Formation is consistent with this suggestion. The Middle Cambrian-Upper Cambrian boundary thus lies somewhere within the Arctomys-Waterfowl (see also p. 18); further collections are needed to place the boundary with greater precision.

Environment of Deposition

The widespread cross-lamination and ripple-marks of the Waterfowl Formation suggest deposition in very shallow water, whereas the widespread stromatolites and mud-cracks, the presence in one place of raindrop-imprints, and one discovery of salt-crystal casts, testify to intermittent emergence. The dense limestones normally yield no direct clues as to the depth of water in which they were formed although their association with flat-pebble conglomerates strongly suggests very shallow water. The presence of hemispherical stromatolites of the type believed to have formed in the intertidal zone, in close association with dense limestones, also strongly suggests that the latter were deposited in water depths measurable in inches.

Features of very shallow-water deposition and intermittent emergence extend over a belt at present sixty miles wide, and formerly possibly twice that (p. 19). The Waterfowl Formation probably accumulated near sea-level on a broad shelf of carbonate deposition. The influx of terrigenous clastics was so slight that only rarely were the carbonate-depositing processes inhibited; the bulk of the terrigenous clay was carried off the shelf, whereas much of the silt, and such sand as reached the shelf, remained. From time to time, carbonate-floored tidal flats of vast extent were developed. The sea water over such a vast shallow area almost certainly has hypersaline, but there is little evidence that evaporites were deposited. On the seaward part of the carbonate shelf, slightly deeper, strongly agitated water of more normal salinity permitted the development of biocalcarenites from time to time.

Sullivan Formation (Walcott, 1920)

Walcott defined the Sullivan Formation as comprising those beds lying immediately above the Arctomys Formation of Sullivan Peak, near Glacier Lake. The original description by Walcott (1920, p. 15) is as follows:

Upper Cambrian	1a	Compact grey limestone............	325 feet
Sullivan 1,440 feet	1b	Shale with interbedded limestone	975 feet
(422.4 m.)	1c 1d	Oolitic limestone and shale	140 feet

In 1923 this description was enlarged and the type section more accurately located. The description and remarks regarding this formation are quoted below in part.

"Type locality - Grey limestone above with arenaceous shale and interbedded limestone on the north side of Glacier Lake canyon valley and the south cliffs and slopes of Sullivan Peak about a mile east of the foot of southeast Lyell Glacier.
Derivation - From Sullivan Peak, 7,858 feet (2,395 m).
Character - Hard, grey, rather thin-bedded, semi-crystalline limestone above, with arenaceous shales predominating below. The dominant feature is the development of arenaceous shales.

Thickness – At the type locality in Glacier Lake canyon the upper limestone has a thickness of 325 feet (99 m.). The arenaceous shales and interbedded limestones continue down for 1,115 feet (339.8 m.), making a total thickness of 1,440 feet (438.9 m.).
Organic remains – Upper Cambrian fauna of about the horizon of the Eau Claire formation of the northern Mississippi valley section" (Walcott, 1923, p. 461).

In 1928, Walcott stated (p. 244) that the Sullivan Formation was "known only at Glacier Lake and the headwaters of the Saskatchewan River drainage", and that he had measured only one section, but went on to assign intervals of his Clearwater Canyon[1] and Siffleur River sections to the Sullivan Formation, in an inconsistent manner. Although he considered the formation to be fundamentally an interval of shales with interbedded limestones in the Clearwater Canyon section he included the equivalent of his unit 1a of the Arctomys Formation (Waterfowl Formation of this report) in the "Sullivan". At Siffleur River, he assigned at least 690 feet of uninterrupted carbonates belonging to the Lyell Formation to the "Sullivan". On the other hand, in his Ranger Canyon section, Walcott (1928, p. 267) assigned a 145-foot interval of "Gray oolitic limestone...with partings of calcareous and magnesian limestone shale", which correlates on lithology and fauna with the type Sullivan, to the "Lyell Formation". In Walcott's Cotton Grass Cirque section, he assigned (ibid., p. 286) a 190-foot interval of "Reddish-brown, more or less arenaceous shales and friable thin-bedded, arenaceous limestone with a few thin, hard layers", which correlates with the combined type Sullivan and underlying Waterfowl Formation, to the "Lyell Formation".

In regard to the contained fossils, Walcott stated:

> "This formation contains a Crepicephalus fauna and hence is to be correlated with the Sherbrooke and Paget formations" (Walcott, 1928, p. 244).

This statement appears to have been refuted, at least in regard to the fauna, by Resser (1942b) when he published the descriptions and illustrations of the Sullivan fauna. All are Cedaria zone genera and species.

The foregoing confusion stems almost entirely from mis-correlation of the widely recognizable, fossiliferous rock-unit of "shales with interbedded limestones" that Walcott recognized at Sullivan Peak.

In 1954, North and Henderson stated that:

> "The entire interval between the base of the Bosworth formation and that of the great Lyell limestone... is occupied by a carbonate sequence, consisting mostly of thinly bedded blue limestone with intervals of oolitic and argillaceous limestone and some shale. This sequence makes up Walcott's own Sullivan formation in the area north of Bow Lake, and its typical thickness is about 1,000 feet..." (p. 47-48).

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1 Walcott used the word "canyon" to refer to almost any mountain valley (Glacier Lake Canyon, Ranger Canyon, Clearwater Canyon). The sections so named were measured, not in the valley-bottoms, but on the flanks of the surrounding mountains.

In 1955, Hughes correlated the Sullivan Formation of the Glacier Lake area with the fossiliferous portion of the Tangle Ridge Formation. This correlation was based on the presence of Cedaria zone faunas in both formations.

The type section established by Walcott is very thick and well exposed. It is proposed to restrict the name, Sullivan Formation, to the shale-bearing part of the section, that is, to remove the uppermost 325 feet, the "compact grey limestone", from the original description. This restriction is justified by the fact that the top of the formation as originally proposed by Walcott corresponds to no mappable contact, but rather to the top of a local topographic feature. Furthermore, the revised contact coincides with Walcott's final concept (1928, p. 244) of the formation, and coincides approximately with the upper contact indicated in Plate 92 (1928). (It should be noted that the lower contact indicated falls within the type Waterfowl Formation of this report, that is, the upper part of Walcott's type Arctomys Formation.)

Origin of Name

From the type locality on the southern slopes of Sullivan Peak, near Glacier Lake, Banff National Park, Alberta.

Type Section

The type section is superjacent to and continuous with the type sections of the Waterfowl and Arctomys Formations (see pp. 16, 19). The Sullivan Formation occurs between altitudes of 7,200 feet to 8,600 feet. The exposures are excellent. Several normal faults of minor throw cut the section, but beds on either side of the faults can be easily correlated. A detailed description of the type section is contained in the Appendix.

Summary of Lithology

The Sullivan Formation consists of shales with subordinate interbeds of limestone. Minor amounts of siltstone normally occur, mainly at the base, but here and there at higher levels as well.

The predominant shales of the Sullivan are greenish grey, olive, brownish grey, and khaki-coloured, fissile to conchoidal-fracturing, and commonly calcareous. The common greenish colours are intensified on weathering, thus accounting for the characteristically greenish aspect of Sullivan outcrops. Most sections contain minor intervals of non-fissile, yellow-grey, tan-weathering calcareous mudstone.

The most common of the various limestones of the formation, which ordinarily occur in intervals ranging from a few millimetres to thirty feet, is trilobite-pelmatozoan biocalcarenite, mostly medium- and coarse-grained. In these rocks, well-rounded and well-sorted pelmatozoan bioclasts occur side-by-side with intact trilobite cranidia and pygidia. Scattered ooliths are common and many grains, especially trilobite fragments, are coated with oolite-like material. Some biocalcarenites are cemented by clear spar, and others have original pore spaces infilled by calcisiltite. Glauconite is found only rarely in biocalcarenite beds in the Main Ranges; along the Mountain Front it is generally present and commonly abundant.

Oolite beds, two inches to fifteen feet thick, are characteristic of the Sullivan Formation, and are especially prominent near the top of the formation. These rocks are generally medium- and coarse-grained and commonly include a scattering of pelmatozoan bioclasts or more rarely trilobite bioclasts. Original pores are filled with clear spar or calcisiltite.

Calcisiltite, commonly siliceous, generally forms thin lenticular beds and nodules among shales. Where it forms important intervals, the thin beds are generally separated by shale partings.

Flat-pebble and equant-pebble conglomerates form a small proportion of most Sullivan sections. They occur either at the base or top of beds of biocalcarenite or oolite, or are associated with intervals of calcisiltite.

Hemispherical to sub-spherical algal stromatolites, common in the Sullivan, are generally established on, and partly buried by biocalcarenite or oolite.

Dolomitization in the Sullivan limestones is erratic, and a dolomite bed can generally be traced laterally into limestone. Only in the southeastern corner of the area, where the Sullivan Formation is thin, do the carbonate rocks consist entirely of dolomite. Dolomites derived from biocalcarenites and oolites are easily recognized by relict fabric. Where dolomite is fine or very finely crystalline and carries no relict clastic fabric, derivation from dense limestone may be assumed. The dolomitized beds are easily recognized from a distance by their bright orange weathered surfaces.

Intervals dominated by very thin lenticular beds and laminae of calcareous siltstone occur near the base of the Sullivan Formation nearly everywhere in the Main Ranges. Northeastward toward the Mountain Front, siltstones become increasingly prominent, and may occur at any level. The siltstones weather a distinct orange-brown.

The Sullivan Formation is recessive-weathering at the base, in contrast to the cliffs of the underlying Waterfowl. Near the top, the formation forms steep slopes as the content of carbonates increases; thus the topographic break at the contact with the overlying, cliff-forming Lyell Formation is much less marked than that at the lower contact.

Contacts

The Sullivan-Waterfowl contact, as described on page 22, is marked by the abrupt appearance of shales above a predominantly carbonate sequence. The Sullivan-Lyell contact, on the other hand, is gradational. As the contact is approached, the limestone content of the Sullivan increases markedly and progressively. The individual limestone beds, generally consisting of oolite with large stromatolites, thicken greatly. The contact is drawn at the top of the highest shale bed. Oolite beds and large stromatolites are commonly found above that level.

Thickness and Distribution

The Sullivan Formation is 1,391 feet thick at the type section. The thicknesses at Mount Whiterose, to the west, and Nigel Pass, to the north, are unchanged within the limits of accuracy of measurement. The formation displays a normal lithologic development at Tangle Ridge, where the thickness exceeds 820 feet, no complete section being exposed because of faulting. Farther north, the Sullivan Formation grades laterally into the sequence of predominantly carbonate rocks comprising the Lynx Group. At Chetamon Mountain, near Jasper, the only sign of Sullivan equivalents is a seventy-foot, non-mappable interval of which half is shale.

Southeastward along the tectonic strike from the type section, the formation thins to 512 feet at Mount Ogden and 220 feet at White Man Mountain. The formation is not recognizable in sections including equivalent strata, a short distance to the south and west of the latter point.

From the thick sections in the Main Ranges, the Sullivan thins rapidly eastward to the Mountain Front. Only twenty feet thick at Ghost River, near its southward truncation at the base of the Devonian, the formation thickens northwestward along strike, at first slowly, to 68 feet at Clearwater River near Peters Creek, then rapidly to 266 feet in the Bighorn Range near Cripple Creek. No further change in thickness is detected between Cripple Creek and Wapiabi Gap, where the Sullivan is last seen in so easterly a structural plate. In the next major plate to the west, the thickness is almost constant from Windy Point, on North Saskatchewan River (280 feet), to Mount Dalhousie, on Brazeau River (258 feet), and Mount Russell, near the head of Cardinal River (240 feet). The Sullivan is not present at Roche Miette, having been truncated at the base of the Devonian between that point and Mount Russell.

Fauna and Age

The known faunas of the Sullivan Formation belong to lower and middle Cedaria subzones of the Upper Cambrian Dresbachian Stage. The lower Cedaria subzone, containing Bolaspidella, has been recognized in the Sullivan Formation only in the Bourgeau (Sundance) Range; the middle Cedaria fauna is known from many outcrops of the Sullivan in the southern Rocky Mountains.

Environment of Deposition

The alternation of contrasting lithologies in the Sullivan Formation raises serious difficulties in the interpretation of the environment in which it was deposited. On the one hand, the shales are deposits of a minimum-energy marine environment. On the other hand, interbedded oolites, well-sorted biocalcarenites, and conglomerates testify to a highly agitated, shallow marine environment, and the stromatolites found at several levels testify to periods of inter-tidal emergence. Every bedding-plane at which clastic limestone abruptly overlies shale offers a problem in interpretation because the wave or current energy required to move medium and coarse ooliths and bioclasts would surely have churned up underlying muds, yet the clastic limestones are not argillaceous. Although further study is needed the writers at present consider that the Sullivan Formation accumulated in a shallow to very shallow marine environment. At any one place the supply of terrigenous clastics was intermittent, and during interruptions in the supply, limestone-depositing processes were active. The silty zones of the formation, particularly the one at the base, may reflect either periods of unusually large influx of terrigenous clastics, or periods of marine regression.

