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LITHOSTRATIGRAPHY OF THE LOWER CRETACEOUS COAL-BEARING SEQUENCE, FOOTHILLS OF ALBERTA

J. ROSS McLEAN

Canada

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LITHOSTRATIGRAPHY OF THE LOWER CRETACEOUS COAL-BEARING SEQUENCE, FOOTHILLS OF ALBERTA

Abstract

The Lower Cretaceous sequence in the Foothills of Alberta consists of a complex interfingering of mudstone, siltstone and sandstone with subordinate coal, conglomerate, limestone and bentonite. Lithofacies changes along the Foothills necessitate changes in nomenclature.

The Blairmore Group in the southern Foothills of Alberta is divided into four formations in ascending order: Cadomin, Gladstone, Beaver Mines and Ma Butte. The Gladstone Formation is modified slightly from its original definition by excluding the basal conglomerate and sandstone unit to which the name Cadomin Formation is applied. Ma Butte is a new name, introduced for the sequence of beds between the Beaver Mines and Crowsnest Formations. Use of the name Mill Creek, formerly used to encompass the Ma Butte and Crowsnest sequence, is discontinued. The name Crowsnest is retained for the prominent volcanogenic unit overlying the Ma Butte Formation. The Crowsnest Formation is not recognized north of the Oldman River and the Ma Butte is absent north of Clearwater River. The Beaver Mines Formation is recognized as far north as Ram River although between Waiparous Creek and Ram River, its lower beds are atypical of the formation and are an unmappable southern extension of the Malcolm Creek Formation.

The nomenclature for the Lower Cretaceous succession in the central and northern Foothills of Alberta is substantially modified. The proposed succession, from the base upward, is: Cadomin Formation, Gladstone Formation, Malcolm Creek Formation including Moosebar, Torrens and Grande Cache Members, and Mountain Park Formation. All of these formations are included in the Blairmore Group, the use of which is extended to the central and northern Alberta Foothills to emphasize the elements of similarity to the southern Alberta Foothills section. Use of the name Luscar is discontinued as it has not been used consistently and because the interval to which it was originally applied can be usefully divided into two distinct formations. The name Gladstone is applicable from the type area to near the Smoky River, north of which the name Gething is preferable. The Malcolm Creek and Mountain Park Formations are recognized to the Alberta-British Columbia border. North of this, the same interval is divided into the Moosebar, Gates, Hulcross and Boulder Creek Formations.

Coal seams of current economic interest south of Smoky River are confined to the Grande Cache Member of the Malcolm Creek Formation. They have been observed in the Alberta Foothills everywhere north of Waiparous Creek. One to six major seams occur in the member with thicknesses up to about 11 m. Thick coal seams are also present in the Gething Formation along the Smoky River and to the north.

Résumé

La succession du Crétacé inférieur dans les Foothills en Alberta est constituée d'une interdigitation complexe de mudstone, de siltstone et de grès avec du charbon, du conglomérat, du calcaire et de la bentonite subordonnés. Le lithofaciès change le long des Foothills, nécessitant des modifications dans la nomenclature.

Le groupe de Blairmore dans le sud des Foothills de l'Alberta se répartit en quatre formations qui sont, par ordre d'importance; les formations de: Cadomin, Gladstone, Beaver Mines et Ma Butte. La formation de Gladstone a été modifée légèrement dans sa définition initiale, par l'exclusion du conglomérat de base et de l'unité de grès qui s'appellent maintenant la formation de Cadomin. Ma Butte est un nouveau nom donné à la succession de couches situées entre les formations de Beaver Mines et de Ma Butte. Le nom de Mill Creek, anciennement réservé à la succession de Ma Butte et de Crowsnest, n'est plus en usage. Le nom de Crowsnest désigne l'unité volcanogénique dominante qui repose sur la formation de Ma Butte. La formation de Crowsnest s'arrête au nord de la rivière Oldman, et celle de Ma Butte, au nord de la rivière Clearwater. La formation de Beaver Mines s'étend jusqu'à la rivière Ram au nord, même si, entre le ruisseau Walparous et la rivière Ram, ses couches inférieures sont atypiques de la formation et constituent une extension de la formation de Malcolm Creek vers le sud, qu'il est impossible de cartographier.

La nomenclature de la succession du Crétacé inférieur dans le centre et le nord des Foothills de l'Alberta est sensiblement modifiée. La succession proposée est, de la base au sommet, la suivante: formation de Cadomin, formation de Gladstone, formation de Malcolm Creek, y compris les nivaux de Moosebar, de Torrens et de Grande Cache, et formation de Mountain Park. Toutes ces formations font partie du groupe de Blairmore, qui englobe le centre et le nord des Foorhills de l'Alberta de façon à faire ressortir les éléments de similarité avec la partie sud des Foorhills de l'Alberta. Le nom de Luscar est éliminé parce qu'il n'a pas été utilisé de façon régulière et parce que l'intervalle qu'il désignait initialement peut être divisé naturellement en deux formations distinctes. Le nom de Gladstone est applicable à partir de la région type jusqu'à proximité de la rivière Smoky, au nord de laquelle il est préférable d'utiliser le nom de Gething. Les formations de Malcolm Creek et de Mountain park se trouvent à la frontière de l'Alberta et de la Colombie-Britannique. Au nord de cette limite, le même intervalle se répartit dans les formations suivantes: Moosebar, Gates, Hulcross et Boulder Creek.

Des filons de charbon qui présentent actuellement un intérêt économique, au sud de la rivière Smoky, sont confinés dans le niveau de Grande Cache de la formation de Malcolm Creek. Le niveau contient un à six filons importants d'épaisseurs allant jusqu'à 11 m. D'épais filons de charbon reposent aussi dans la formation de Gething le long et au nord de la rivière Smoky.

LITHOSTRATIGRAPHY OF THE LOWER CRETACEOUS COAL-BEARING SEQUENCE, FOOTHILLS OF ALBERTA

INTRODUCTION

Lithostratigraphic nomenclature for the Lower Cretaceous succession in the Foothills of Alberta and northeastern British Columbia has evolved from three loci: the Crowsnest Pass, the Cadomin-Mountain Park coal mining area, and the Peace River-Pine River area (Fig. 1). The earliest lithostratigraphic names were applied in these areas with little regard to the lateral extent of their applicability. In some cases, the units were ill-defined and their usage left open to the interpretation of later workers. This paper is the first to propose an integrated system of lithostratigraphic nomenclature based on detailed stratigraphic studies along the entire Foothills belt from the Crowsnest Pass area to the Peace River.

The Foothills can be divided into three segments for the purposes of this discussion: (1) southern Alberta as far north as Waiparous Creek; (2) central and northern Alberta to near the Alberta-British Columbia border and; (3) northeastern British Columbia. In the first, no clear resolution of the nomenclature has been achieved previously and a combination of formal and informal names has been in use, based on the proposals of Norris (1964) and Mellon (1967) (Table 1, columns 6 and 8). This nomenclature has been modified in this paper to emphasize distinct lithological differences. In the central and northern Foothills, the nomenclature of MacKay (1929a) is used (Table 1, column 9) but, north of the Athabasca River difficulty in recognizing the Mountain Park Formation has led to a modified nomenclature (Table 1, column 10). The nomenclature in this area is changed substantially due to the recognition of a widespread marine shale tongue not recognized by MacKay. The nomenclature in northeastern British Columbia, most recently documented by Stott (1968; in preparation), is widely accepted and appears to be applicable everywhere between the Alberta border and the Peace River (Table 1, column 11).

Fifty major outcrop and subsurface sections, encompassing at least one complete formation, and a large number of shorter sections from the southernmost Alberta Foothills to the northeastern British Columbia Foothills (Fig. 1) have been examined during this study, and, as a result, the relationship between the three nomenclatural sets can be clearly shown (Table 2). The purpose of this paper is: (1) to illustrate that relationship; (2) to present modifications in the nomenclature of the central and southern Foothills which are more useful to the interpretation of the sequence and (3) to show the relationship of the coal measures to other stratigraphic units.

The major obstacles to clarification of the nomenclature have been: (1) the failure of early geologists to recognize a marine tongue (Moosebar Member) in the northern and central Alberta Foothills, and (2) the attempt by Mellon (1967) to extend his southern nomenclature into the central Alberta Foothills despite major changes in lithology.

Acknowledgments

The lithostratigraphic nomenclature proposed in this paper was critically assessed by Drs. D.G. Cook, E.R.W. Neale, N.C. Ollerenshaw, T.P. Poulton and D.F. Stott of the Institute of Sedimentary and Petroleum Geology. Their suggestions and comments were useful in resolving some points of disagreement and misunderstanding. Special thanks are extended to Dr. W.G.E. Caldwell who took time during a busy sabbatical year to assess the merits of the proposed nomenclature.

Drs. D.K. Norris and D.W. Gibson critically read the manuscript and made many useful suggestions for its improvement.

The author was assisted ably during field investigations by Blair Clarke (1975 and 1976), Paul Johnson (1977), John Moorhouse (1978), and Dorian Sylvestre (1979).