Lyell Formation (Walcott, 1920)

The Lyell Formation was erected and briefly described by Walcott (1920, p. 15). Later (Walcott, 1923, pp. 460, 461) he described the type section in greater detail, and expanded his description of the formation:

"Lyell Formation (Cambrian, Upper)

Type locality - Massive-bedded grey and oolite limestone at head of Glacier Lake canyon valley about 2 miles (3.2 km.) above head of lake and about 48 miles (77.2 km.) northwest of Lake Louise Station on the Canadian Pacific Railway, Alberta, Canada.
Derivation - From Mount Lyell, 11,495 feet (3505.6 m.), on the Continental Divide northwest of Glacier Lake...
Character - Massive-bedded cliff-forming rough weathering magnesian limestone forms the upper portions of the formation, with thinner-bedded grey and oolitic limestones beneath.
Thickness - At the type locality in Glacier Lake canyon valley the upper magnesian beds have a thickness of 1,270 feet (387.1 m.) subjacent to which the thick-and-thin-bedded grey limestone extend down 430 feet (131 m.), a total of 1,700 feet (518.1 m.) for the formation...
Organic remains - An Upper Cambrian fauna is fairly well-developed in the lower limestone" (Walcott, 1923, p. 460).

In 1928, the available stratigraphic data on the Lyell Formation was summarized, and the type section was more precisely located as "Head of Glacier Lake canyon at foot of southeast branch of Lyell Glacier, and extending along the northern cliffs of Mount Forbes" (Walcott, 1928, p. 228). Plate 87 (ibid.) is annotated to show the limits of the Lyell Formation at the type locality, although the upper contact is shown a little too high to correspond exactly with Walcott's description.

In areas remote from the type locality, Walcott applied the name, Lyell, to intervals including the correlatives of the type Lyell, but also embracing older and younger beds. Thus at Ranger Canyon he included (1928, p. 266) both Sullivan and Lyell equivalents in the "Lyell", while at Cotton Grass cirque (ibid., p. 285) the entire interval between the top of the Arctomys (restricted) and the base of the interbedded shales and limestones with Symphysurina and Leiostegium (part of the Mons Formation) was assigned to the "Lyell". At Clearwater Canyon (ibid., p. 332) the name "Lyell" was applied to the interval between the top of the Sullivan Formation and the same shaly zone of the Mons Formation referred to above. This upward shift in the upper contact of the Lyell was repeated by North and Henderson (1954, p. 65), who refer to the "Mons" (meaning the shaly, fossiliferous unit referred to above, which is only a part of the type Mons) directly overlying the "massive Ottertail (Lyell) dolomite."

Confusion has thus arisen chiefly through miscorrelation with the type section, and not because the type section was imprecisely located or the limits of the formation ill-chosen for practical purposes. The unit identified as the Lyell Formation by Walcott is a thick, widespread, easily mappable unit. The name is here retained, and the definition of the formation is clarified.

Type Locality and Type Section

The type locality has already been indicated in quotes from Walcott (1928) (see above). Although the lowest ice-scoured outcrops exposed by the retreat of Mons Glacier are particularly good, the base and middle part of the formation are not exposed there and the revised type section was measured on the eastern wall and eastern shoulder of a steep gully draining a northern spur of Mount Forbes, which enters Glacier River 2 1/2 miles upstream from the west end of Glacier Lake. The Lyell Formation in this gully (Lat. 51°54'N; Long. 116°56'30"W) lies between 5,000 and 6,000 feet, above sea-level. The slopes, although partly forested, are very steep, and some mountaineering technique is required when examining the section. Exposures are fairly good in the lower quarter of the formation, and excellent at higher levels. The upper contact is not exposed, but the lower contact is very well exposed by midsummer, when the avalanche cone in the gully has melted back.

Summary of Lithology

The Lyell Formation is a thick unit dominated by carbonate rocks. In the Main Ranges, limestone is the dominant carbonate; farther east, the formation consists mainly of dolomite, in large part recognizable as having originated by dolomitization of limestone. Descriptive emphasis will be placed on the limestones, as revealing more of the conditions of deposition.

The formation is dominated by dense limestones, mainly micrites with some calcisiltites which are locally silty and argillaceous. These are predominantly thin-bedded and flaggy with tan-weathering dolomite partings similar to those described in detail in connection with the Waterfowl Formation on page 20. Minor thick massive beds with random dolomite mottling also occur. Nodular-bedded calcisiltites with a peculiar and distinctive clotted fabric form important intervals. This clotted calcisiltite fabric is identical with the fabric of many algal stromatolites and accordingly is tentatively attributed to the activities of blue-green algae. The bedding style of these dense limestones is well preserved despite dolomitization to pine-crystalline to microcrystalline dolomite.

Minor beds of pellet-sparite and intraclast-sparite limestone occur in the formation, generally in association with intervals of dense limestone. Pelmatozoan biocalcarenite and trilobite-pelmatozoan biocalcarenite occur both as isolated, medium and thick beds, and as thick beds forming intervals tens of feet thick. Some of these beds are sandy.

Beds of oolite, and the easily recognized dolomitized oolite, are prominent in some sections, such as the type section, and rare or absent in others. They are most commonly found at the base of the formation.

A few thin and medium beds of flat-pebble conglomerate, usually composed of uniform pebbles of calcisiltite, occur in most sections, but are nowhere prominent. In distinct contrast are other, mostly medium beds of blocky to rounded pebbles of a mixture of carbonate rocks. Similar beds are found in which the carbonate lithoclasts are in the sand range, and "lithocalcarenite" or "microconglomerate" might be more appropriate names. Such beds, and the pebble conglomerates as well, are commonly sandy to very sandy, grading to very calcareous sandstones. The conglomerate and "microconglomerate" beds are prominent in the middle of the formation; because they are generally dolomitized, they give rise to a middle zone characteristically striped by yellow-weathering dolomite beds.

In most sections there are a few beds of very argillaceous limestone, or more commonly, dolomite, or "calcareous/dolomitic mudstone"; mud-cracks are commonly associated with these beds. Many sections contain intervals in which partings of green or dark grey shale separate thin beds of limestone.

Most sections of the Lyell Formation are characterized by a scattering of blebs or nodules, and very rare thin beds, of grey chert. The chert-bearing beds are generally closely associated with silty or sandy beds.

Algal stromatolites, found at a few widely separated levels in many sections, are most common near the base and top of the formation.

The Lyell Formation is resistant to erosion. In the very thick sections of the Main Ranges, the middle part of the formation is slightly less resistant than the top and base, and the formation may appear as a double cliff.

Contacts

The base of the Lyell Formation is gradational, interfingered and doubtless diachronous. It is characterized by a rapid increase in the content and thickness of carbonate beds in the underlying Sullivan Formation, to the eventual exclusion of shale beds. The contact is drawn at the top of the highest shale bed. In contrast, the upper contact is marked by the sudden appearance of the shales and calcareous mudstones of the overlying Bison Creek Formation, and there is no evidence of interfingering.

Thickness and Distribution

The Lyell Formation is 1,130 feet thick at the type section by the writers' measurement. (It is not clear how or precisely where Walcott obtained the figure of 1,700 feet, which is undoubtedly in error.) A thick section is present at Tangle Ridge, to the north, but a complete section is nowhere exposed. Farther north, the Lyell loses its identity and merges into the Lynx Group, as the underlying Sullivan and overlying Bison Creek Formations grade laterally into the Lynx Group. Southeastward along the strike, no complete section of the formation has been measured. An incomplete section at Paget Peak is 1,350 feet thick, and another at White Man Mountain is over 1,050 feet thick. Like other Upper Cambrian formations, the Lyell loses its identity south and west of White Man Mountain.

The Lyell thins slowly eastward, in contrast to the rapid thinning of the underlying Sullivan Formation. The overlying Bison Creek Formation undergoes parallel thinning and changes laterally to carbonates, so that the top of the Lyell becomes unrecognizable eastward. The formation is thus recognizable only in and to the west of the Sawback Range and structural units continuous with it. At the most easterly measured sections in which it is recognized, the Lyell Formation is 815 feet thick in the Bourgeau (Sundance) Range, nine miles south of Banff, 912 feet thick at Mount Cory, at the south end of the Sawback Range, and 959 feet thick at Pulsatilla Pass, north of Mount Eisenhower.

Fauna and Age

Walcott stated that the fossils of the Lyell Formation indicate that it is younger than the Sherbrooke and Ottertail Formations and possibly older than the Sabine but the few fossils he reported from the Lyell were in fact collected from beds assigned by the writers to the Sullivan and Bison Creek Formations.

Only unidentifiable trilobite fragments have been found by the writers in the Lyell Formation. From the known ages of the underlying Sullivan and Bison Creek Formations, however, it is possible to suggest that the Lyell is probably medial and late Dresbachian.

Environment of Deposition

The lithologies and primary structures of the Lyell Formation are very similar to those of the Waterfowl Formation, and lead to a similar interpretation of the environment of deposition (see p. 23), that is, the Lyell Formation accumulated near sea-level on a broad shelf of carbonate deposition with very slight influx of terrigenous clastics. In the case of the Lyell Formation, the prominence of beds believed to be products of the activities of blue-green algae lends strength to the interpretation based on other features of the formation.

Remarks

In a large part of the Front Ranges, the Sullivan Formation is recognizable, but the Bison Creek Formation is not, because it has undergone a facies change to carbonate rocks indistinguishable from those of the Lyell Formation. Thus the Lyell, Bison Creek, and Mistaya Formations are merged into a single carbonate unit, which Aitken (in press), has informally treated as the upper division of the Lynx Formation.

Paget Formation (Walcott, 1908, obsolete)

Walcott erected the Paget Formation in the section measured on the southeastern slope of Paget Peak, above Kicking Horse Pass. The type description is as follows:

"Paget Formation

Type Locality – Southeastern slope of Paget Peak, beneath the Sherbrooke Formation, which forms the high cliffs of Paget Peak and Mt. Daly. The Paget formation breaks down more

readily than the Sherbrooke, presenting a slightly broken cliff line. The most accessible locality found is on the east face of the west ridge of Mount Bosworth (Sherbrooke ridge).
Derivation - From Paget Peak, the type locality.
Character - Bluish grey and oolitic limestones, usually thin bedded.
Thickness - At Mount Bosworth, 360 feet.
Organic Remains - Upper Cambrian fauna" (Walcott, 1908, p. 3).

The description of the Paget Formation was enlarged upon in Walcott's second publication of 1908 (1908b, p. 205). Of importance is the addition to the description of "interbedded bands of green siliceous shale" in the lower 300 feet of the formation.

In 1928 Walcott made the following observations regarding the Paget Formation:

"This formation might be included with the Sherbrooke as its upper 60 feet (18.3 m.) of heavy, blue limestone is underlain by 300 feet (91.4 m.) of grey oolitic beds much like the oolitic limestone of the Sherbrooke. There are no diagnostic forms that serve to distinguish it from the Sherbrooke fauna. My reason for separating it as a distinct formation was because it forms a marked topographic feature on Mount Bosworth and on Paget Peak" (Walcott, 1928, p. 243).

The Paget Formation was remeasured by the writers at the type locality on the southeastern slope of Paget Peak. Only 130 feet of slaty green shale and oolitic limestone were found below the first cliff on Paget Peak. The faunas from this unit, as well as the lithology, provided correlation with the Sullivan Formation. The upper, 60-foot "blue limestone" unit of Walcott, was 64 feet thick where measured. Its upper limit, that is, the contact of the type Paget with the type Sherbrooke Formation, was found to be not a depositional contact, but rather a secondary contact between limestone and derived crystalline dolomite, which cuts across the plane of the bedding.

At the type locality, neither the lower part of the formation nor its contact with the underlying Bosworth Formation is exposed. Walcott's thickness for the shaly unit is therefore an estimate, as he indicated (1908b, p. 205). The estimate is doubtless substantially in error, as the shaly unit (Sullivan Formation) is 512 feet thick on the west limb of the syncline of which Paget Peak occupies the east limb.

North and Henderson (1954) declared the Paget Formation obsolete, as it was merely a local oolitic limestone and shale equivalent of the Bosworth Formation. Although in the writers' view the Paget is not equivalent to any part of the type Bosworth, it is not the intention of the writers to revive the name. The type section is incomplete; its lower contact is concealed, and its upper contact is a replacement rather than a depositional contact, and cannot be mapped. For these reasons, and the fact that it straddles the contact between two other well-established formations, the writers concur in considering the Paget Formation obsolete.

The shaly part of the type Paget Formation is equivalent to the Sullivan Formation. The uppermost, 60-foot limestone unit of the type section belongs to the basal part of the Lyell Formation.

Sherbrooke Formation (Walcott, 1908, obsolete)

The Sherbrooke Formation, established by Walcott in a section continuous with the type section of the Paget Formation, on Paget Peak, was originally described as follows:

"Sherbrooke Formation

Type Locality - Western slopes of Mount Bosworth, overlooking Sherbrooke Lake, Canadian Rocky Mountains, five miles north of Hector, on the Canadian Pacific Railway, British Columbia.
Derivation - From Sherbrooke Lake, below the typical locality.
Character - Bluish grey, arenaceous, dolomitic, massive, and thin-bedded shaly limestones, with a few oolitic layers and cherty inclusions.
Thickness - At Mount Bosworth, 1,360 feet.
Organic Remains - Upper Cambrian, passing at summit into Ordovician" (Walcott, 1908, pp. 2, 3).

Walcott's second publication of the same year (1908b) provided a detailed section of the Sherbrooke Formation, giving the thickness as 1,375 feet, and listing its faunas. From the faunal list it appears that Walcott located the Crepicephalus zone of the Upper Cambrian.

In 1928, Walcott concluded his remarks on the Sherbrooke Formation with the following observations:

"The Sherbrook (sic) as a distinct formation is known only in the western part of Mount Bosworth. It has not been traced to the east, northwest, or north, unless the Sullivan Formation at Glacier Lake represents it" (Walcott, 1928, p. 242).

The Sherbrooke Formation was considered obsolete by North and Henderson (1954), and no purpose would be served by re-establishing it. Walcott himself was unable to recognize it in other sections. The lower contact at the type section, as Walcott himself recognized (1908b, p. 205) is an irregular replacement contact, rather than a depositional one, and is not mappable.

The upper contact of the formation, as described by Walcott in 1908 and on page 309 of his 1928 report, lies within a limestone succession, whereas on page 242 of the 1928 report it is placed 110 feet higher, at the top of the highest beds preserved on Paget Peak. In either case, the contact cannot be recognized elsewhere. The type section of the Sherbrooke Formation appears on lithologic grounds to represent part of the Lyell Formation, the Bison Creek Formation, and part of the Mistaya Formation, however, small faunas obtained from the shaly interval ("Bison Creek" part) are older than any known from the Bison Creek Formation. In these respects the section at Paget Peak is anomalous, and requires further study.

Sabine Formation (Schofield, 1921)

This formation was established by Schofield at Sabine Mountain, overlooking Canal Flats, British Columbia. The original designation of the formation is as follows:

"Western Flank	Eastern Flank
	Devonian. . . Jefferson limestone
	Disconformity
	Upper Cambrian. . . Sabine formation
Beltian. . . Kitchener formation	Middle Cambrian. . . Elko formation"

(Schofield, 1921, p. 76)

Elsewhere on the same page, Schofield wrote:

> "At the base of the wall (east wall of the Trench), the Elko formation outcrops and is overlain conformably by the fossiliferous Middle Cambrian (sic) (Sabine) formation which is in turn overlain by the Devonian limestone."

Of the geologists who have subsequently studied the geology of Sabine Mountain and adjacent areas on strike with it (Walker, 1926; Evans, 1933; Henderson, 1954; Leech, 1959), only Henderson found it practicable, or indeed, possible to map the Sabine Formation. In this connection, Henderson writes (1954, p. 22):

> "The Sabine Formation occurs only in the southern part of the Western fault block (i.e., in the immediate vicinity of Sabine Mountain, auth.). Elsewhere its stratigraphic equivalent, the Upper Cambrian portion of the McKay, does not differ sufficiently in lithology from the rest of the McKay to permit separate mapping".

Walcott (1928) applied the name, Sabine Formation, to an interval of interbedded shales and limestones occurring in his Tilted Mountain Brook (pp. 291-294) and Glacier Lake (p. 342) sections. The interval which he assigned to the Sabine in the latter section in 1928 had been included earlier (1920, 1923) in the type section of the Mons Formation, and Resser, in a footnote (Walcott, 1928, p. 342) noted that "It is somewhat doubtful whether this is a true representative of the Sabine formation". It should further be noted that Walcott, on other pages of the same volume (1928, pp. 224-226), included the "Sabine" interval in his description of the type Mons.

In any event, it is extremely inadvisable to extend a formation that can be mapped only in the immediate vicinity of its type section to areas more than 100 miles distant, across an intervening belt in which it is completely unknown. For this reason, use of the term is avoided here.

Mons Formation (Walcott, 1920 obsolete)

Walcott established the Mons Formation in the section on the eastern slopes of Division Mountain, Glacier Lake Valley. The original designation of the Mons was (Walcott, 1920, p. 15):

Upper Cambrian	1a	Calcareous shale and limestone	235 feet
Mons	1b	Massive bedded grey limestone	740 feet
(1,480 feet)	1c	Limestone and Shale	320 feet
(467.2 m.)	1d	Oolitic limestone	185 feet

Walcott later (1923, pp. 459, 460) amplified the above description, adding considerable detail as to the exact locality of the type section, the lithology, faunas, and thickness. The more important portions of his description are as follows:

"Type Locality - Alternations of calcareous shale forming steep and ragged slopes near the lower and southeast side of Mons Glacier near the base of a northwest ridge extending down from Mount Forbes.
Character - Massive beds of calcareous shale with intercalated layers of grey limestone above with a massive-bedded dull grey limestone and calcareous shale below.
Organic remains - A post-Cambrian pre-Ordovician fauna of Lower Ozarkian age."

In 1924, Walcott applied the name Mons Formation, to outcrops in the Stanford Range of British Columbia, including the type section of the Sabine Formation. Kindle stated in 1924 that if Walcott was correct in considering the Mons and Sabine as synonymous units then Sabine should be used since it had priority; however, the name Mons appeared in print in 1920, and Sabine only in 1921. Nevertheless, Walcott (1928, p. 342) accepted Kindle's recommendation, and applied the name, Sabine, to the lower 505 feet of his type Mons section at Glacier Lake. On the other hand, the type designation of the Mons Formation, elsewhere in the same volume (pp. 224-226), is retained as for 1920, that is, the full 1,470 feet, including the 505 feet assigned to the Sabine Formation on page 342.

Walcott's usage of the term, Mons, was as inconsistent in other localities as it was at the type section. In at least two sections, Ranger Canyon and Clearwater Canyon, he placed the base of the Mons at the base of the distinctive, recessive unit of greenish grey-weathering, calcareous shales with interbedded limestones that forms the highest unit (1a) of the type section of the Mons. In other sections, in which outcrop is not continuous from the Lyell to the Sarbach, it appears to have been Walcott's intent to place the base of the Mons at this level. This has led subsequent authors to use the term, Mons Formation, to mean a shaly unit whose base corresponds to the base of Walcott's 1a, one of the most easily recognized horizons in the Lower Palaeozoic of the southern Rocky Mountains and one which closely approximates the base of the Ordovician (see North and Henderson, 1954; de Wit, 1956; Usher, 1959).

The original designation of the Mons Formation (ignoring the later, unwarranted use of the term, Sabine Formation) embraces three distinct and widely mappable rock-units, namely, the original 1d plus 1c, unit 1b, and unit 1a. These correspond, respectively, to the Bison Creek and Mistaya Formations, here proposed, and the "Mons" of several authors. In areas where the Bison Creek Formation is not developed, the base of the type Mons is not recognizable, and furthermore, the formation as originally defined straddles one of the most distinct lithologic markers in the entire region (see above).

For these reasons the authors consider the use of the term, Mons Formation, obsolete as applied to Upper Cambrian formations. The drastic restriction of the term to a unit comprising less than one fifth of the type section would appear to contravene Article 14(b) of the Stratigraphic Code (1961), and is not recommended, but revision of Ordovician formations is beyond the scope of this paper. The raising of the term, Mons, to Group rank is inadvisable, because the base of the type Mons falls within a sequence (Waterfowl-Sullivan-Lyell-Bison Creek-Mistaya) which displays the community of character appropriate to a group. Furthermore, a "Mons Group", so defined would straddle an excellent regional marker horizon, and have its top in such a position as to obscure that community of character shared by the upper type Mons and the Sarbach Formation.

Bison Creek Formation (proposed)

The name Bison Creek Formation is proposed for a recessive unit of alternating limestones and shales, that overlies the Lyell Formation and underlies the Mistaya Formation.

Origin of Name

The name is derived from Bison Creek, a stream on the southwest slope of Mount Murchison, that crosses the Banff-Jasper Highway 6 1/2 miles south of the North Saskatchewan River Bridge, Banff National Park.

Type Locality

The type section was measured on Mount Murchison, above and west of the north branch of Bison Creek, on slopes above the cliffs of the Lyell Formation, between 7,500 and 8,100 feet elevation (Lat. 51°54'N; Long. 116°40'W, approximately).

Summary of Lithology

The Bison Creek Formation is dominated by argillaceous rocks, of which only a part may properly be referred to as grey and green shales, generally calcareous. Equally important, and forming thick units, is a group of rocks that might be called argillaceous or shaly limestones, very calcareous, non-fissile shales, very calcareous mudstones, or marlstones. These grey and grey-green, generally thin-bedded rocks generally lack primary fissility, but are readily subject to the development of slaty cleavage. A large proportion, probably the majority, of these rocks contain less than 50 per cent carbonate. Minor intervals are silty, especially near the base of the formation. The marlstone beds weather in part grey, and in part orange. Intervals of Bison Creek marlstone commonly carry abundant nodules and lenticular thin beds of grey dense limestone, and discontinuous streaks of biosparite limestone.

The limestones of the Bison Creek Formation form resistant units very similar to those interbedded with the shales of the Sullivan Formation, and like them increase in thickness and importance upward in the section.

The limestones are generally dense and include both thin-bedded to nodular varieties with partings of tan-weathering, very finely crystalline dolomite, and thick-bedded, massive varieties with irregular dolomite mottlings. Subordinate in aggregate thickness are medium and thick beds of pelmatozoan-trilobite biocalcarenite, commonly coarse-grained and identical with certain beds of the Sullivan Formation. At either the top or the base of these beds there is commonly a layer of limestone-pebble conglomerate in which the pebbles are flat in one bed and rounded or angular-equant in another. Limestone conglomerates are prominent near the top of the formation in most sections. Oolitic beds are rare in the Bison Creek Formation but where found, are generally near the top of the formation.

All Bison Creek outcrop sections studied to date have numerous horizons containing large, well developed, hemispherical to subspherical algal stromatolites. These established upon and within both dense and coarse-grained limestone beds.

The Bison Creek Formation is recessive relative to the underlying Lyell and overlying Mistaya Formations, and the resistant limestone beds form ledges in a slope whose angle is dominated by the weathering of the shales and marlstones. It is, however, much more resistant than the Sullivan and Arctomys. Where the angle of dip is very low, the recessive expression of the formation is minimized, and locally, as in the flat-lying block extending from Glacier Lake to Mount Saskatchewan, it is difficult to delineate on topographic criteria alone.

A detailed description of the type section is contained in the Appendix.

Contacts

The base of the Bison Creek Formation is a depositional contact marked by an abrupt change from the predominantly carbonate deposition of the Lyell to an interval of partly argillaceous deposition. In most sections, the lithologic change is clearly reflected in the topography. The top of the formation, like the tops of the Arctomys and Sullivan Formations, is gradational, and is marked by an upward increase in the content and thickness of limestone beds, to the eventual exclusion of shales and marlstones. The top has been drawn at the top of the highest bed of shale or mudstone; because of the gradational nature of the contact, it is not sharply reflected in the topography.

Thickness and Distribution

The Bison Creek Formation is 629 feet thick at the type section. It thickens gradually westward to 664 feet at Mount Whiterose. The formation disappears to the north and east, not so much by thinning, as by facies change into a carbonate unit that forms a part of the Lynx Group. Thus, the formation is 608 feet thick at Tangle Ridge, the most northerly section in which it has been recognized, but there it has a much lower proportion of shale and marlstone than at the type section. Although time-equivalent strata are present in the three most easterly blocks of Cambrian strata along Brazeau River, the formation is not recognizable there, nor is it recognizable in any of the sections along Athabasca River. The easternmost exposures of the formation along Bow River are seen in the Sawback and Bourgeau (Sundance) Ranges, where the formation is 236 feet thick and the content of argillaceous rocks is again reduced relative to the type section. The formation is clearly recognizable in a disturbed section on Nestor Peak, near Mount Assiniboine, and is also recognizable at White Man Mountain, disappearing by facies change south and west of that point.

Fauna and Age

The Bison Creek Formation is exceedingly fossiliferous and all the faunal zones of the Franconian Stage are present. The Bison Creek at the type locality is probably the time-rock equivalent of the Franconian Stage with some Trempeleauan, since a fauna tentatively assigned to the Elvinia zone has been found near the base of the formation, and a Saukia fauna is known from the top. More detailed collecting from this formation will probably prove it the equal of the type Croixian in abundance and variety of fossil species.

Environment of Deposition

The Bison Creek Formation presents problems of origin parallel to those of the Sullivan Formation, namely, the alternation of quiet-water shales and marlstones with coarse biocalcarenites and conglomerates indicative of turbulent conditions. Algal stromatolites, present at many levels, demonstrate the recurrence of very shallow-water to intertidal conditions. The paucity of oolites suggests that the formation was laid down in marine waters which in general were of relatively normal temperature and salinity and this may in part account for the rich fauna of the formation.

Remarks

The rock unit here named the Bison Creek Formation was included in the type Mons at its lowest unit (see discussion of Walcott's Mons Formation, p. 35), but later (1928, p. 342) was removed from the Mons and identified as the Sabine Formation. Reasons for not using the name Sabine Formation in the present area are given elsewhere (p. 34).

Mistaya Formation (proposed)

The name Mistaya Formation is proposed for a resistant unit of carbonate rocks that overlies the Bison Creek Formation and underlies distinctive, pale greenish grey-weathering, recessive shales.

Origin of Name

The name is derived from Mistaya River, a north-flowing tributary of the North Saskatchewan River that is followed by the Banff-Jasper Highway. Cliffs of the Mistaya Formation on Mount Murchison overlook the river.

Type Locality and Type Sections

The type section is on the southwest slopes of Mount Murchison between altitudes of 8, 100 and 8, 500 feet and it is continuous with the type section of the underlying Bison Creek Formation, above and west of the north branch of Bison Creek.