HISTORICAL REVIEW

Southern Alberta Foothills

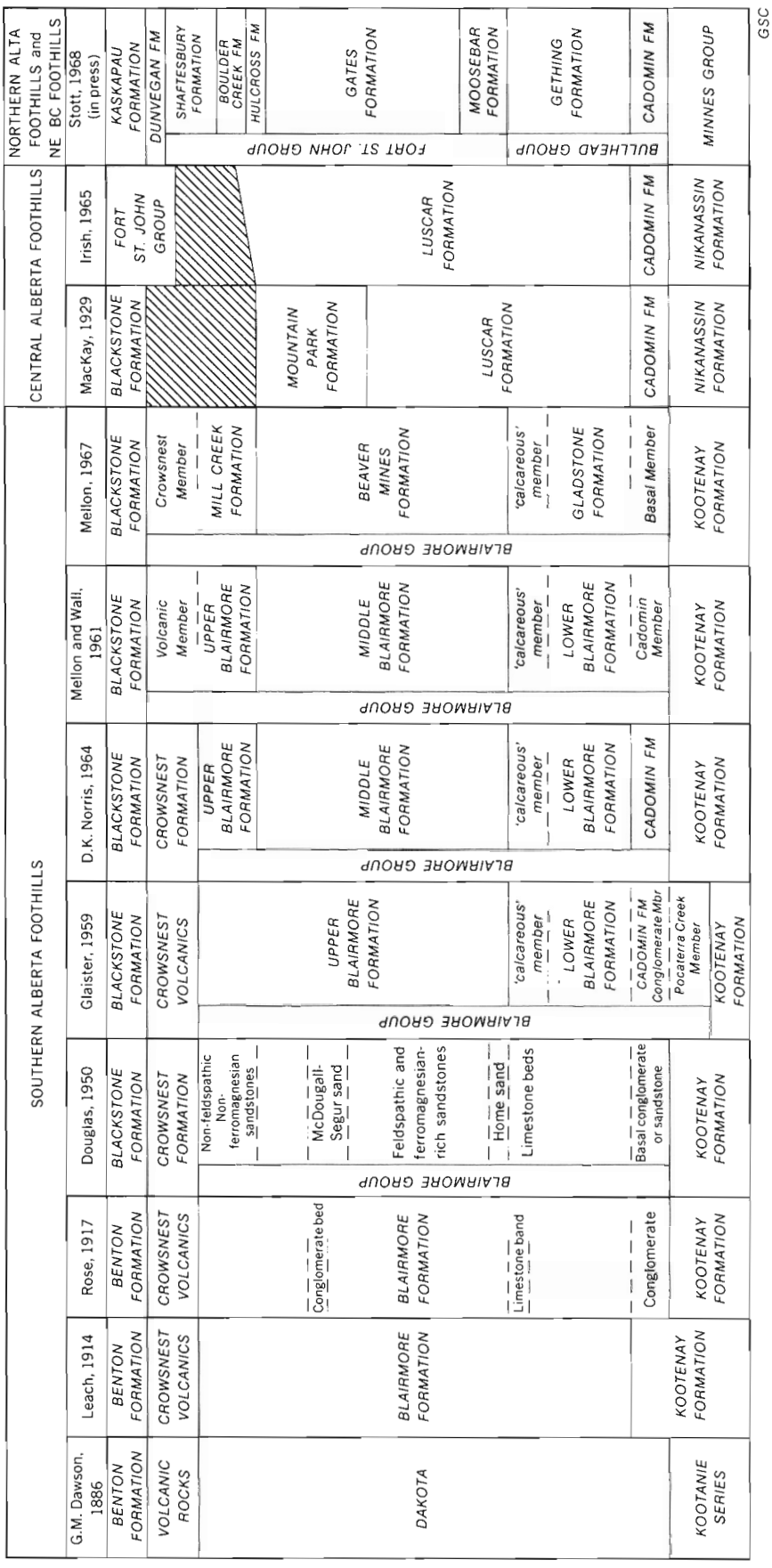
The basic framework of Lower Cretaceous stratigraphy was established by G.M. Dawson (1886), although none of his names has been retained. He separated (Table 1, column 1) the non coal-bearing Dakota (now Blairmore) from the coal-bearing Kootanie Series below and the Volcanic Rocks (now Crowsnest Formation) above. Leach (1914) introduced the name Blairmore in place of Dakota and Crowsnest Volcanics for Dawson's Volcanic Rocks (Table 1, column 2). Rose (1917) removed the prominent conglomerate bed (now Cadomin Formation) from the Kootenay Formation and placed it at the base of his Blairmore Formation (Table 1, column 3). He recognized two distinctive units within the Blairmore: (1) a limestone band probably equivalent to part or all of the 'Calcareous' member of the present Gladstone Formation, (2) a prominent conglomerate bed higher in the formation. Douglas (1950) recognized seven informal units within his Blairmore Group (Table 1, column 4) which formed the basis for subsequent formal division of the group (column 5 to 8).

Glaister (1959) divided the Blairmore Group into a lower and upper Blairmore Formation with the division made at the top of the limestone and calcareous shale beds identified earlier by Rose (1917) and Douglas (1950). Douglas's (1950) Home Sand, at the base of Glaister's upper Blairmore is not recognized regionally and has not been given formal status. Within the lower Blairmore, Glaister (1959) recognized the basal conglomerate as a formal member, the Cadomin conglomerate, and the upper limestone-bearing beds as an informal "Calcareous" member (Table 1, column 5). Norris (1964) gave the Cadomin formational status within the Blairmore Group and divided the rest of the Blairmore into three informal formations: Lower, Middle and Upper Blairmore. The division between Lower and Middle Blairmore coincided with Glaister's (1959) definition. The Middle - Upper Blairmore division was made at the distinct break between what Douglas (1950) referred to as feldspathic, ferromagnesian-rich sandstones and non-feldspathic, non-ferromagnesian sandstones.

Mellon and Wall (1961) made two fundamental changes: (1) they reduced the Cadomin to member status within the Lower Blairmore, and (2) they included the Crowsnest

TABLE 1

Historical review of lithostratigraphic nomenclature.



Formation in their Upper Blairmore Formation as an informal member (Table 1, column 7), thus extending the Blairmore Group to include a lithologically distinct unit never before included. Mellon (1967) then applied the formal names (Table 1, column 8) Gladstone, Beaver Mines and Mill Creek to the three divisions of the Blairmore Group.

Central and Northern Alberta Foothills

Prior to the work of MacKay (1929a and b, 1930), the Lower Cretaceous sequence in the central Foothills of Alberta had been correlated with the Kootenay Formation of the Crowsnest Pass area, based on the occurrence of coal seams presumed to be of the same age. MacKay (1929a and b, 1930) showed that a prominent conglomerate bed which lay above the coal measures south of the Bow River and below the coal measures to the north could be mapped from the Crowsnest Pass area along the Foothills to the Smoky River area (Fig. 1). He named this conglomerate the Cadomin Formation after the active coal mining town of that name along the McLeod River (Fig. 1). The overlying coal-bearing sequence was named the Luscar Formation and the non coal-bearing, greenish coloured, coarser grained sequence above, the Mountain Park Formation. Both are names of old mining towns (Fig. 1). This three-fold division of the Lower Cretaceous sequence (Table 1, column 9) has been utilized by later workers from just north of the North Saskatchewan River (Erdman, 1950; Douglas, 1956a) to just south of the Athabasca River (Mountjoy, 1960a, 1960b). Between the Athabasca and Smoky Rivers, the Mountain Park Formation was not recognized and the entire interval between the Cadomin and the Shaftesbury Formations was included in the Luscar Formation (Lang, 1947; Irish, 1965; Thorsteinsson, 1952).

The criteria for separation of the Mountain Park and Luscar Formations have not always been clear. In the type area, the Mountain Park Formation is a prominent, ridge-forming unit, at least in its upper part, but the nature of the boundary with the underlying Luscar was not specified by MacKay (1929c, 1930). The main difference between the Mountain Park and Luscar Formations is the lack, or scarcity, of coal seams in the former (MacKay, 1940, 1943; Erdman, 1950) and the more recessive nature of the latter. Douglas (1956a, p. 22) clearly stated his criteria for differentiating the two formations:

> . . . The separation of the Mountain Park formation from the upper part of the Luscar is dependant, in large measure, on the presence of thick, massive-bedded sandstones and the absence of coal. In general, the Mountain Park sandstones are a stronger green than otherwise similar sandstones in the upper Luscar, which are paler greenish-grey in colour. Some coal seams may be present in the Mountain Park formation, but the thicker and potentially mineable seams are restricted to the Luscar, and, where shown divided, to the upper part. It is unlikely that the contact between the two formations as mapped represents the same stratigraphic horizon, but its nature and variation, if any, are unknown.
>
> The sandstones of the overlying Mountain Park formation differ little from those of the upper part of the Luscar. The contact between the formations is arbitrarily drawn at the base of the first massive sandstone above the sandstone capping the No. 3 (highest) coal seam. . . (Douglas, 1956a, p. 20).

This seems to be the most practical definition available. Lang (1947), working just north of the Athabasca River (Fig. 1) was not able to differentiate the Mountain Park Formation from the Luscar Formation and mapped them together as Luscar Formation suggesting that the beds of the Mountain Park Formation either thinned out north of the Athabasca River Valley, or lost their ridge-forming character and typical green colour. MacKay (1955) also indicated difficulty in mapping the Mountain Park in the Brûlé area (Fig. 1), but stated that it was recognizable to the west, in the Pocahontas area. Irish (1965) mapped only the Luscar Formation north of the Athabasca River, but indicated that upper strata of the Luscar Formation may be equivalent in age to part or all of the Mountain Park Formation to the south.