Summary of Lithology

The Mistaya is a formation of resistant carbonate rocks, among which dense limestones or their dolomitized equivalents are about equal in amount to coarsely particulate limestones or derived dolomites.

Dense limestones of the Mistaya are mainly of the thin-bedded type with thin dolomite partings, similar to those described in connection with the Waterfowl and Lyell Formations. These limestones, and especially the partings, are silty in certain intervals.

Particulate limestones of the Mistaya are dominated by medium to very thick, massive beds of fine to coarse pelmatozoan-trilobite biocalcarenite. These beds become increasingly important upward, at the expense of the dense limestones.

Horizons of algal stromatolites are prominent in the Mistaya Formation, and the individual stromatolites, whether of hemispherical, club-shaped, or loaf-like form, commonly attain large sizes. Some stromatolites of the latter form are so extensive as to be taken for thick massive beds. At a number of localities, the spaces between stromatolites formed of dense limestone are filled with biocalcarenite; elsewhere, the stromatolites are buried in thin-bedded, dense limestone with dolomite partings. Stromatolites are especially large and prominent near the top of the formation, and form the highest beds at a number of localities.

Oolite beds are present in a number of sections of the Mistaya, but are generally unimportant. Beds with algal pisolites are rare. Limestone-pebble conglomerates occur in most sections, but in unimportant amounts. Small blebs, nodules, or lenses of grey chert occur at one or more horizons in most of the sections studied.

At some localities, such as Mons Glacier and Tangle Ridge limestone is the sole component; elsewhere dolomite is the main constituent and in some sections the only one. Dolomites derived from dense limestones can generally be recognized by a very finely crystalline to dense fabric, an inherited pattern of thin bedding, and the characteristic "invasions" of altered limestone beds by altered parting material. Medium to very thick, massive dolomite beds of fine- to coarse-crystalline fabric, may in most instances be interpreted as derived from biocalcarenite.

The Mistaya Formation is strongly cliff-forming, and stands in contrast to the moderately recessive Bison Creek Formation below, and the strongly recessive, basal Ordovician shales above.

A detailed description of the type section is included in the Appendix.

Contacts

The Mistaya-Bison Creek contact is gradational and interfingering and it has been drawn at the top of the highest bed of shale or marlstone. The top of the Mistaya is marked by an abrupt change from carbonate deposition to that of greenish grey-weathering shales, orange-weathering siltstones, and minor limestones (Unit 1a of Walcott's type Mons, see p. 35). This marked change in slope and colour is one of the most prominent and easily traced contacts in the Lower Palaeozoic of the southern Rocky Mountains. At most localities studied, the contact appears to be conformable, but at Arête Mountain, on Brazeau River, there is a small erosional channel filled with quartzite at the contact.

Thickness and Distribution

The Mistaya Formation is 335 feet thick at the type section. It thickens rapidly westward to 528 feet on the northern slopes of Mount Forbes, near Glacier Lake, and thins again to 448 feet at Mount Whiterose, ten miles farther west. Because it is mappable only where the underlying Bison Creek Formation can be recognized, the Mistaya has the same distribution as the latter, and both merge northeastward into the Lynx Group. At Tangle Ridge, the most northerly section examined containing recognizable Mistaya Formation, the unit is 381 feet thick. The most easterly sections in which the formation is exposed are in the Sawback and Bourgeau (Sundance) Ranges, where it varies in thickness between 150 and 220 feet. Traced southeastward along the tectonic strike from the type locality, the formation is last seen at Nestor Peak, near Mount Assiniboine, where the thickness exceeds 250 feet (base covered).

Fauna and Age

Although trilobite fragments are fairly common in Mistaya biocalcarenites, only one collection of identifiable fossils has been recovered from the formation. This collection, from the contact with the overlying shales at Mount Murchison, was found to be indicative of the *Saukia* zone of the Trempeleauan.

Environment of Deposition

The dense limestones of the Mistaya Formation reveal little regarding the environment of origin, but their association with forms of algal stromatolites indicative of intertidal origin (Logan, *et al.*, 1964) suggests that they probably accumulated in very shallow *water*. The abundance of biocalcarenites in the formation indicates that from time to time an abundant fauna thrived in turbulent sea water of more or less normal salinity, generally unfavourable to the development of oolites. Although some intervals of the formation are silty, the rate of influx of terrigenous clastics must have been very low, and the turbidity of the water always low enough to favour carbonate-depositing mechanisms.

Remarks

The Mistaya Formation was included by Walcott (1920, p. 15) in the type Mons Formation, as unit 1b but as noted elsewhere (p. 35), the base of the Mons in other sections was commonly placed at the base of the overlying putty-coloured, greenish grey-weathering shales, equivalent to Walcott's 1a, that is, at the top of the Mistaya.

Tangle Ridge Formation (Hughes, 1955, invalid)

Restudy by the writers of the type section established by Hughes (1955, pp. 90-92) confirms that the Tangle Ridge Formation includes the Arctomys, Waterfowl, and Sullivan Formations. Fossil collections made by Hughes from the Sullivan and the top of the Waterfowl and by the writers from the Sullivan substantiate this observation. The upper boundary of the Tangle Ridge Formation, "at the abrupt upward change from green shale to putty-coloured, cherty, Ordovician limestone, "(ibid.), is in fact the base of the Lyell Formation. A little higher on the same ridge, a normal fault, down-thrown on the west side, brings beds low in the Lyell Formation against beds correlative with the upper part of the type Sarbach Formation and most of the Lyell, the Bison Creek, the Mistaya, and the lower part of the Ordovician succession are missing. Low on the west side of Tangle Ridge the fault in question, visible in Hughes (1955) Plate XVIII, juxtaposes the top of the cliff-forming Pika with the top of the cliff-forming Lyell, so that the fault is not apparent.

Because the Tangle Ridge Formation comprises three thick, mappable units, and embraces equivalents of the original Arctomys and Sullivan Formations (Walcott, 1920), it was a redundant name when erected. Its retention would cause only confusion, and the authors considered it invalid.

Lynx Group (Walcott, 1913, revised)

Mountjoy (1962, p. 13) reviewed and restricted the Lynx Formation:

> "The Lynx Formation was named by Walcott (1913, p. 334) for thin-bedded, grey and bluish grey limestone with bands of shale, with type section on Chushina Ridge between Snowbird Pass and Billings Butte, directly east of Mount Robson. The section is difficult to reach and is obscured by several tributary glaciers of the main Robson Glacier (Walcott, 1928, Plate 105, facing p. 356). The only systematic description of the Lynx Formation is Burling's description (in Walcott, 1928, pp. 366-367) of the much better exposed and accessible Rearguard (Iyatunga) Mountain section, about 2 1/2 miles along strike to the northwest. There the Lynx Formation is about 3,500 feet thick and consists of alternating units of cliff-forming carbonates and recessive-weathering argillaceous carbonates. This section will be considered as a supplemental type section. According to Burling (1923) shales at the base of the Lynx Formation exhibit shallow-water phenomena. Walcott (1928, pp. 245, 360) noted that these strata were probably representative of the Arctomys Formation. In this

paper the Lynx Formation is emended to exclude thin-bedded and silty shales and carbonates of Arctomys lithologies from the base. The contact with the overlying Lower Ordovician Chushina Formation is placed following Burling's (1955, p. 26) suggestion: '...where massive cliff-forming limestones gave way to thin-bedded limestones, shales and interformational conglomerates...'."

The Lynx Formation, so defined, is equivalent to the entire sequence, Waterfowl-Sullivan-Lyell-Bison Creek-Mistaya. Because the base of the Chushina Formation corresponds lithologically and faunally to the base of Walcott's 1a of the type Mons (see Mountjoy, 1962, pp. 15, 16), the Lynx Formation spans the entire Upper Cambrian. It is here proposed to elevate the unit to group status, not only because this will help clarify the relationship between the Glacier Lake and Mount Robson sections but also because Lynx Group will be a useful unit for small-scale mapping of the region in which the five-fold sequence of Glacier Lake is developed.

In dealing with the region in which the Sullivan Formation but not the Bison Creek Formation is recognizable, Aitken (in press) informally divided the Lynx (as Lynx Formation) into upper and lower divisions. The writers propose to formalize this usage, placing the boundary between Lower and Upper Lynx at the top of the Sullivan Formation, so that the Lower division of the Lynx Group embraces the Waterfowl and Sullivan Formations, and the Upper division embraces the Lyell, Bison Creek, and Mistaya Formations or a carbonate unit equivalent to them (see Fig. 4).

Ghost River Formation (Walcott, 1921, obsolete)

Walcott erected the Ghost River Formation, of uncertain age, in the area in which Ghost River flows through the easternmost range of the Rocky Mountains. The formation has been considered Cambrian by some authors and Devonian by others.

Aitken (1963, and 1966) reviewed the Ghost River Formation at its type section, and showed that the formation embraces part of the Pika Formation, the Arctomys, Lower Lynx, and incomplete Upper Lynx, these formations being very thin at Ghost River. He recommended that the name, Ghost River Formation, be abandoned.

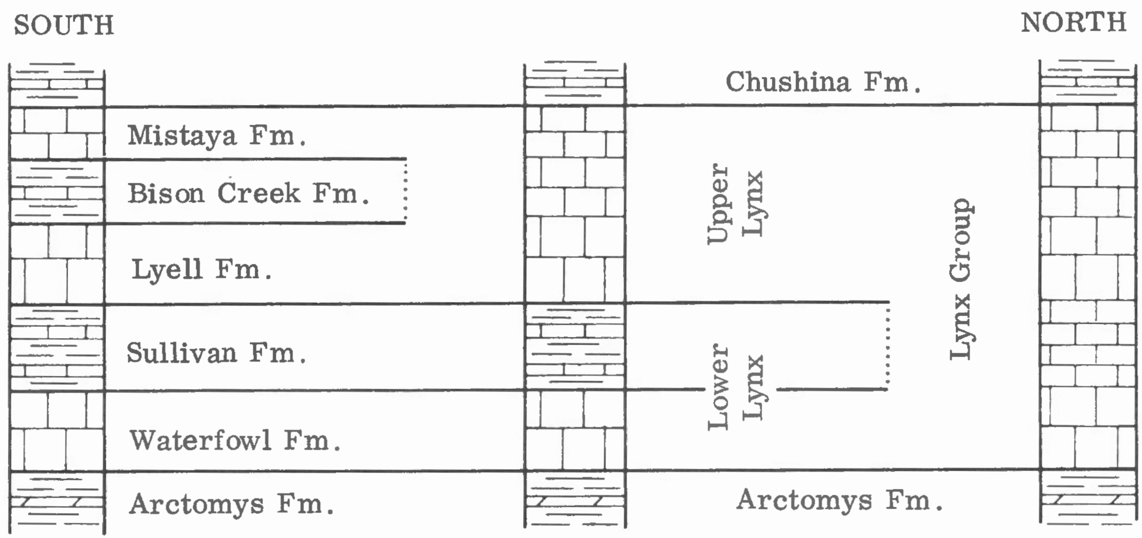

Figure 4. Stratigraphic relationships of the Lynx Group

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PLATES

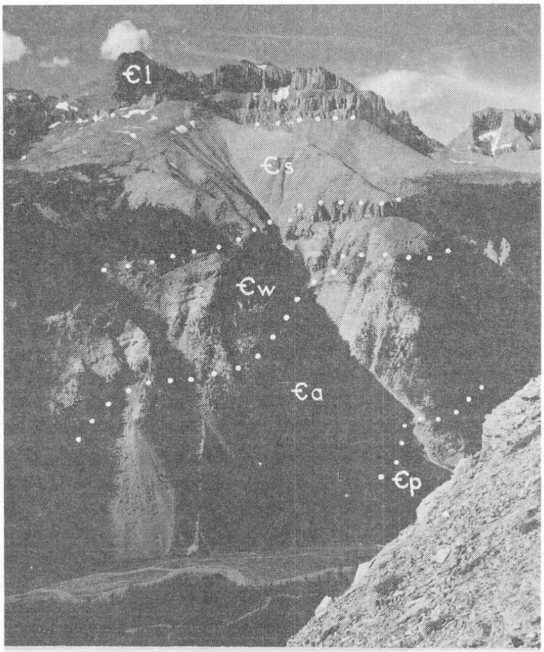


Plate I A.
Type sections of the Arctomys, Waterfowl, and Sullivan Formations, viewed from the northern slopes of Mount Forbes. Ꞓl-Lyell Fm.; Ꞓs-Sullivan Fm.; Ꞓw-Waterfowl Fm.; Ꞓa-Arctomys Fm.; Ꞓp-Pika Fm. (Aitken P61-8-6).

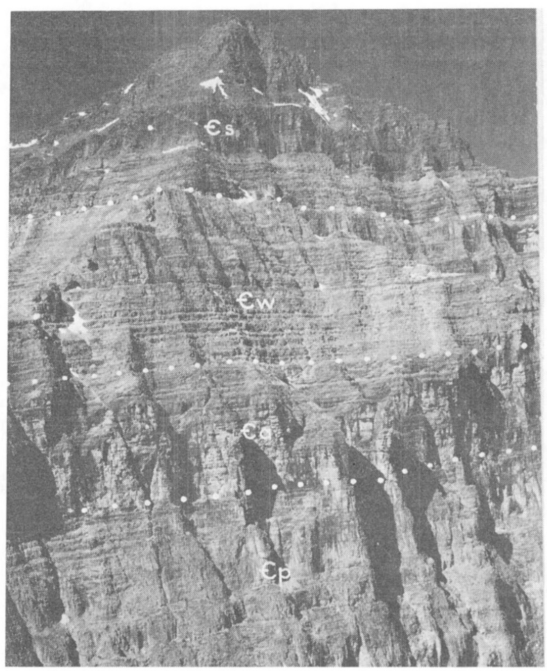
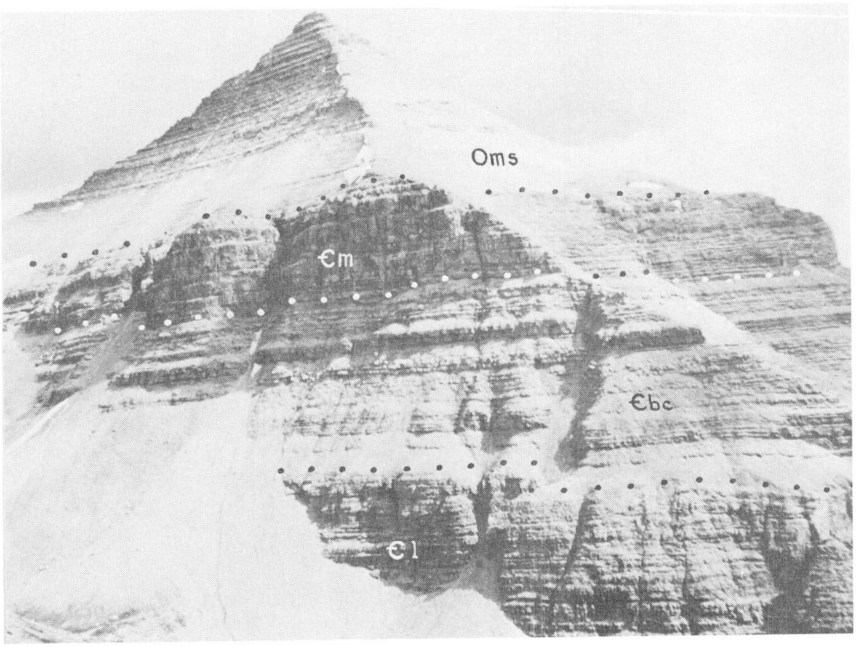


Plate I B.
Arctomys, Waterfowl, and incomplete Sullivan Formations, summit of Mt. Whymper. Note the partly cliff-forming character of the Arctomys and Sullivan, and the relatively recessive-weathering Waterfowl. Ꞓs-Sullivan Fm.; Ꞓw-Waterfowl Fm.; Ꞓa-Arctomys Fm; Ꞓp-Pika Fm. (Aitken, P62-18-7).

Plate II A. Lyell (incomplete), Bison Creek, and Mistaya Formations, overlain by Ordovician strata ("Mons-Sarbach"). View southeasterly across Bison Creek from the type section of the Bison Creek and Mistaya Formations on Mount Murchison. Oms-"Mons-Sarbach"; €m-Mistaya Fm.; €bc-Bison Creek Fm.; €l-Lyell Fm. (Greggs-13).

Plate II B. Type section of the Lyell Formation, overlain by Bison Creek, Mistaya, and "Mons-Sarbach" exposures on the northern slopes of Mt. Forbes. Oms-"Mons-Sarbach"; €m-Mistaya Fm.; €bc-Bison Creek Fm.; €l-Lyell Fm.; €s-Sullivan Fm. (Greggs-9).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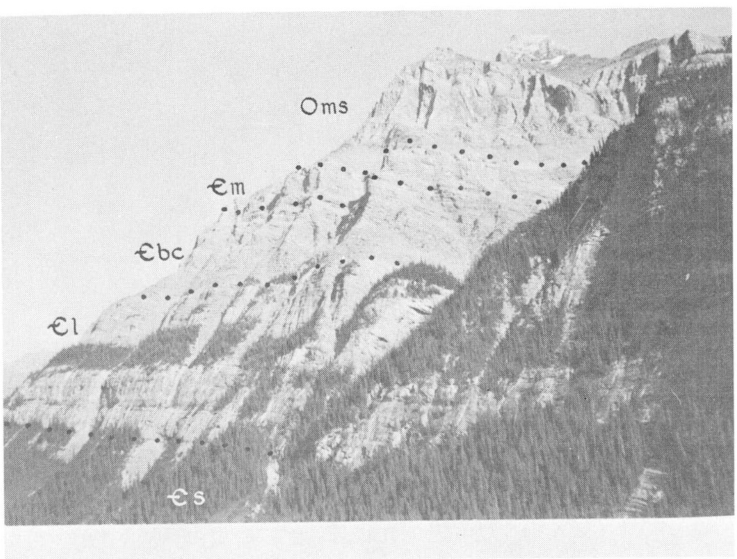
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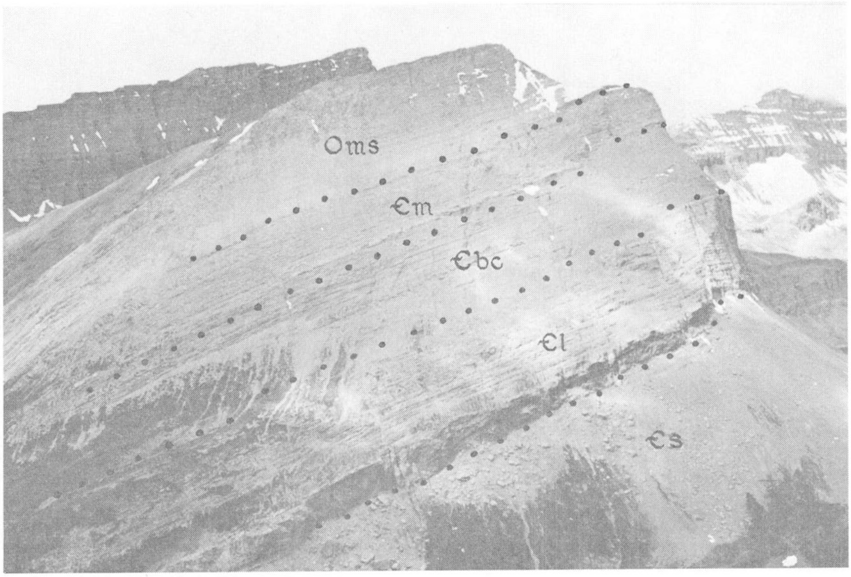
Plate III A. Sequence Sullivan (covered)-Lyell-Bison Creek-Mistaya-"Mons-Sarbach", north side of Nigel Pass. Oms-"Mons-Sarbach"; €m-Mistaya Fm.; €bc-Bison Creek Fm.; €l-Lyell Fm.; €s-Sullivan Fm. (Aitken, BW64-3-3).

Plate III B. Sequence Lyell (top only), -Bison Creek-Mistaya-"Mons-Sarbach", in the Bourgeau (Sundance) Range, eight miles south of Banff. Oms-"Mons-Sarbach"; €m-Mistaya Fm.; €bc-Bison Creek Fm.; €l-Lyell Fm. (Greggs-4).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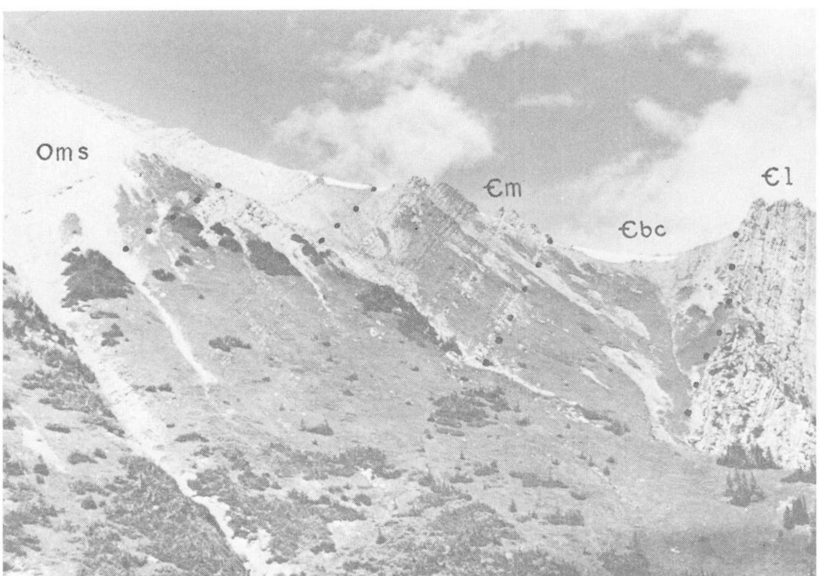
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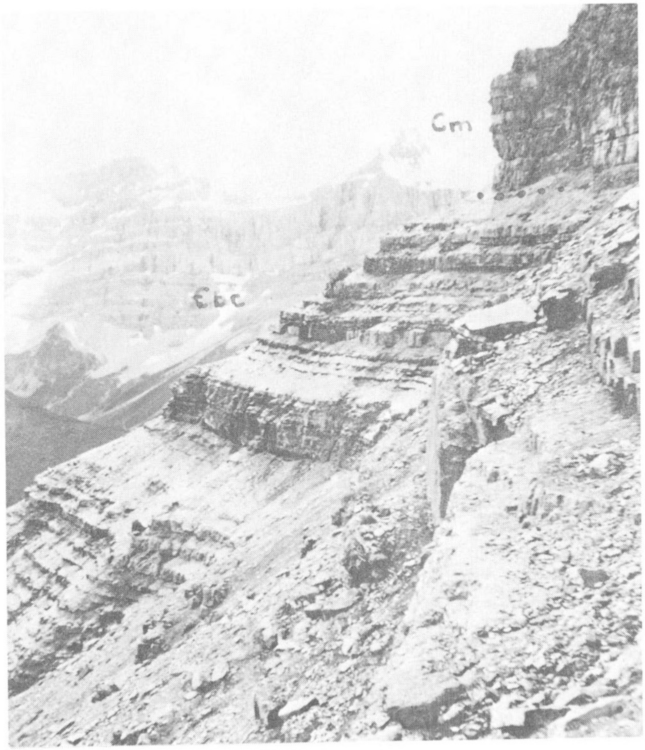
Plate IV A. Type section of the Bison Creek Formation, and lower cliffs of type section of Mistaya Formation on Mt. Murchison (Greggs-5).

Plate IV B. Bison Creek Formation at Mt. Whiterose. Note the abrupt basal and gradational upper contacts, and the massive, stromatolotic limestone forming the top of the underlying Lyell Formation. Єm-Mistaya Fm.; Єbc-Bison Єreek Fm.; Єl-Lyell Fm. (Aitken, P63-9-1).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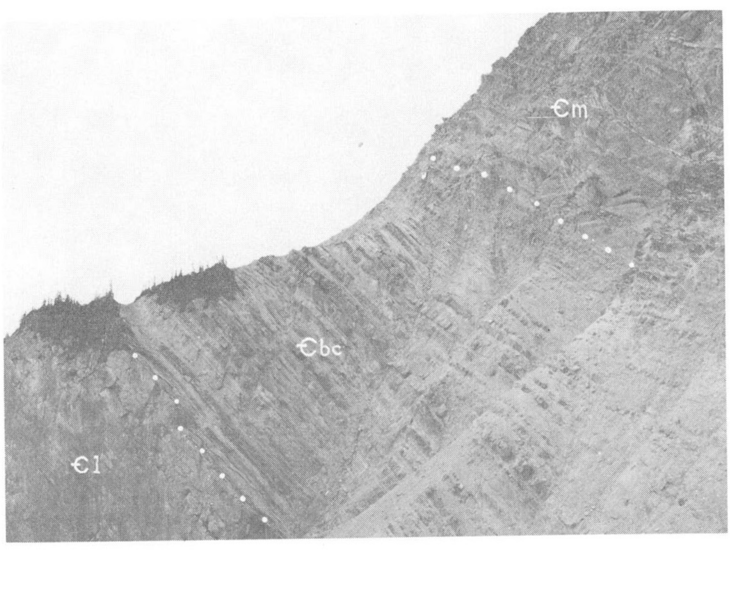
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Plate V A. Polygonal stromatolites, Arctomys Formation, Mt. Whiterose, viewed perpendicular to bedding. Hammer is eleven inches long (Aitken, P63-10-3).

Plate V B. Same bed as above, viewed parallel to bedding. Scale in inches (Aitken, P63-10-4).