Mellon (1967, Fig. 55) did not recognize the Mountain Park and Luscar as formations, but considered them facies within his Beaver Mines Formation. He stated:

> . . . The Beaver Mines Formation is 710 feet (215 m) thick on Ram River and is divisible into two parts, correlative with the coal-bearing upper part of the Luscar and overlying Mountain Park Formation of other investigators. . . (Mellon, 1967, p. 51).

Thus, he recognized that the beds above his Gladstone Formation could be divided into upper Luscar and Mountain Park. His relegation of these to 'facies' suggests that he did not consider different facies suitable as formations. However, many, if not most, formations have facies equivalents in other formations. For example, the Gates and Moosebar Formations of northeastern British Columbia are in large part facies equivalents with a gradational and interdigitating contact, but are considered separate and distinct formations. It is pertinent to note here, that the Clearwater and Grand Rapids Formations of the central Alberta Plains (Williams, 1963), equivalent to the Moosebar and Gates Formations of northeastern British Columbia, were not differentiated but rather were grouped together as a single formation by Mellon (1967, p. 63).

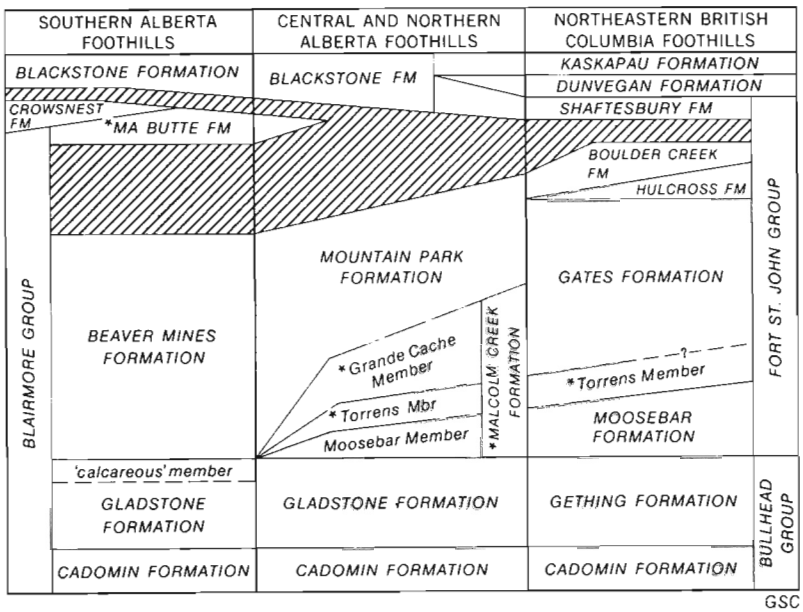
Mellon and Wall (1961, 1963) were the first to describe the presence of a marine shale unit within the Luscar Formation which they correlated with the Moosebar Formation of the northeastern British Columbia Foothills (Stott, 1960, 1963b, 1968). Mellon (1967) relegated this important stratigraphic unit, as well as the overlying coal-bearing beds, to the basal part of his Beaver Mines Formation without giving them formal status of any kind. Neither of these distinct lithological units is represented in the type section of the Beaver Mines. This problem is discussed more fully in a later section.

Northeastern British Columbia

The history of lithostratigraphic nomenclature of the Lower Cretaceous succession in northeastern British Columbia has been reviewed and thoroughly documented by Stott (1968). The nomenclature is currently undergoing some revision (Stott, in preparation) and Table 1 (column 11) shows the revised names. The succession is readily divisible into alternating nonmarine and marine formations. The Cadomin, Gething and Moosebar Formations have been traced as far south as the Smoky River (Stott, 1968; Fig. 2), where the undifferentiated Luscar Formation was previously mapped by Thorsteinsson (1952) and Irish (1952, 1965). The Hulcross Formation (Table 2, Fig. 2) thins dramatically to the southeast and has not been traced southeast of the Alberta-British Columbia border in the Foothills (Stott, 1968, Fig. 18e). The Gates and Boulder Creek Formations cannot be differentiated to the south where the Hulcross is not recognized.

TABLE 2

Lithostratigraphic nomenclature used in this paper.



SUMMARY OF PROPOSED REVISIONS

Southern Alberta Foothills

The name Blairmore Group, as now defined, was utilized by all geologists from Rose (1917) to Norris (1964) (Table 1, columns 2 to 6). It includes all strata from the base of the Cadomin Formation to the base of the Crowsnest Formation.

The basal conglomeratic unit of the Blairmore Group has been found to be an extremely useful, mappable unit and the name Cadomin Formation has been uniformly applied to this unit, and its eastern sandstone equivalents by Norris (1964), Ollerenshaw (1966, 1968, 1969, 1972a, 1972b, 1979) and McLean (1977). It is proposed that it be separated from Mellon's (1967) Gladstone Formation and that the name Gladstone be retained for the beds between the Cadomin and the Beaver Mines Formations.

The American Commission on Stratigraphic Nomenclature (1970, article 4a) states: "Where revision removes only a minor part of a previously established unit, the original name may be retained for the major part."

Removal of the Cadomin from Mellon's (1967) type Gladstone Formation involves removal of only a single unit of conglomerate and/or coarse-grained sandstone in most cases, which is lithologically distinct from the remainder of Mellon's Gladstone Formation. As illustrated in Figure 2, this is a very minor part of the total thickness and, thus, it is believed that its removal will not have an adverse effect on the utility of the name Gladstone.

The upper part of the Gladstone Formation, informally referred to as the 'Calcareous' member by Glaister (1959), and Mellon (1967), is retained as an informal member since its lower boundary is often difficult to establish precisely.

The name Beaver Mines Formation as defined by Mellon (1967) is retained as far north as Waiparous Creek (Fig. 1). At Waiparous Creek and to the north, distinct lithological changes in the post-Gladstone beds necessitate a change of nomenclature, which is discussed later.

All geologists have recognized a separation of the Crowsnest Formation from the underlying Blairmore Group, with the exception of Mellon and Wall (1961, 1963) and Mellon (1967). The latter reduced the Crowsnest to member status within his Mill Creek Formation of the Blairmore Group. Formations have always been defined on the basis of their mappability and the Crowsnest Formation has been found to be mappable since the earliest days. Therefore, it has been given formational status. Mellon's (1967) study was predominantly sedimentological and ignored the traditional mappability in favour of unifying the Crowsnest with underlying beds on the basis of some intertonguing of characteristic lithologies and similarity of indigenous floral remains. The author does not subscribe to this lithostratigraphic practice and retains Crowsnest Formation as a separate and distinct unit above the Blairmore Group.

Removal of this major upper portion from Mellon's (1967) Mill Creek Formation leaves a portion of the original beds below the Crowsnest Formation unnamed as it would be confusing to try to redefine the name Mill Creek to embrace only these lower beds. As well, the name Mill Creek has been previously used three times, twice as a formation name in the United States (Kercher, 1960), and in Canada (J.W. Dawson, 1886) as a biostratigraphic rather than a lithostratigraphic unit. Therefore, use of the name Mill Creek Formation in the nomenclature of the Lower Cretaceous succession in the southern Foothills of Alberta is discontinued. The name Ma Butte Formation is herein proposed for the sequence between the Beaver Mines and Crowsnest Formations.

Central and Northern Foothills of Alberta

The name Cadomin is retained for the basal conglomerate and sandstone unit, as originally proposed by MacKay (1929a, b and c). The Luscar Formation of MacKay (1929a, b and c, 1930) can be subdivided into two distinct and useful units (Table 2) of formational rank. The lower unit, comprising strata above the Cadomin Formation and below the Moosebar marine tongue, is correlated with the Gladstone Formation of the southern Foothills on the basis of lithological similitude and homotaxis, and that name is extended as far north as the Smoky River. North of that area, lithological differences necessitate use of the name Gething Formation for laterally equivalent strata.

The upper unit, comprising strata from the top of the Gladstone to the base of the Mountain Park Formation, is herein named the Malcolm Creek Formation (Table 2). Three formal members are recognized within this formation (Table 2). In ascending order these are: Moosebar Member, Torrens Member and Grande Cache Member.

The name Luscar might have been retained as a group name, encompassing the Gladstone and Malcolm Creek Formations on the basis of entrenchment of the name in the literature. However, its use is discontinued for two reasons: (1) it is divisible into two formations, lithologically distinct from one another, without common characteristics which would make them a natural grouping distinct from units below and above; (2) there has been some confusion generated by use of the name Luscar for different intervals in different areas. For example, as shown in Table 1 (column 10), Irish (1965) and others have used the name Luscar for the entire post-Cadomin, pre-Shaftesbury interval between Athabasca and Kakwa Rivers because of difficulty in identifying the Mountain Park Formation. Therefore, it was applied to a much greater stratigraphic interval than was intended by the original definition of MacKay (1929a, b and c, 1930). Its extensive use in this sense as well as in the original sense has seriously impaired the value of the name Luscar.

The name Mountain Park is retained for the beds above the Malcolm Creek Formation and below the distinctive dark shales of the Blackstone and Shaftesbury Formations. Its use, extended over a wider area than previously, is discussed in the following section.

Use of the name Blairmore Group in the central and northern Foothills of Alberta is advocated to accentuate the similarities in nomenclature and lithology between this area and the southern Alberta Foothills. It encompasses the Cadomin, Gladstone, Malcolm Creek and Mountain Park Formations and can be used as far north as the Smoky River region.