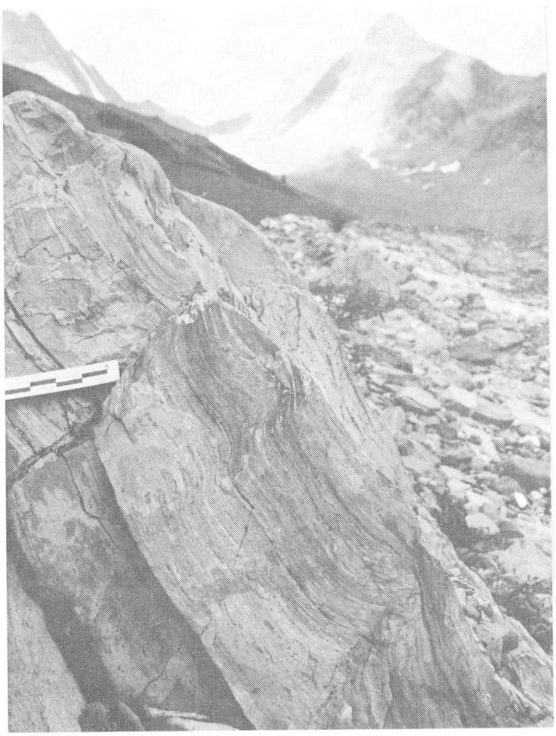


Plate VI A. A stripped bedding plane on a block of limestone from the Lyell Formation, Nigel Pass. Patches of pancake-shaped stromatolites are interspersed with patches of lithified corrugated algal mat. This surface has the aspect of intermittently emergent algal flats existing to-day (Aitken, BW64-2-16).

Plate VI B. Near view of the lower right-hand part of the block shown above. Staff is graduated in feet (Aitken BW64-2-17).

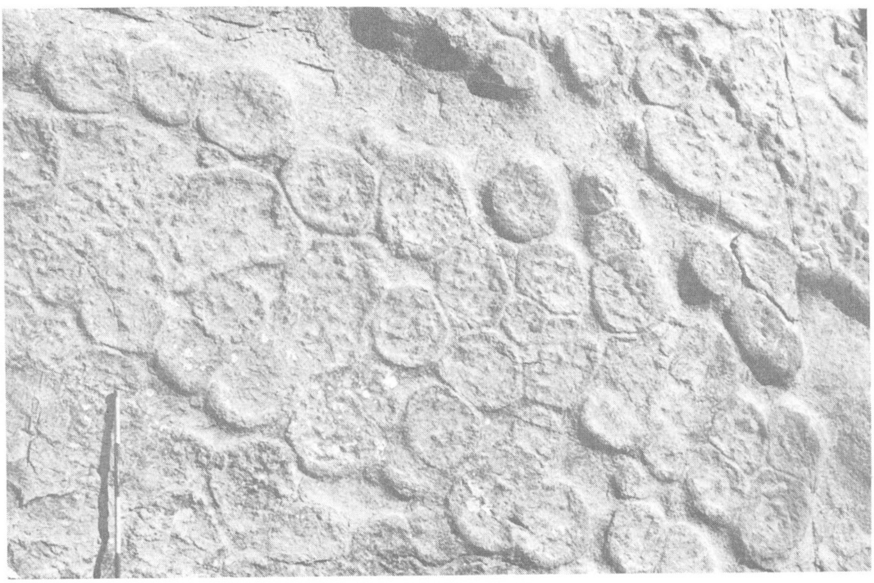
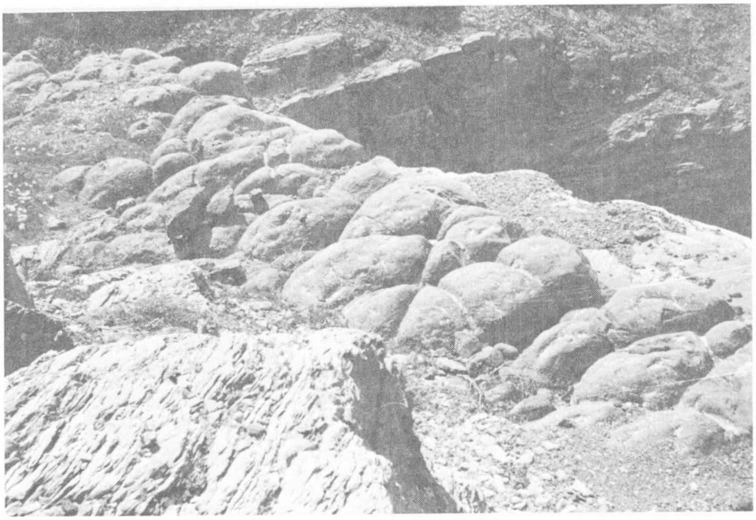


Plate VII A. Algal stromatolites, Mistaya Formation. Ice-polished outcrops below terminus of Mons Glacier (Greggs-1).

Plate VII B. Thin-bedded dense limestone with dense dolomite partings, grading to irregular limestone nodules in a dense dolomite matrix, Mistaya Formation, exposures below terminus of Mons Glacier (Aitken, P62-10-3).



APPENDICES

APPENDIX 1

TYPE SECTION OF THE ARCTOMYS FORMATION (RESTRICTED)[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds: Cliff-forming, thin-bedded limestone; minor grey dolomitic siltstone and oolite; assigned to the Waterfowl Formation.		
	Gradational contact		
37	Siltstone, grey to buff, dolomitic, laminated, with abundant calcite-filled micro-vugs. Polygonal stromatolites common. At the top, vuggy edgewise conglomerate, siltstone chips in siltstone matrix. Buff-weathering, moderately resistant.	8	771
36	Shale and mudstone, maroon to pale purple, dolomitic, silty, with 20 per cent laminae and interbeds of siltstone as above. Burrows and disturbed laminae common. Recessive.	11	763
35	Siltstone, dolomitic, and minor silty dolomite, grey, buff, laminated in part. Small calcite-filled vugs at the top. Weathers yellow-tan, resistant.	19.5	752
34	Dolomite, light and dark grey microcrystalline, very dense, silty, very siliceous, with laminations and contorted laminations.	3.5	732.5
33	Siltstone, green and pale green, dolomitic, laminated, platy, grading to shale. Yellow-weathering, recessive.	14	729
32	Covered, recessive.	9	715
31	Siltstone, very light grey, dolomitic, abundant micro-vugs, massive, buff-weathering.	1	706

[1] Measurement and description by Aitken.

Unit		Thickness (feet) Unit	Total from Base
30	Finely interlaminated siltstone, light grey, and shale, pale green. Rare burrows. Moderately recessive.	60.5	705
29	Limestone, light grey, dolomitic, microcrystalline, abundant micro-vugs. Authigenic quartz prominant in residue.	.5	644.5
28	Shale, green and pale green, dolomitic, waxy, conchoidal to platy fracture, partly silty. Minor thin beds of grey siliceous dolomite. Yellow-weathering, moderately recessive.	32	644
27	Covered, recessive.	11.5	612
26	Thinly interbedded and interlaminated shale, green, waxy, conchoidal; siltstone, deep green; and dolomite, grey, microcrystalline, very siliceous, in part nodular. Moderately resistant	24.5	600.5
25	Shale, dull green, dolomitic, conchoidal, with thin laminae of green siltstone. In the middle of the unit, 2 feet of siltstone, light grey, very calcareous, with scattered small vugs. Moderately recessive.	25	576
24	Interbedded and interlaminated shale, light green, minor purple-red, platy; and siltstone, light green, dolomitic. Moderately recessive.	29.5	551
23	Siltstone, buff, calcareous, dolomitic, porous, cross-laminated, with abundant micro-vugs. Weathers yellow-tan.	3	521.5
22	Interlaminated and interbedded siltstone, greenish grey, buff, dolomitic, and shale, maroon below, green above. Disturbed laminae and micro-breccia are common. Moderately recessive.	32.5	518.5
21	Very poorly exposed. Dolomite, light brownish grey and yellow-grey, microcrystalline, laminated, siliceous. Top of interval sheds talus of porous, calcareous, shale-chip-breccia. Recessive.	25	486

Unit		Thickness (feet) Unit	Total from Base
20	Siltstone and minor mudstone, green to light yellow-green, dolomitic, commonly laminated, contorted laminae common. Towards the top becomes very light yellow-grey, cross-laminated, with abundant micro-vugs. Polygonal stromatolites are common. Weathers yellow-tan.	41	461
19	Covered, recessive.	26	420
18	Limestone, grey calcisiltite, silty, partly interlaminated with dolomite, very light yellow-grey, microcrystalline, and partly as nodules enveloped in similar dolomite. At the base of the unit a zone of large elliptical limestone concretions. Weathers grey and tan, cliff-forming.	38	394
17	Limestone, light grey and greenish grey, very silty, grading to calcareous and dolomitic siltstone. Mainly laminated and very thin bedded with minor medium beds. Minor partings of dull green shale. Moderately cliff-forming, becoming recessive at the top.	80	356
16	Limestone, grey calcisiltite and intraclast-calcisiltite, variably dolomitized; partings of shale, yellow-green, dolomitic, conchoidal, partly with chloritic laminae, grading to shaly siltstone. Network of polygonal cracks. Moderately cliff-forming.	30.5	276
15	Limestone as above but lacking partings. Cliff-forming.	6	245.5
14	Limestone with shale partings as unit 16, partings are purple at base of unit.	8.5	239.5
13	Siltstone, very light yellow-grey, dolomitic, partly calcareous, laminated, with scattered micro-vugs. Weathers yellow-brown, moderately resistant.	14	231

Unit		Thickness (feet) Unit	Total from Base
12	Shale, purple-red, conchoidal, with blebs of green chlorite and common laminae of buff siltstone. Burrows and contorted laminae are common, grading to a micro-breccia of thin chips of shale in siltstone matrix. Uppermost foot of unit is green in colour. Recessive.	13	217
11	Interlaminated and interlensed siltstone, green to white, dolomitic, and shale, mainly light green, minor purple, silty, dolomitic, with lenses of chlorite. Polygonal stromatolites well developed. Several lenses of fine breccia consisting of chips of altered shale in a matrix of vuggy, chloritic fine-crystalline white calcite.	22	204
10	Poorly exposed, recessive. As unit 11, but purple coloration is dominant, green subordinate.	20	182
9	Shale, light greenish yellow, silty, dolomitic, laminated, platy; minor thin beds of siltstone, light green, yellow, calcareous and dolomitic, partly porous. Unit weathers yellow, recessive.	21.5	162
8	Shale, reddish purple, silty, non-fissile, with blebs of deep green chlorite, alternating with subordinate intervals of siltstone, green, dolomitic, yellow-weathering, thin-bedded. Recessive.	30	140.5
7	Interlaminated green siltstone and yellow shale, as below. Recessive.	9	110.5
6	Shale, purple-red, with green chloritic silty laminae and lenticles, and scattered thin beds of yellow siltstone. Recessive.	28.5	101.5
5	Covered, recessive.(Because of difficulties in measuring, thickness of Unit No. 5 may be in error by a factor as great as 2).	41	73

Unit		Thickness (feet) Unit	Total from Base
4	Shale, maroon and dark green, very dolomitic, silty, brecciated, recessive.	5	32
3	Siltstone, grey-buff, light green, dolomitic, laminated.	2	27
2	Shale, purple-red, blocky, with lenticles and laminae of buff siltstone, and rosettes of bright green chlorite. At the top, a 1/2-inch bed of calcareous breccia as described under unit 11. Recessive.	7	25
1	Siltstone, laminated grey and yellow-grey, dolomitic, hard massive; disseminated pyrite. Forms a cliff continuous with the uppermost cliff of the underlying formation.	18	18
	Abrupt lithologic change		
	Underlying beds: dolomite, light brownish grey, very fine equicrystalline, with relict fine particulate limestone fabric, further underlain by trilobite-pellet calcisiltite. These beds are assigned to the Pika Formation.		

APPENDIX 2

TYPE SECTION OF THE WATERFOWL FORMATION[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds: siltstone, light grey to white, calcareous, dolomitic, in very thin beds, laminae, and lenticles, separated by partings of shale, grey-brown, dolomitic, silty. Flat-pebble conglomerate of siltstone pebbles is very prominent. Burrows and disturbed laminations are widespread. Interval weathers reddish brown, recessive.		
	Abrupt lithologic change		
39	Limestone, grey, very fine- to medium-grained pelmatozoan biocalcarenite, dolomitic, silty, medium- and thick-bedded, massive, cliff-forming.	20	544
38	Siltstone, brownish grey, very calcareous, laminated, grading to silty limestone; regularly thin-bedded, grey-weathering. Horizons of large stromatolites at the base and in the middle. Moderately resistant.	12	524
37	Limestone, dense, mainly brown silty micrite below, mainly grey silty calcisiltite above, in irregular very thin beds with prominent partings of silty argillaceous dolomite. The dolomite partings "invade" and cut across the thin limestone beds. Unit is massive, cliff-forming.	40	512
36	Limestone, as above, but platy, less resistant.	5	472
35	Thinly interbedded limestone, grey calcisiltite, very silty and sandy, and siltstone and very fine sandstone, very calcareous; partings of tan-weathering laminated argillaceous dolomite, very fine equicrystalline. Massive, cliff-forming.	19.5	467

[1] Measurement and description by Aitken.