LITHOSTRATIGRAPHY

Introduction

Figure 2 is a southeast-northwest cross-section showing columnar logs for a series of surface and subsurface sections examined during this study between the Crowsnest Pass area of southwestern Alberta and the Wolverine River of northeastern British Columbia (Fig. 1). The relationship of the various formations, members and groups to one another is shown as well as the general lithofacies types in each unit. The following discussion concentrates on the lithostratigraphy

of the central and northern Foothills of Alberta referring to adjacent areas only where they are essential to understanding of the lateral relationships of stratigraphic units.

Blairmore Group

Definition

The name Blairmore was introduced by Leach (1914, Map 107A) as a formation name for a sequence of chiefly dark sandstone and sandy shale between the Kootenay Formation and Crowsnest Volcanics. Number and names of divisions of the Blairmore Group have changed with time as discussed above and illustrated in Table 1.

No type section was designated by Leach (1914) and none has ever been proposed. Norris (1964) established the section on Ma Butte (Fig. 1) as the principal reference section. It is well exposed through the Beaver Mines and Ma Butte Formations, but the Gladstone Formation, which was exposed in a bulldozer cut, is now mostly covered. The three formations which constitute the bulk of the Group - Gladstone, Beaver Mines, Ma Butte - are defined by type sections and are within 30 km of the town of Blairmore.

A unit below the Cadomin Formation is included in the Blairmore Group in two areas south of the Bow River (Fig. 1). This is the Pocaterra Creek "Member" (Allan and Carr, 1947; see Table 1, column 5) which is recognized in the Alberta Foothills area from the Bow River south to about latitude 50°20' and in the Fernie area of southeastern British Columbia (Gibson, 1977; in preparation).

The Blairmore Group rests disconformably on the Kootenay Group, or on the Nikanassin Formation. This is often not apparent in a single exposure, but is prominent on a regional scale (Norris, 1964; Stott, 1973). The upper contact with the Crowsnest Formation is gradational and probably conformable. Beyond the limits of the Crowsnest Formation, the Blackstone Formation rests abruptly and disconformably on the Blairmore Group.

Distribution and thickness

The Blairmore Group is 650 m thick in the type area. The maximum reported thickness, in the Fernie area of southeastern British Columbia, is estimated at about 2000 m. A distinct west to east thinning occurs with thicknesses of about 300 m reported from the easternmost Foothills. Use of the name Blairmore Group is confined to the Rocky Mountain fold-thrust belt and is not used in the adjacent Plains.

The Blairmore Group previously has been recognized in mapping as far north as the North Saskatchewan River (Mountjoy and Price, 1974). However, there are many similarities in lithology with equivalent beds farther northwest and some similarities (Cadomin and Gladstone Formations of this paper) in nomenclature. Therefore, it is suggested that extension of the name Blairmore Group to the vicinity of the Smoky River would emphasize the elements of continuity in the Lower Cretaceous stratigraphy of the Foothills. Thicknesses of 400 to 600 m prevail in the region between the North Saskatchewan and Smoky Rivers with the same west to east thinning trend that was observed farther south.

Lithological characteristics

The basal unit, the Cadomin Formation, is typically a very resistant, siliceous, pebble conglomerate, but includes beds of quartzose sandstone and, in some sections, particularly in the eastern Foothills, is entirely quartzose sandstone.

The lower part of the overlying Gladstone Formation is a series of interbedded grey mudstone to sandstone, the proportions of which are very variable. Very thick to massive sandstone beds which rarely exceed fine-grain size, often exhibit a distinct upward decrease in grain size. The upper Gladstone Formation is characterized by dark grey argillaceous limestone and fossiliferous calcareous shale. North of the Clearwater River (latitude 52°) limestone beds are rare or absent, but fossiliferous calcareous shales are common.

The Beaver Mines Formation in the south, and the Mountain Park Formation in the north (Fig. 2), are composed of interbedded mudstone to very fine grained sandstone with subordinate, but prominent, coarser and thicker sandstone units with abrupt bases and fining-upward grain size. Conglomerate beds are a minor constituent in some sections.

The Malcolm Creek Formation (Fig. 2), confined to the area north of Waiparous Creek (Fig. 1) consists, in ascending order, of the dark marine mudstones of the Moosebar Member, the prominent, sandstone-dominated Torrens Member and the coal-bearing Grande Cache Member.

The Ma Butte Formation consists of mudstone to very fine-grained sandstone with subordinate coarser sandstone and conglomerate beds. Tuffaceous mudstones are common in the upper part of the formation in the type area, but disappear to the northwest along the Foothills. The entire formation is absent north of the Clearwater River (Fig. 1).

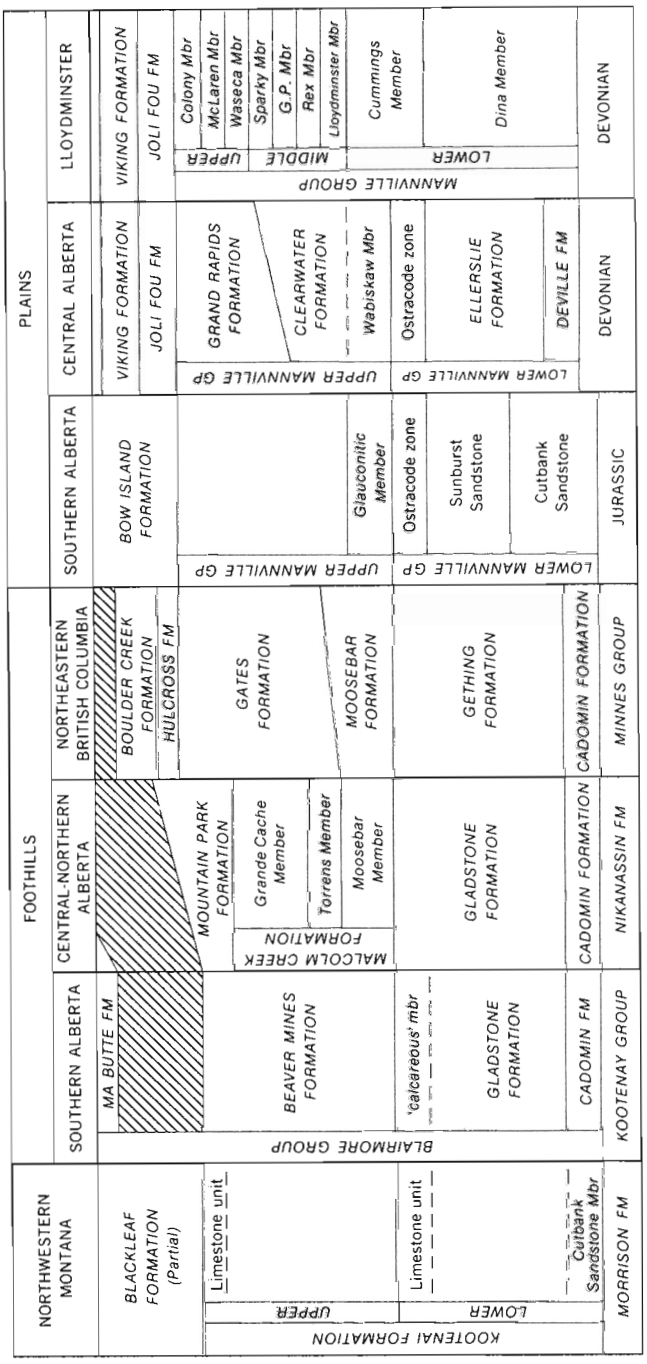
Colour can be distinctive but varies from south to north. Shades of red and green, often mottled, are common south of the Bow River (see Douglas, 1950; Mellon, 1967). Shades of grey predominate to the north except in the Mountain Park Formation where greenish-grey is the dominant colour in the type area but is confined to a subdued shade in the uppermost part of the formation in the Smoky River region.

Age and correlation

The lower age limit of the group is uncertain and may be quite different from one area to another. Fossil evidence is very sparse in the Cadomin and lower Gladstone Formations. The possible age range is as old as latest Jurassic and as young as Aptian (see review in McLean, 1977, p. 799). Marine microfossils in the Moosebar Member of the Malcolm Creek Formation date the middle of the Blairmore Group as early to Middle Albian (J.H. Wall, pers. comm.). Paleobotanical evidence indicates an age of late Middle Albian or older for the top of the Blairmore Group in the central to northern Foothills, with a slightly younger age probable in the Smoky River region (A.R. Sweet, pers. comm.). The top of the Blairmore Group in the southern Foothills, where the Ma Butte Formation is present, is probably late Middle to Late Albian (Mellon, 1967, p. 74).

Correlation with the Bullhead and lower Fort St. John Groups in northeastern British Columbia is clearly shown in Figure 2. To the south in northwestern Montana, the Blairmore Group is equivalent to the Kootenai Formation and the lower part of the Blackleaf Formation (Table 3). In the southern Plains of Alberta the Mannville Group is equivalent to the Cadomin, Gladstone and Beaver Mines Formations and the Bow Island Formation is correlative with the Ma Butte Formation. The Mannville Group of the central Plains of Alberta is equivalent to the Blairmore Group of the central to northern Foothills (Table 3).

TABLE 3
Correlation of stratigraphic units in Foothills with areas in the Alberta Plains and in northwestern Alberta.



Pocaterra Creek Formation

South of the Bow River (Fig. 1), there are two areas in which beds similar to the lower Blairmore Group occur below the Cadomin Conglomerate. This unit was named the Pocaterra Creek Member of the Blairmore Formation by Allan and Carr (1947). One area extends from the Bow River south to about latitude 50°20' (Allan and Carr, 1947; Gibson, 1977) and the second is in the Fernie region (Fig. 1) of southeastern British Columbia (Gibson, 1977). The unit was not examined in detail during this study and is included only for the sake of completeness since it is considered a part of the Blairmore Group.

The type section, designated by Allan and Carr (1947, p. 28), is near the headwaters of Pocaterra Creek (Section 15-19-8W5). It consists of poorly bedded, blocky grey to olive-grey mudstones with some well-bedded carbonaceous shales, and hard, fine-grained quartzitic sandstones. Coarse-grained grey cherty sandstones and chert pebble conglomerates are subordinate but prominent components. In the type area, one or more conglomerate beds occur at the base, distinguished from the Cadomin Formation by smaller clast size, a lack of green pebbles and a paucity of white quartzite pebbles (Allan and Carr, 1947). Grey-green, honey-yellow and maroon mudstones and calcareous nodules, up to 20 cm diameter, are characteristic of the Pocaterra Creek "Member" (Allan and Carr, 1947, p. 28). The unit varies in measured thickness from 122 to 6 m. It pinches out laterally but it is not known if this is depositional or erosional. Both upper and lower contacts are abrupt but both may be conformable (Gibson, in preparation). However, fossil evidence is inadequate to determine this at the present time.

The Pocaterra Creek "Member" was designated a member of the Blairmore formation by Allan and Carr (1947). The Blairmore has subsequently been elevated to group status but no-one has proposed elevation of the Pocaterra Creek to formation status. However, according to the American Commission on Stratigraphic Nomenclature (1970, article 7), a member is part of a formation. The Pocaterra Creek is lithologicaly distinct from the overlying Cadomin Formation and cannot legitimately be considered a member within it. Therefore, it is considered to have formational status and is left within the Blairmore Group, although it might equally well be separated from both the Blairmore and Kootenay Groups.

Cadomin Formation

Cadomin is the only formation name which is used throughout the entire length of the cross-section (Fig. 2). It has been described by McLean (1977) and Stott (1968, 1973) and the interested reader is referred to those papers for additional detail. The formation is characterized by conglomerate, with clasts up to 40 cm maximum dimension. Average size ranges from less than 1 to 5 cm diameter. Matrix is generally fine- to coarse-grained sand, and the cement is silica. Clasts are predominantly chert and quartzite. As a whole, the Cadomin is resistant to erosion and usually forms prominent outcrops. Thickness ranges from less than 1 m to over 180 m. More than one bed of conglomerate occurs in some sections with interbedded sandstone, siltstone and mudstone, often with a high carbonaceous content and occasionally thin to thick coal beds, particularly in sections north of the Smoky River (Fig. 1).

In general, the average clast size in the formation decreases to the northeast and in a few of the more easterly outcrop sections, such as on Gladstone Creek, the formation is composed entirely of sandstone. However, it is a prominent, massive-weathering unit which is readily distinguishable from beds below and above, and is equivalent to the more typical conglomerate of the Cadomin farther west. The name Dalhousie sandstone was applied to equivalent sandstone beds in the Turner Valley area (Hume, 1938) but there does not appear to be any good reason for perpetuating a separate name for this easterly sandstone facies, which interfingers with conglomerate to the west, and the name Cadomin is applied throughout (McLean, 1977).

The conglomerate is interpreted as a pediment lag and alluvial fan deposit, which accumulated during a period of erosion subsequent to deposition of the Kootenay Group, Nikanassin Formation and Minnes Group (McLean, 1977).

Gladstone Formation

Definition

The type section (holostratotype of Hedberg, 1976), of the Gladstone Formation is on Gladstone Creek. Figure 1 shows its general location and Table 4 its specific location.

Mellon (1967, p. 16) proposed the name Gladstone to encompass the beds from the top of the Kootenay Formation (now Group, see Gibson, 1979) to the base of his Beaver Mines Formation. This included the herein defined Cadomin Formation which, at the type section of the Gladstone Formation, is composed entirely of sandstone, atypical of the formation as a whole which is characteristically a conglomerate. The Cadomin is a prominent and extensively used stratigraphic marker in mapping and coal exploration along the length of the Foothills (McLean, 1977) and, therefore, it is considered important to retain it as a separate formation. Its removal from the Gladstone does not impair the use of that name for the remainder of the formation as explained above. Therefore, the Gladstone Formation is herein redefined to include all strata between the top of the Cadomin Formation and the base of the Beaver Mines Formation in the Foothills south of Waiparous Creek and between the Cadomin and Malcolm Creek Formations from Waiparous Creek to Smoky River (Fig. 1, Table 2). Both contacts are abrupt, the lower being conformable and the upper either conformable or disconformable. A stratigraphic column of the type section is shown in Figure 2. A written description, not provided by Mellon (1967), is given in Appendix A.

Distribution and thickness

The Gladstone Formation is 81.7 m thick at its type section. Thickness variations to the northwest are shown in Figure 2. The formation generally thickens to the west. For example, the thickness increases from 140 m at Gap Lake on the eastern edge of the Foothills to 180 m at Wapiabi Creek on the western edge (Fig. 1).

Mellon (1967) and Holter and Mellon (1972) extended usage of the name Gladstone Formation from the type area to the Cadomin area which is the type area of MacKay's (1929a, b, and c, 1930) Luscar Formation. The essential lithological characteristics of the Gladstone Formation can be recognized as far as the Smoky River. Northward beyond the Smoky River, the lithological character of the interval between the Cadomin and Moosebar Formations changes and, accordingly, use of the name is discontinued and replaced by Gething (Table 2).

TABLE 4

Locations of type and reference sections.

SECTION	NTS TOPOGRAPHIC MAP 1:50,000 SCALE	UNIVERSAL TRANSVERSE MERCATOR GRID (UTM) LOCATION		
		Easting	Northing	Zone
TORRENS RIDGE	Narraway River 93-I/8E	2942	60198	10
GLADSTONE	Beaver Mines 82G/8E	7060	54765	11
MALCOLM CREEK	Grande Cache 83E/14E	3563	59743	11
GUSTAVS FLATS	Grande Cache 83E/14E	3572	59786	11
WAPIABI CREEK	Nordegg 83C/8 and Job Creek 83C/7E	5332 5344	58152 58150	11 11
MA BUTTE	Crowsnest 82G/10	6789	55114	11

GSC

Lithological characteristics

The Gladstone Formation as defined herein has been informally divided into two members (Glaister, 1957, 1959; Norris, 1964; Mellon, 1967) which are retained here. The lower member, comprising half or less of the formation, is characterized by fine- to very fine-grained sandstone beds, up to 8 m thick, usually with a distinct upward decrease in grain size, interbedded with siltstone, mudstone and claystone beds, 2 cm to several metres thick. Colours are light grey to light greenish-grey and maroon. The latter two often form a mottled pattern in southern Foothills exposures. Lamination is uncommon and most beds have a massive appearance. Recognizable sedimentary structures are rare.

North of the Bow River (Fig. 1) the lower part of the Gladstone has lithological characteristics similar to those of the type section, but the colours are predominantly greys with no greenish or reddish hues observed. Macerated carbonaceous material becomes more common to the north, with root zones and plant fragments commonly observed, and even a few thin clayey coal seams. An 80 cm-thick seam is present in the section at Cadomin. Fining-upward sandstone beds, as well as the common occurrence of carbonaceous debris and root zones, characterize this lower part of the Gladstone Formation.

The upper part, the 'Calcareous' member of Glaister (1957, 1959) and Mellon (1967), is characterized by limestone and calcareous mudstone, siltstone and subordinate sandstone (Plate 1A). Limestone beds which are dark grey with light grey weathering, and exhibit a platy weathering character, are mainly aphanitic and structureless although allochthonous shell fragments are common in some beds, sometimes forming a coquina. Pelecypods and gastropods are readily recognizable (Plate 1B) and ostracodes and charophytes were observed in a few beds. Interbedded mudstones are dark grey with light grey weathering, and a platy habit. Horizontal lamination was observed in some beds. A churned, bioturbated appearance and scattered shells are common. Siltstone and sandstone beds are medium to dark grey with light grey weathering. Horizontal to wavy lamination is common, and distinct ripple bedforms were observed in one bed. All are very calcareous.