Unit		Thickness (feet) Unit	Total from Base
34	Shale, brown, dolomitic, mainly platy, pyritic, recessive.	1.5	447.5
33	Limestone, mainly grey calcisiltite, with scattered pellets, intraclasts, and trilobite bioclasts, alternately thin-bedded, flaggy, with tan-weathering argillaceous dolomite partings, and very thick-bedded, massive, with aligned argillaceous dolomite mottlings. Five feet below the top, a two-foot massive bed contains scattered oncolites. At the top, a six-inch bed of flat-pebble conglomerate. Cliff-forming.	49	446
32	Limestone, grey, mainly calcisiltite and subordinate intraclast-sparite with scattered trilobite fragments; irregular, discontinuous dolomitic laminae; mainly massive, resistant.	10.5	397
31	Limestone, intraclast-sparite with scattered trilobite fragments, very thick-bedded, massive, resistant.	17.5	386.5
30	Covered, recessive.	17	369
29	Claystone, very dolomitic, light yellow-grey with pink and black laminae, flaggy, buff-weathering, recessive.	2	352
28	Limestone, light yellow-grey calcisiltite, silty; well developed stromatolitic laminations; massive, resistant.	5	350
27	Siltstone, yellow, very dolomitic, pyritic; laminated, platy, to very thick-bedded, massive; moderately resistant.	14	345
26	Covered, recessive.	6	331
25	Siltstone as above.	2	325

Unit		Thickness (feet) Unit	Total from Base
24	Fifteen to fifty per cent nodules and lenses of limestone, grey silty calcisiltite, enveloped in dolomite, yellow-grey, very fine-crystalline. Unit is non-bedded, massive, cliff-forming.	17.5	323
23	Covered, recessive.	30.5	305.5
22	Dolomite, yellow-grey, very fine-crystalline, silty, variably argillaceous, grading to claystone, dolomitic; blocky at the base, partly platy above. Weathers buff with silty laminae in relief. Near the top, bedding planes are strewn with flat pebbles. Moderately resistant.	15	275
21	Limestone, brown dolomitic silty micrite, with laminae and partings of dolomite, buff, very fine-crystalline, very silty; shaly-platy at the base, grading upward to medium-bedded, massive. Near the top, minor dolomitized pellet-sparite limestone.	59	260
20	Dolomite, light grey-brown, very finely crystalline, slightly calcareous, very silty (40%), laminated, massive, orange-weathering.	2	201
19	Limestone, thin-bedded, silty micrite with dolomite partings, as above; at the base, one 2-foot massive bed of the same. Resistant.	10	199
18	Limestone, brown micrite, dolomitic, in thin beds made discontinuous by "invasion" of the buff very fine-crystalline dolomite which forms prominent partings; massive, cliff-forming.	34.5	189
17	Shale, grey-brown, slightly calcareous, conchoidal fracture, recessive.	2	154.5
16	Dolomite, grey-brown, microcrystalline, very dense, very siliceous, laminated, massive, blocky fracture, orange-weathering; moderately resistant.	4	152.5

Unit		Thickness (feet) Unit	Total from Base
15	Dolomite, grey, dense, argillaceous, shaly, very pyritic, orange-weathering, with scattered nodules of grey limestone and rare one-inch lenses of flat pebble conglomerate; moderately resistant.	7.5	148.5
14	Covered, recessive.	15	141
13	Interlaminated limestone, brown dolomitic micrite, and dolomite, grey, microcrystalline; rare laminae of siltstone, light brown, very calcareous; resistant.	24	126
12	Siltstone, and sandstone, very fine-grained, buff, calcareous and dolomitic, cross-laminated, resistant.	5	102
11	Covered, recessive.	12.5	97
10	Siltstone, grey-buff, dolomitic, massive.	1.5	84.5
9	Limestone, brown dolomitic micrite, in laminated thin beds with thin partings of argillaceous dolomite. Discontinuous thin beds of flat-pebble conglomerate are common. Cliff-forming.	7	83
8	Limestone, brown dolomitic micrite, very thin bedded, shaly at the base, with prominent partings of dolomite, buff, microcrystalline, argillaceous, silty, making 50 per cent of the unit. One foot above the base a one-foot bed of flat-pebble conglomerate. Cliff-forming.	5	76
7	Dolomite, grey, microcrystalline, argillaceous, laminated, buff-weathering, non-resistant.	4	71
6	Limestone grey, dense, mainly calcisiltite, laminated, thin-bedded, massive, partly silty, partly sandy. Two feet below the top, a one-foot zone of well developed stromatolitic laminations in calcisiltite with dolomite laminae. Cliff-forming.	14	67
5	Covered, recessive.	6	53

Unit		Thickness (feet) Unit	Total from Base
4	Dolomite, light buff, very fine and microcrystalline, very silty, partly calcareous; laminated, massive, buff-weathering. Scattered thin lenticles of crystalline quartz oriented parallel to the bedding. Resistant.	4	47
3	Limestone, brown dolomitic micrite and grey dolomitic calcisiltite, in thin lenticular and nodular beds with prominent partings of dolomite, grey, microcrystalline, partly calcareous, very finely laminated. Three feet above the base a 1 1/2-foot bed of fine oolite, very dolomitic, with traces of trilobite fragments. Cliff-forming.	36	43
2	Siltstone, grey, largely dolomitic, partly silicified, laminated and cross-laminated, buff- to orange-weathering, resistant.	2.5	7
1	Dense limestone with dolomite partings as above, resistant.	4.5	4.5
	Gradational contact		
	Underlying beds: siltstone, overlying maroon shale and mudstone, assigned to the Arctomys Formation.		

APPENDIX 3

TYPE SECTION OF THE SULLIVAN FORMATION (REVISED)[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds: limestone, grey oolite, very thick-bedded, massive, strongly cliff-forming, assigned to the Lyell Formation.		
43	Shale as below, recessive.	3	1391.5
42	Limestone, medium and coarse oolite, dolomitic, in very thick massive beds separated by very minor beds of shale, grey, tan-weathering.	26	1388.5
41	Shale, light greenish grey to olive, calcareous, splintery, with abundant laminae and lenticles of calcisiltite. In the middle, a strongly lenticular 4-to 8-inch bed of conglomeratic calcarenite.	18	1362.5
40	Limestone, grey calcisiltite, dolomitic, very silty, siliceous, in very thin, lenticular, laminated and cross-laminated beds, with partings of shale, light buff, very calcareous. Fifteen per cent 2- to 4-inch beds of oolite as below and flat-pebble conglomerate. Slightly resistant.	28	1344.5
39	Limestone, oolite as below, a single massive bed.	3	1316.5
38	Limestone, pale green to greenish grey calcisiltite, in thin platy beds with partings of shale, yellow, calcareous, fissile. Ten per cent limestone, grey dolomitic oolite as below, in beds 6 inches and less thick. Weakly resistant.	17.5	1313.5
37	Sixty per cent shale, greyish olive, minor yellow-buff, calcareous, fissile, tan-weathering, mostly		

[1] Measurement and description by Aitken.

Unit		Thickness (feet) Unit	Total from Base
	with nodules and thin lenticular beds of limestone, light grey and greenish grey calcisiltite, sparsely fossiliferous, silty, very siliceous, partly argillaceous, grading to calcareous mudstone. Forty per cent limestone, grey medium oolite, variably dolomitic, partly conglomeratic, in beds 6 inches to 4 feet thick. Unit forms a series of ledges.	61	1296
36	Shale as below, partly with limestone nodules as below. Contains 3 widely spaced beds of conglomeratic oolite as below, one foot, two feet and three inches in thickness. Recessive.	34.5	1235
35	Limestone, medium and coarse oolite, conglomeratic, siliceous, in two massive resistant beds separated by 6 inches of shale as below.	3.5	1200.5
34	Shale, yellow to khaki, minor pale green, very calcareous, fissile, commonly with scattered trilobite remains, locally glauconitic, five per cent containing nodules and lenticular thin beds of limestone, grey silty calcisiltite, as below. Ten per cent resistant beds of limestone, oolitic biocalcarenite as below, in widely spaced beds 6 inches and less in thickness. Recessive.	53	1197
33	Shale, as below, with three 18- to 24-inch massive beds of limestone, medium oolite, very dolomitic.	11	1144
32	Ninety per cent shale, yellow-grey, slightly calcareous, fissile, to conchoidal, olive-weathering. Ten per cent limestone, medium-grained pelmatozoan oolite, and oolitic pelmatozoan biocalcarenite, commonly siliceous, in massive, resistant, 6-inch to 2-foot beds. Limestone beds are distinctly lenticular, and have mammillate tops.	35.5	1133

Unit		Thickness (feet) Unit	Total from Base
31	Shale, as below, with 5 per cent limestone, fine-grained trilobite-pelmatozoan biocalcarenite, partly conglomeratic, in widely spaced 1- to 4-inch beds. Recessive.	40	1097.5
30	Shale, light yellow-grey, variably calcareous, weakly fissile to conchoidal. Rare beds contain up to ten per cent of sand-sized pelmatozoan and trilobite bioclasts.	51.5	1057.5
29	Eighty per cent mudstone, yellow-grey, calcareous. Twenty per cent shale, khaki, calcareous, weakly fissile, with abundant lenticular thin beds of limestone, light grey, microcrystalline or calcisiltite, very argillaceous, siliceous. Very rare 1- to 3-inch beds of biocalcarenite as below.	54	1006
28	Mudstone, yellow-grey, calcareous, non-bedded, non-fissile, weathers olive and tan.	29.5	952
27	Limestone, grey conglomerate, rounded pebbles of limestone in a matrix of biocalcarenite.	1.5	922.5
26	Shale, as below, recessive.	15	921
25	Limestone, blocky angular pebbles of laminated calcisiltite in a sparite matrix with scattered pockets of biocalcarenite; pyritic. This bed terminates to the west in a stromatolite.	1	906
24	Shale as below, recessive.	9	905
23	Shale, as below, with rare glauconitic laminae and rare glauconite-replaced trilobite remains. At top and base, 3-inch beds of oolite as below.	2	896
22	Mudstone, yellow-grey calcareous, non-fissile, tan-weathering, moderately recessive.	20.5	894

Unit		Thickness (feet) Unit	Total from Base
21	Limestone, medium oolite, with scattered rounded flat pebbles.	.5	873.5
20	Shale, weakly fissile, and similar non-fissile mudstone, yellow-grey, calcareous, mostly containing about 40 per cent nodules and thin lenticular beds of limestone, light grey calcisiltite, siliceous, very argillaceous, with scattered very fine bioclastic debris.	55	873
19	Shale, as below, 30 per cent of which contains interbeds of dense limestone as below. Three-inch to 1-foot beds of limestone, mainly trilobite-pelmatozoan-biocalcarenite and minor conglomerate, occur about every 20 feet. Trilobites are replaced by glauconite at the tops of certain beds. Recessive.	134	818
18	Ninety per cent shale, brownish grey to olive-khaki, calcareous, fissile, half of which is interbedded with very thin beds of limestone, light grey silty calcisiltite, very siliceous. Ten per cent limestone, grey oolite and trilobite-pelmatozoan-biocalcarenite, partly oolitic, in medium beds commonly topped by small stromatolites.	83.5	684
17	Limestone, oolite as below, partly conglomeratic.	3	600.5
16	Shale, brownish grey, calcareous, fissile, olive-weathering, recessive.	13.5	597.5
15	Limestone, grey, fine and medium oolite, not well sorted, very dolomitic, with abundant coarse trilobite fragments and many orange-weathering lenticles of dolomite, yellowish grey, microcrystalline. GSC Loc. No. 55332.	4	584
14	Shale as below, the uppermost 4 feet of which contain 50 per cent thin beds and nodules of limestone, grey calcisiltite, siliceous. In the middle		

Unit		Thickness (feet) Unit	Total from Base
	of the unit a 1-foot bed of limestone, as below.	22	580
13	Seventy per cent shale, yellow-grey to green, calcareous, fissile and conchoidal; certain intervals contain up to 25 per cent lenticular thin beds and nodules of dense lime-stone as above. Thirty per cent limestone, 1- to 2-foot beds of pelmatozoan-trilobite biocalcarenite and fossiliferous oolite, dolomitic, commonly silty, occurring at 3- to 4-foot intervals. Layers of flat-pebble conglomerate common in limestone beds. Uppermost bed is capped with subspherical stromatolites, one foot in diameter, with brain-like outer surface. A ledgy unit.	88	558
12	Shale, olive to khaki, calcareous, partly silty, fissile to conchoidal, olive-tan weathering. Six- to 18-inch beds of limestone, grey siliceous oolite and grey oolitic pelmatozoan-trilobite biocalcarenite, occur every 4 to 10 feet. Trilobite remains are locally replaced by glauconite. Locally, limestone beds are patchily silicified. Fifteen feet below the top, a 4-inch bed of flat-pebble conglomerate with biocalcarenite matrix. Unit is recessive.	96	470
11	Shale and non-fissile mudstone, yellow-green, calcareous, with widespread trilobite fragments, locally glauconitized. One-foot beds of limestone, pale green argillaceous calcisiltite, occur every 10 to 20 feet. Fifteen feet below the top, a massive 8-inch bed of biocalcarenite as above.	123	374
10	Shale, greyish green, calcareous, platy, olive-brown weathering. Six- to 12-inch beds of limestone, oolite and biocalcarenite as above, occur every 5 to 10 feet, associated with beds of similar thickness of light green calcisiltite. Rare flat-pebble		

Unit		Thickness (feet) Unit	Total from Base
	conglomerate and disturbed beds. From the base, GSC Loc. No. 55334. Moderately recessive.	63	251
9	Shale as below, recessive.	32	188
8	Shale, greyish green, calcareous, platy, silty, olive-brown weathering. Six- to 12-inch beds of oolite, silty, siliceous, are spaced at about 10-foot invervals. Certain bedding planes in the shales are littered with shale chips and fossil fragments. Recessive.	21	156
7	Sixty per cent siltstone, very calcareous, thin-bedded, as below. Forty per cent shale, light yellow-brown below, green above, calcareous, silty, olive-brown weathering. The shale contains numerous inarticulate brachiopods in a zone 15 to 20 feet below the top. Minor, widely spaced 6- to 8-inch lenticular beds of pelmatozoan-trilobite-biocalcarenite, partly oolitic, and subordinate brachiopod biosparite.	39	135
6	Siltstone, very calcareous, thin-bedded as below. Calcareous shale as above appears first as partings between siltstone beds and increases in importance upwards. Minor limestone appears in widely spaced 2- to 8-inch beds of pelmatozoan biocalcarenite. Moderately recessive.	40	96
5	Shale, light yellow-brown, calcareous, weakly fissile, recessive.	4	56
4	Siltstone, grey, very calcareous, grading to silty limestone (calcisiltite), very thin-to medium-bedded, brown weathering. Six feet below the top, a 6-inch bed of pelmatozoan biocalcarenite. Moderately recessive.	15.5	52
3	Limestone, grey pelmatozoan-trilobite biocalcarenite, dolomitic; a single massive bed.	1.5	36.5

Unit		Thickness (feet) Unit	Total from Base
2	Shale, light yellow-brown, dolomitic, silty, weakly fissile, recessive.	5	35
1	Siltstone, light grey to white, calcareous, dolomitic, in very thin flaggy beds, laminae, and lenticles, separated by partings of shale, grey-brown, dolomitic, silty. Flat-pebble conglomerate with pebbles of siltstone and silty limestone is very prominent. Burrows and disturbed laminations are widespread. Interval weathers reddish brown, moderately recessive.	30	30
	Abrupt lithologic change		
	Underlying beds: limestone, grey bio-calcarenite, medium and thick-bedded, massive, forming the upper part of a continuous carbonate cliff. Assigned to the Waterfowl Formation.		