The 'Calcareous' member varies greatly in thickness as illustrated in Figure 2. It is well developed at the type section of the Gladstone Formation and is thick and well developed at Waiparous Creek. The anomalously thin section at Sheep River will be discussed later. To the north of Waiparous Creek (Fig.1), limestone beds are not well

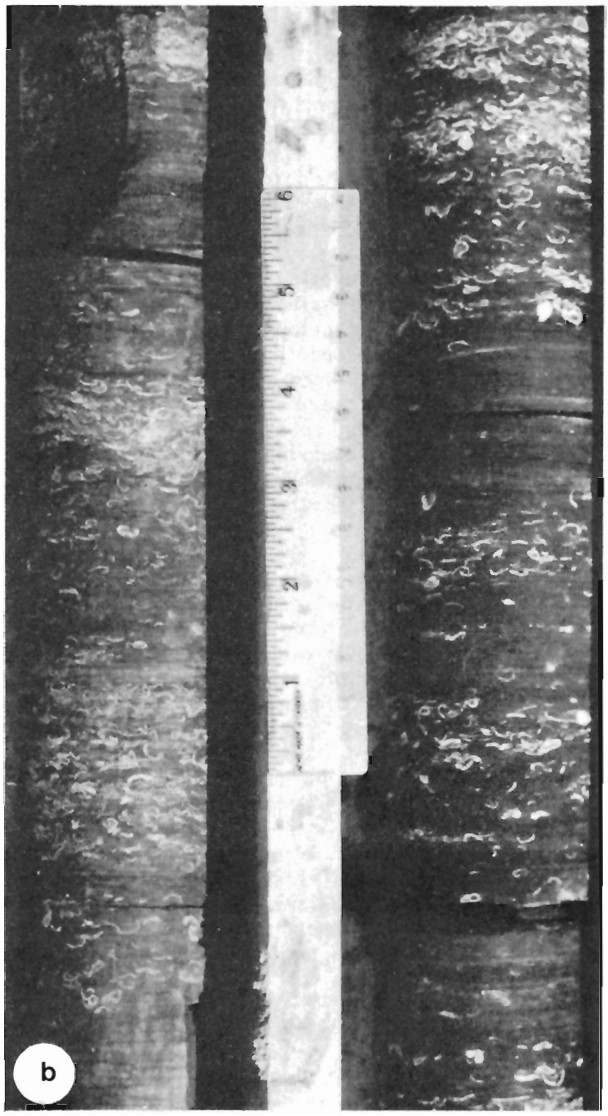


PLATE 1a. *Interbedded limestone and mudstone of the 'calcareous' member, Gladstone Formation. Waiparous Creek section. ISPG 1356-26.*

PLATE 1b. *Disarticulated pelecypods of brackish to fresh water origin, near top of Gladstone Formation. Little Berland core 70-02. ISPG 1356-25.*

developed but very calcareous shales or mudstones are prominent in the outcrop section at Burnt Timber Creek, and in core from the Fall Creek and Little Berland River locations (Figs. 1 and 2).

The 'Calcareous' member is equivalent to the Ostracode zone in the Plains stratigraphy (Loranger, 1951) and contains the characteristic Metacyprid ostracode fauna.

The 'Calcareous' member loses its identity north of the Clearwater River (Fig. 1) (Mellon, 1967, p. 46-50) where distinctive limestone beds are replaced by fossiliferous calcareous mudstones to sandstones. However, the upper part of the formation, stratigraphically equivalent to the 'Calcareous' member, is still distinct from the lower part and is characterized by dark grey mudstones, most of which are distinctly bioturbated and many contain fragments of pelecypod and gastropod shells as well as some ostracodes and charophytes (Plate 1B). In some sections, foraminifera, indicative of brackish water conditions were found associated with the nonmarine fauna. Typically, sandstone beds are much subordinate to mudstone and siltstone, and where present are thin to medium bedded and may exhibit either a coarsening-upward, or a fining-upward grain size. This upper unit can be recognized clearly as far north as the McIntyre Mines Railroad section on the Smoky River (Fig. 1).

In two of the sections which were studied in detail-Sheep River and Cadomin (Figs. 1 and 2) - there is an unusually high proportion of sandstone in all but the uppermost few metres of the Gladstone Formation. The sandstones are usually the uppermost unit of coarsening-upward sequences, but some have an abrupt base and exhibit a

decrease in grain size upward. The section at Sheep River contains a few extensively bioturbated beds but also some distinctive root zones. Most of the finer grained beds -- mudstones and siltstones -- are a prominent greenish-grey colour and have a massive appearance with no recognizable sedimentary structures. Carbonaceous detritus is rare and no coal beds are present. The section at Cadomin (Plate 2A) is very carbonaceous throughout and contains several thin coal seams as well as the 80 cm-thick seam mentioned previously. These beds are similar to those observed in the lower part of the Gladstone Formation but lack the thick, fining-upward, sandstone beds.

Age and correlation

The nonmarine fauna occurring in the upper part of the Gladstone Formation is not age sensitive (Mellon, 1967, p. 75). However, foraminifera from marine mudstones interbedded with nonmarine strata in the upper part of the formation north of the North Saskatchewan River, indicate an age of Early to Middle Albian (J.H. Wall, pers. comm., 1979). As with the Cadomin Formation, the lower age limit is not known precisely. Stott (1968, p. 39), from several lines of evidence, suggested a Hauterivian to Albian age for the laterally equivalent Gething Formation, with some evidence suggesting, but not proving, that the younger age is more likely.

The Gladstone Formation is laterally equivalent to the Gething Formation of northeastern British Columbia and to the Lower Mannville Group of the southern Alberta Plains (Table 3), and the McMurray Formation of the central and northeastern Plains (see Mellon, 1967, p. 77).

Depositional environments

The lower part of the Gladstone Formation was deposited on an alluvial plain; the thick, fining-upward sandstones representing probable point bar deposits of meandering channels with the finer interbedded sediments representing typical floodplain deposits (e.g. Vincent, 1977; McLean and Jerzykiewicz, 1978). Mellon' s (1967, p. 182) influx type of cyclically bedded deposits refer to this alluvial plain depositional setting. Holter and Mellon (1972, Fig. 8, p. 133) do not indicate this model for their "lower Luscar facies", but it is present in the lower part of all sections studied by the author.

The upper part of the Gladstone contains an abundant fresh water fauna consisting of ostracodes, pelecypods, gastropods, fish teeth and bones, and charophytes. A lacustrine environment is suggested by this evidence. However, a mixed population of the fauna with marine foraminifera (Wall, 1979, pers. comm.) in several sections of the upper Gladstone Formation north of the North Saskatchewan River, favours an estuarine rather than lacustrine environment (McLean and Wall, 1981). The Gladstone Formation reflects a gradual lowering of energy levels accompanying the slow southward transgression of the boreal sea.

Comparison with the Gething Formation

The type section of the Gething Formation is exposed along the canyon of the Peace River where it is between 485 and 545 m thick (Stott, 1969).

> . . . In general, it comprises interbedded mudstone, coal, and sandstone. The repetition of numerous thin units is a characteristic feature of the Gething in this region. Sandstones in the canyon area are dominantly fine-grained, silty to argillaceous, and are commonly carbonaceous. They are brown to grey on a fresh surface and weather brown. Only a few units exceed 25 feet in thickness and many are channel structures. The mudstones are mainly brownish-grey to green and most are carbonaceous. . . (Stott, 1969, p. 3)

The formation thins markedly to the south of the type area and is only 140 m thick in the Wolverine section (Fig. 2) and 100 m thick at Mount Torrens (Fig. 2). However, the essential lithological character of the formation is maintained and, particularly pertinent to this discussion, coal seams, a metre or more thick, commonly occur in sections as far south as the Smoky River (Gustavs Flats section, Fig. 2). There is no indication of a fresh- to brackish-water sequence in the upper beds as seen in the Gladstone Formation.

At Gustavs Flats, a major coal seam occurs immediately below the overlying Moosebar Formation. Eight kilometres to the northeast, along the Smoky River, a nearly complete section of the interval between the Cadomin and Moosebar Formations is exposed (Plate 2B). There are only minor coal seams and some marine influence is indicated in the upper 20 m. The section is lithologically more similar to the Gladstone Formation than the Gething Formation, and is placed in that formation. To the south, the next section at Little Berland River is also distinctly similar to the type Gladstone Formation and lacks the thick coal seams of the Gething. None of the measured sections south of the Smoky River contains the number or thickness of seams observed at Gustavs Flats.

The nature and position of the boundary between the Gething and Gladstone Formations is uncertain at present. It lies between the two outcrop sections on the Smoky River and appears to trend in a nearly north-south direction (Fig. 1). The contact is undoubtedly gradational from the coal-bearing, probably deltaic, setting of the Gething to the estuarine environment of the Gladstone to the south. The extent of Gladstone-type sediments to the north and east of the Foothills is unknown.

Comparison with the lower Luscar Formation

The presence of the Moosebar marine tongue (Fig. 2) was not recognized south of the Smoky River until the work of Mellon and Wall (1961 and 1963). Consequently, what is now recognized as an important stratigraphic horizon has not been mapped south of the Smoky River. The reason for this is the generally recessive weathering nature of the Moosebar tongue as well as the underlying and overlying beds. Two authors (Douglas, 1956a; Mountjoy, 1960a, b) have subdivided the Luscar Formation, but the division does not correspond to the base of the Moosebar.

Douglas (1956a, p. 20) divided the Luscar into upper and lower divisions with the contact at the base of the sandstone underlying a major coal (his No. 2 seam) which marks the change, at Nordegg (Fig. 1) from the grey shales and sandstones of the lower part to greenish-grey beds of the upper part. Mountjoy (1960b) divided the Luscar in the Miette area (just south of the Athabasca River, see Fig. 1) into two parts with the contact at the base of a prominent, ridge-forming, coarse-grained, conglomeratic sandstone unit. Field study by the writer of a section in this area suggests that this bed is in the same relative stratigraphic position as

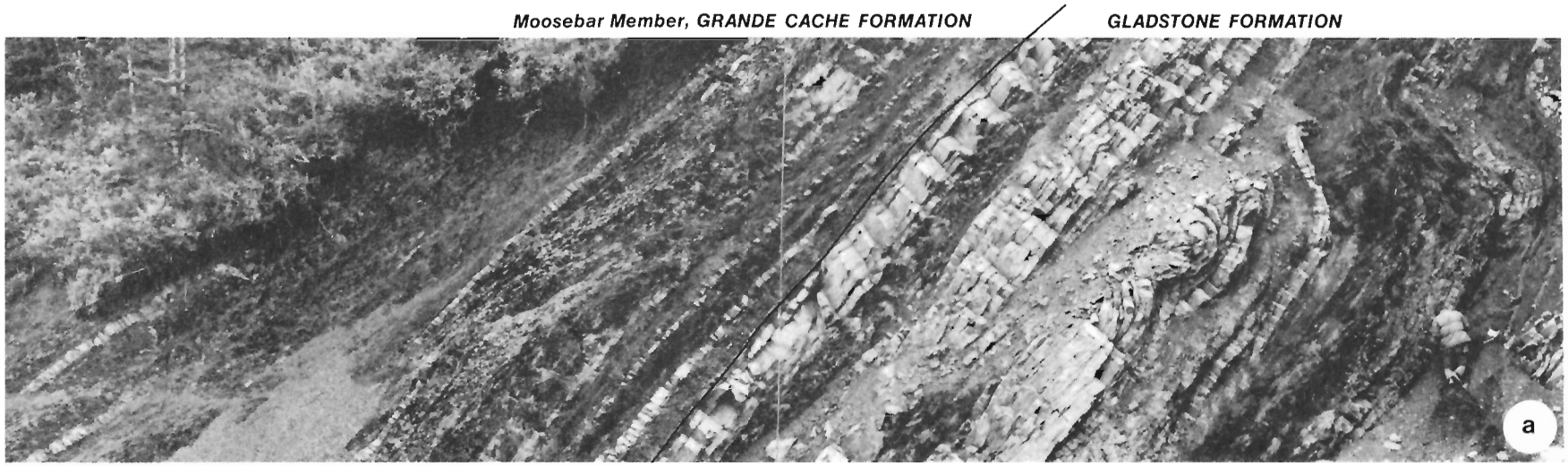


PLATE 2a. *Interbedded sandstone, siltstone and mudstone at top of Gladstone Formation. Coal seam to left of assistant, with minor structure just above. A few pelecypods in uppermost bed are related to 'calcareous' member to south. Overlain abruptly by dark mudstone at the Moosebar Formation. Cadomin section. ISPG 663-5 and ISPG 663-6.*

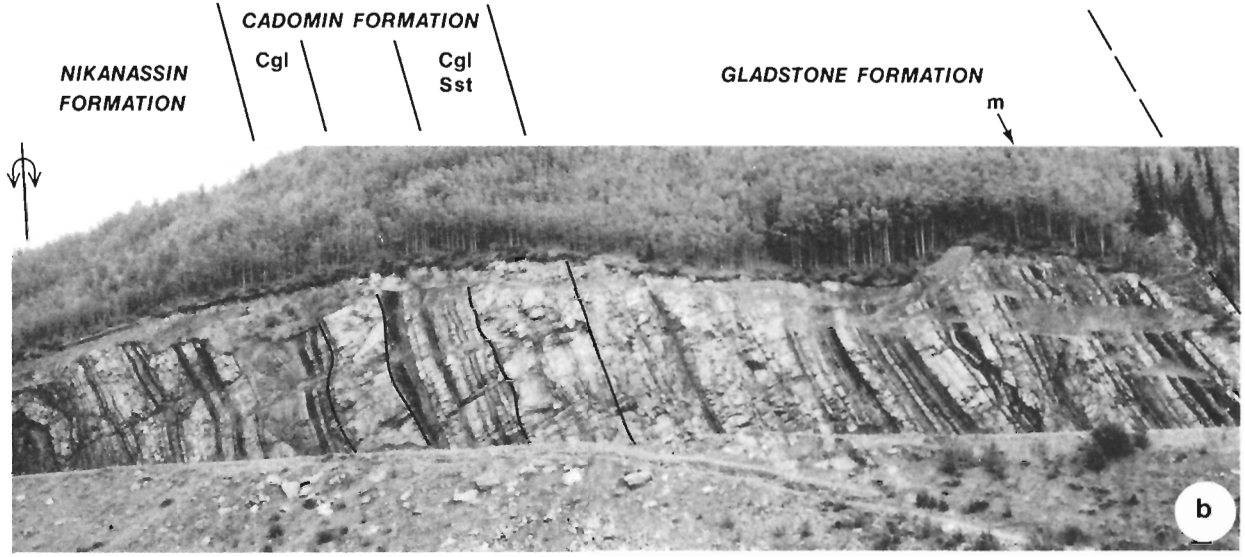


PLATE 2b. *Nikanassin Formation on left, overlain abruptly by lower conglomerate bed of Cadomin Formation. Coal-bearing sequence between, overlain by conglomerate and conglomeratic sandstone of upper Cadomin Formation. Transitional to Gladstone Formation with marine bed (m) near top. Contact with Moosebar Formation just to right of photo. McIntyre Mines Railroad section. ISPG 1356-11.*

the sandstone of Douglas, well above the base of the Moosebar marine shale. This bed represents a regionally significant marker herein called the Torrens Member of the Malcolm Creek Formation. It is well above the upper boundary of the Gladstone Formation discussed previously, and will be considered in a subsequent section.

The informal lower Luscar Formation of Douglas (1956a) and Mountjoy (1960a and b) can be subdivided into smaller and more useful lithostratigraphic units and, thus, their nomenclature will not utilized here.

Malcolm Creek Formation

Definition

The name Malcolm Creek is proposed for the sequence of strata between the top of the Gladstone Formation and the base of the Mountain Park Formation (Table 2). Both contacts are abrupt but apparently conformable. The formation is well exposed at several outcrop sections in the vicinity of the town of Grande Cache, Alberta (Fig. 1). The section on Malcolm Creek (Figs. 1 and 2) is designated the type section. The precise location is given in Table 4: a written description is presented in Appendix A. The Gustavs Flats section, which is more accessible, is designated as a principal reference section.

The formation consists of three distinct lithological units which are given formal member status. These are, in ascending order: (1) Moosebar Member, characterized by dark grey mudstones with more siltstone and sandstone interbeds upward; (2) Torrens Member, characterized by sandstone; and (3) Grande Cache Member, characterized by coal seams interbedded with carbonaceous mudstone, siltstone, and subordinate sandstone.

Distribution and thickness

The Malcolm Creek Formation is 189.7 m thick at the type section. To the south, it maintains a thickness varying from 160 to 130 m to about the Ram River (Cripple Creek-Gap Lake logs, Fig. 2). South of there, it thins markedly to only 18.5 m at Waiparous Creek (Figs. 1 and 2). A lack of complete exposures between Cripple Creek and Waiparous Creek precludes an exact picture of the nature of this thinning. The formation has not been recognized south of Waiparous Creek.

The Malcolm Creek Formation has been recognized as far northwest as the Alberta-British Columbia border. Just north of the border at Torrens Ridge (Fig. 1), the Hulcross Formation (Fig. 2, Table 2) is still recognized, so that the underlying beds are still referred to the Gates Formation, and the central and northern Alberta Foothills nomenclature is not applied (Fig. 2).

The name Malcolm Creek Formation is restricted by definition to the Foothills structural province.

Lithological characteristics

The Malcolm Creek Formation is readily divisible into three lithologically distinct units in most of its area of occurrence. These have been given formal member status and are described in detail below.

The lowest beds, the Moosebar Member, are characterized by dark grey mudstone with a thin bed of pebbly, glauconitic mudstone at the base. Interbeds of silt and very fine-grained sandstone occur upward, increasing in grain size and bed thickness upward. The Moosebar passes upward gradationally into the Torrens Member characterized by sandstone, very fine- to fine-grained, with an overall increase in grain size upward. Sandstone up to very coarse-grained and occasionally pebbly is common towards the top of the member. The Torrens is overlain, usually abruptly, by the Grande Cache Member, characterized by thick coal seams interbedded with thicker sequences of grey to olive-grey, predominantly fine grained clastic sediments. Coarser grained clastic sediments are a subordinate but distinctive lithofacies. Carbonaceous detritus is abundant throughout and root zones are common.

Age and correlation

Foraminifera from the Moosebar Member, identified by J.H. Wall of the Geological Survey of Canada, give an age of Early to Middle Albian. More specific age designations of Early Middle Albian in the Victor Lake section near Grande Cache and Middle Albian for the subsurface section at Little Berland River (Fig. 1) were given. No fossils were recovered from the Torrens or Grande Cache Members. An upper limit on age is imposed by paleobotanical determinations on the highest beds in the Malcolm Creek section which A.R. Sweet of the Geological Survey of Canada dated as late Middle Albian or younger.

The Malcolm Creek Formation correlates with the Moosebar Formation and the lower part of the Gates Formation in the more southeasterly outcrops of the northeastern British Columbia Foothills (Table 2), with a lower part of the Beaver Mines Formation in the southern Alberta Foothills, with the Clearwater Formation and lower part of the Grand Rapids Formation of the central Alberta Plains (Table 3), and with the lower part of the Upper Mannville Group in the southern Alberta Plains.

Moosebar Member

Definition

The type section of the Moosebar Formation of northeastern British Columbia is along the Peace River Canyon (McLearn, 1923, p. 58). It is characterized by dark grey mudstone, with subordinate siltstone and very fine grained sandstone becoming more abundant upward. A description of the type section is given by Stott (1968, p. 48-50), who mapped the formation from the type area as far south as the Smoky River (Fig. 1). The Moosebar Formation overlies the Gething Formation abruptly and disconformably and is overlain gradationally by the Gates Formation.