APPENDIX 4

TYPE SECTION OF THE LYELL FORMATION (REVISED)[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds: a twenty-foot, covered, recessive interval overlain by argillaceous limestones and shales, assigned to the Bison Creek Formation.		
	The units described below are very resistant. Because the middle of the formation is slightly less resistant than its top and base, the topographic expression of the formation is that of two extremely steep cliffs separated by a steeply sloping ledge.		
14	Limestone, dense, dolomitic, alternately brown micrite and grey calcisiltite, with subordinate pellet-sparite and intraclast-sparite, in nodular to wavy-laminated very thin beds with thin partings and mottlings of tan-weathering dolomite. Seventeen feet above the base, a bed of hemispherical stromatolites, displaying one foot of relief. A zone 50 to 53 feet above the base contains much flat pebble conglomerate.	170	1130
13	Limestone, brown micrite, silty, very strongly mottled by argillaceous dolomite, very massive. Bulbous structures at top of unit are doubtful stromatolites.	7.5	960
12	Limestone, brown micrite, argillaceous, at the base with fine wavy laminae of dolomite, grading upward to distinct thin nodular beds with partings of tan-weathering argillaceous dolomite, which commonly "invade" the limestone beds along cracks; very rare blebs of dark grey chert.	56.5	952.5
11	Limestone, grey, fine-grained pelmatozoan biocalcarenite, very sandy (fine quartz sand), cross-laminated, thin- to thick-bedded.	16	896

[1] Measurement and description by Aitken.

Unit		Thickness (feet) Unit	Total from Base
10	Limestone, brown micrite, very argillaceous with abundant lenses and nodules of dark grey chert.	5.5	880
9	Limestone, dense, mainly brown micrite, subordinate grey calcisiltite, argillaceous to very argillaceous, commonly silty, grading locally to calcareous siltstone; very thin-bedded to thin-nodular bedded, platy to blocky fracture. Widely spaced sandy beds as below and very rare beds of sandstone, fine-grained, very calcareous. Rare, very thin beds of lithocalcarenite and pebble conglomerate, commonly sandy. Unit is locally dolomitized.	259.5	874.5
8	Limestone, brown, mainly micrite, largely very silty, grading to calcareous siltstone, very thin-bedded with tan-weathering dolomite partings, and commonly nodular due to "invasion" of thin beds by parting material. A few widely spaced, 4- to 12-inch beds are sandy to very sandy (poorly sorted fine and medium sand). Rare chert nodules occur throughout the interval. Certain beds are locally dolomitized.	59	615
7	Limestone, grey, dolomitic, commonly silty to very silty, rarely slightly sandy, largely fine calcarenite and intraclast-pellet-sparite. Rare beds of clotted calcisiltite (algal (?)) as below. Rare thin beds of fine pebble conglomerate. Unit is locally dolomitized, especially at the top.	181	556
6	Limestone, largely thick massive beds of grey clotted calcisiltite, probably of algal origin (blue-green algae); quartz silt and terminated quartz prisms common. Near the base, several thick massive beds of oolite and oolitic pelmatozoan biocalcarenite.	60	375
5	Limestone, grey clotted calcisiltite in nodular thin beds separated by argillaceous partings. Widespread quartz silt and terminated quartz prisms.	55	315

Unit		Thickness (feet) Unit	Total from Base
4	Limestone, grey, medium-grained pelmatozoan biocalcarenite, partly oolitic, in thick, massive beds.	47	260
3	Limestone, largely grey clotted calcisiltite with scattered pellets, intraclasts, and trilobite fragments, in nodular thin beds separated by argillaceous partings; probably of algal origin (blue-green algae). Widely spaced thick, massive beds of pelmatozoan-trilobite calcarenite, medium-grained, become increasingly important upward.	113	213
2	Limestone, grey clotted calcisiltite, probably of algal origin, very massive. Minor calcarenite as below, dolomitized.	60	100
1	Limestone, grey oolite and oolitic biocalcarenite, fine- and medium-grained, thick-bedded, massive, variably dolomitized.	40	40
	Planar depositional contact		
	Underlying bed: Uppermost, 3-foot shale bed of Sullivan Formation.		

APPENDIX 5

TYPE SECTION OF THE BISON CREEK FORMATION[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds (Mistaya Formation): Limestone, dark grey-green to black, nearly lithographic, silty, thin- to thick-bedded; weathers pale yellow-grey with yellow-brown patches. Forms ledges and cliffs.		
14	Limestone: fine-grained, dark grey-green, argillaceous; very thinly bedded, recessive; blocky weathering. Weathers pale grey.	2	629
13	Limestone and shale: limestone pebble conglomerate, beds 2 feet thick, massive, with soft, grey-green shale interbeds; limestone fine-grained, grey to grey-green. At 619 feet to 624 feet, some beds with well developed ripple-marks. Unit generally recessive except for the limestone beds.	41	627
12	Limestone: dark grey-black, micro-crystalline to lithographic, hard, dense, in beds from 2 feet to 4 feet thick; cliff-forming; weathers pale grey.	22	586
11	Covered interval: talus of limestone and shale fragments.	4	564
10	Limestone: fine-grained, dark grey-green to dark grey-black; fine-crystalline to microcrystalline; composed of several series of thick-bedded limestones, from 2 feet to 4 feet, and very thin-bedded limestones, the thinner bedded lithology predominating. The thicker beds are resistant, ledge-forming; the thinner bedded units are recessive. The whole unit weathers pale grey.	28	560
9	Limestone: a 4-foot bed of limestone pebble conglomerate, mixed with some thin beds of nodular limestone.	4	532

[1] Measurement and description by Greggs.

Unit		Thickness (feet) Unit	Total from Base
8	Limestone: fine-grained, dark grey-green to grey-black; fine-crystalline; a series of massive, thick-bedded limestone, and thin-bedded recessive limestone; weathers pale grey.	8	528
7	Covered interval: may possibly represent grey-green shales or very argillaceous limestones.	18	520
6	Limestone: dark grey to black, lithographic, hard, dense; in beds from 1 inch to 4 inches, with silty laminae; wavy, irregular bedding planes; limestone beds tend to have a nodular weathering habit; weathers medium grey, cliff-forming. From 459 feet to 462 feet, a black, fine-grained, limestone, bearing abundant large, black, resinous chert nodules. Trilobites collected at 482 feet.	52	502
5	Limestone: an alternation of thick-bedded, resistant, dark grey limestone beds, and thin-bedded, recessive, dark grey-green limestones. Limestones, very fine-grained, fine-crystalline, weather pale grey.	50	450
4	Limestone: very fine-crystalline, lithographic, dark grey, dense; one massive bed with algal stromatolites developed on upper surface. Unit very resistant, ledge-forming, weathers medium grey.	4	400
3	Limestone: dark grey to black; lithographic hard, dense; silty laminae common, beds 1 inch to 4 inches thick with undulating, irregular bedding planes; weathering tends to produce a nodular appearance; weathers medium grey; cliff-forming.	13	396
2	Limestones and calcareous mudstones: this very thick unit was measured in detail, and the thickness of each limestone unit and each calcareous mudstone unit was recorded. In general, the upper 160 foot-170 foot of the unit shows equal development of these two lithologies; the		

Unit		Thickness (feet) Unit	Total from Base
	lower 120 feet is composed of twice as much mudstone as limestone. The alternation of the two lithologies is not cyclic or rhythmic, but quite random in so far as thicknesses of each lithologic type are concerned. The limestones are fine-grained to lithographic, with a few finely crystalline patches, dense, dark brown-black, argillaceous; in massive, very resistant beds; ledge or cliff-forming, developing conspicuous ledges along mountainside; weather medium grey. Generally abrupt contacts above and below with the highly calcareous mudstones. Thicknesses of thick-bedded limestone units vary from 2 feet to 11 feet. Mudstones are highly calcareous, fine-grained to lithographic; few patches of finely crystalline limestone; dark grey, hard, dense; with minor thin lenses of bioclastic limestones containing recognizable fossils; very thin-bedded, generally less than 1 inch, with thin soft shaly partings; very recessive units, rarely well-exposed; form talus slopes along mountainside between the more resistant ledges of the thicker bedded limestones; mudstones weather pale to medium grey. Calcareous mudstone units vary in thickness, from 2 feet to 21 feet. At 84 feet above base of unit, a thin horizon of algal stromatolites. At 157 feet above base of unit, a collection of fossils was made, that show the presence of the _Ptychaspis-Prosaukia_ zone. At 174 feet, above base of unit, another well-developed bed of algal stromatolites.	283	383
1	Mudstones: highly calcareous; fine-grained, dark grey, hard, dense; very few, minor thin beds of bioclastic limestone near the base of unit; bedding less		

Unit		Thickness (feet) Unit	Total from Base
	than 1 inch thick; unit very recessive; weathers pale grey. At 62 feet above base of unit, a fossil collection records the presence of the Elvinia zone. At 70 feet above base of unit, another fossil collection was made from the Conaspis zone.	100	100
	Abrupt, planar contact		
	Underlying beds (Lyell Formation): dolomite, dark grey to black, fine-crystalline to cryptocrystalline, hard, dense; a few silty laminae; thick to medium bedded; weathers pale grey to medium grey-brown. Very resistant, strongly cliff-forming unit.		

APPENDIX 6

TYPE SECTION OF THE MISTAYA FORMATION[1]

Unit		Thickness (feet) Unit	Total from Base
	Overlying beds ("Mons Formation"): shale, dark grey-green to medium grey-brown, soft, friable, platy to splintery, calcareous. Limestone interbeds in lower 30 feet. Recessive-weathering, poorly exposed; forms silvery putty-coloured talus slope.		
5	Limestone: fine-crystalline, medium grey-brown, with silty laminae; hard, dense; weathers yellow-brown and grey; upper 18 feet of unit is cliff-forming; one 8 foot bed at top of unit, remainder in 6-inch to 2-foot beds. Algal stromatolite horizon at 296 feet. From 296 feet to 317 feet, a thin-bedded, recessive limestone unit.	39	335
4	Dolomite: fine-grained, rare calcite blebs, medium grey-brown, silty; massive, weathers blocky, poorly bedded at a few horizons; cliff-forming; weathers dark yellow-brown with a grey cast. A black chert horizon at 95 feet. At 105 feet a second black chert horizon; chert in long, thin nodules, 1/2 inch wide by 1 foot long. At 145 feet, top of 2 foot to 3 foot bed of algal stromatolites; all 'heads' about 1 foot to 2 feet diameter. At 170 feet, bedding changes to 8 inches to 1 1/2-inch beds; forms ledges; no other changes from upper portion of unit. At 210 feet, bedding improves, more pronounced, bedded every 1 inch to 3 inches, but still massive-weathering, cliff-forming.	209	276

[1] Measurement and description by Greggs.

Unit		Thickness (feet) Unit	Total from Base
3	Limestone: fine-grained, earthy texture, argillaceous; dark grey-black, tends to be nodular with irregular bedding planes; bedded every 3/4 inch to 1 inch, recessive, weathers pale grey.	12	87
2	Dolomite: fine-grained, dark grey to black, very abundant black, argillaceous, fine stringers and laminae; one massive bed, weathers pale yellow-brown with pale grey, silty streaks, ledge-forming.	4	75
1	Limestone: dark grey-green, to black; nearly lithographic; silty; in beds from 3 inches to 4 feet, thickness of beds quite variable; ledge- to cliff-forming; weathers pale yellow-grey with yellow-brown patches. From 34 feet to 35 feet, a shale interbed.	71	71
	Underlying beds (Bison Creek Formation): interbedded limestone and shale, grey-green, soft, recessive-weathering.		