South of the Smoky River, the Moosebar has been recognized previously at only one locality, Cadomin (Mellon and Wall, 1961, 1963; Mellon, 1967) and has not been mapped. While it has been possible, during this study, to identify the Moosebar in all sections examined north of the Clearwater River, the mappability of the unit is doubtful and, for this reason, the Moosebar has been reduced to member status within the Malcolm Creek Formation. The Moosebar Member abruptly and disconformably overlies the Gladstone Formation and is overlain gradationally by the Torrens Member of the Malcolm Creek Formation.

The Moosebar is given only member status wherever the Malcolm Creek Formation is recognized even though it has demonstrated mappability in the area between the Smoky River and the British Columbia-Alberta border. The name Malcolm Creek Formation is utilized only south of the termination of the Hulcross Formation where the Gates and Boulder Creek Formations of northeastern British Columbia cannot be differentiated (Table 2; Fig. 2). This occurs near the British Columbia-Alberta border since the Hulcross Formation is last recognized at the Torrens Ridge section (Fig. 1). Therefore, the Moosebar Member is recognized in the Alberta Foothills from the British Columbia border to the Clearwater River (Fig. 1).

Distribution and thickness

The Moosebar Formation generally decreases in thickness towards the southeast in the British Columbia Foothills from about 290 m at the type section (Stott, 1963b, 1968) to 70 m at Torrens Ridge.

The thickness of the Moosebar Member also generally decreases to the southeast in the Alberta Foothills (Fig. 2), but there is a reversal of this trend in the central Foothills region from Cadomin to Chungo Creek (Figs. 1 and 2) where the member is up to 117 m thick. Southward, the Moosebar thins rapidly and is very thin or absent south of the Clearwater River (Fig. 1). A very few arenaceous foraminifera (J.H. Wall, per. comm.) recovered from the section at Waiparous Creek (Fig. 1) may be from the most southern extremity of the Moosebar tongue in the Foothills. Generally, the member becomes thinner to the west as the upper part passes by facies change into the base of the Torrens Member.

Lithological characteristics

The basal few centimetres to decimetres of the Moosebar Member is characterized by a layer of pebbles, up to 10 cm in maximum dimension, in a mudstone matrix (Plate 3A). Glauconite grains constitute a small but distinctive proportion of this basal zone, giving it a readily recognized greenish hue. The pebble bed and glauconite have not been observed south of the Clearwater River (Fig. 1).

Mudstone, dark grey to dark olive-grey on fresh surfaces, weathering medium to medium-dark grey, is the most typical lithology. It is usually noncalcareous, but often ferruginous. Hard, rusty-weathering, sideritic concretions are common in some sections. They usually occur as flattened ellipsoidal nodules but in places as continous beds a few centimetres thick. Laminations and thin interbeds of siltstone occur at the base of the Moosebar in the the more southerly sections and increase in number and thickness upward, being replaced by very fine-grained sandstones higher in the section (Plate 4A and B). Sections in the north (e.g. Gustavs Flats, Fig. 2) generally contain less siltstone at the base but siltstone increases in abundance upward as in the southern sections. The top of the Moosebar Member is placed at the base of the first thick to massive sandstone bed above which few, or no, mudstone beds occur. In the writer's experience, there is always a clear distinction between the interbedded mudstone and sandstone of the Moosebar Member and the predominant sandstone of the Torrens Member. Normal graded lamination and thin beds are common. Evidence of bioturbation in the form of burrows and fecal pellets was observed in all sections (Plate 3B). Both are best preserved in interlaminated mudstone and siltstone sequences. Thin, carbonaceous-rich laminations and disseminated, finely comminuted carbonaceous material are more common upward in the section where bioturbation is less prominent.

Age and correlation

Extensive collections of foraminifera, recovered from the Moosebar Member and identified by J.H. Wall of the Geological Survey of Canada (pers. comm., 1980), give a general age of Early to Middle Albian. Specimens from a section near Grande Cache were dated more specifically as early Middle Albian and, at the Little Berland River location (Fig. 1), the Moosebar was dated as Middle Albian. No zonation within the Moosebar appears possible at present.

The Moosebar Member correlates with the Moosebar Formation of northeastern British Columbia and with the Clearwater Formation of the central to northern Alberta Plains. The pebble and glauconite unit at the base is homotaxially and genetically related to the Glauconitic Sandstone of the southern and central Plains of Alberta (Table 3) and the Wabiskaw Member of the Clearwater Formation in the northeastern Alberta Plains.

Torrens Member

Definition

The type section (holostratotype of Hedberg, 1976) of the Torrens Member (Fig. 1) is on an unnamed creek flowing southwest into Saxon Creek from the ridge on which Mount Torrens is situated (Table 4). Figure 3 shows a stratigraphic column of the type section and a written description is given in the appendix. Plates 4A and B illustrate the transitional contact with the Moosebar Member.

The type section is located at the last section in which the Hulcross marine shale was recognized. To the north of the type section, the Boulder Creek and Gates Formations are recognized, separated by the Hulcross Formation. However, to the south, the Hulcross has not been observed and the nomenclature of the central and northern Alberta Foothills is applied. The Torrens is herein defined as a member of the Malcolm Creek Formation but it is also a readily recognizable unit in the Gates Formation of northeastern British Columbia and has been used extensively as a marker horizon in detailed mapping by coal companies actively exploring throughout the region. For this reason, the type section is ideally located so that it is representative of the member in both the Malcolm Creek and Gates Formations.

The member is distinct because it is a prominent resistant unit bounded by two less resistant units - the Moosebar below and the Grande Cache Member above (or the coal-bearing Gates in northeastern British Columbia). The base of the member is as defined in the description of the Moosebar Member. The top is placed at the top of the predominantly sandstone sequence below the less resistant mudstone and coal beds of the overlying Grande Cache Member. In many places, a coal seam directly overlies the Torrens Member (see Fig. 2, Gustavs Flats Section; Plate 4B).

Distribution and thickness

The Torrens Member is 39 m thick at its type section and thins gradually to the southeast as shown in Figure 2. South of the North Saskatchewan River (Fig. 1), it is very weakly developed in some sections, but is a prominent unit in others.

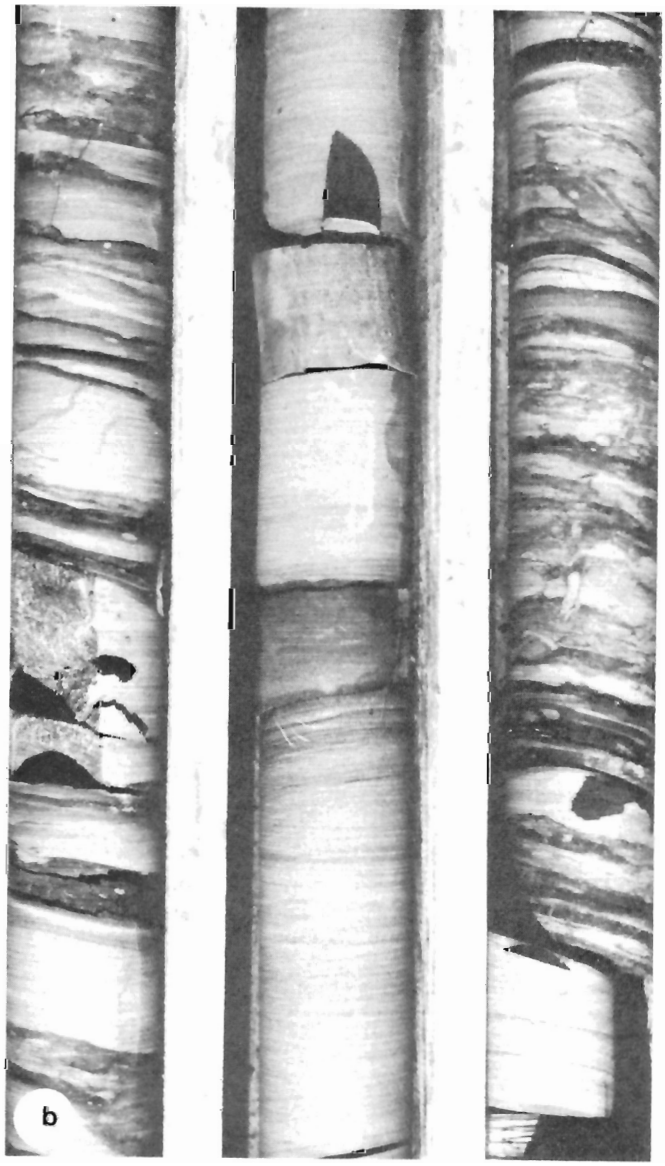


PLATE 3a. *Pebble bed at base of Moosebar Member, Malcolm Creek Formation. Wapiabi Creek section. ISPG 1356-24.*

PLATE 3b. *Upper part of Moosebar Member, transitional to Torrens Member. Note extensive bioturbation in part. Striations at acute angle to bedding are due to rotation inside core barrel. Little Berland core 70-02. ISPG 1356-9.*

North of the type section, the extent of applicability of the name Torrens Member is not known exactly. There is strong evidence south of the Wolverine section (Figs. 1 and 2) of an intertonguing relationship between the lower Gates Formation and the Moosebar Formation, so that the basal sandstone of the Gates in one area may be physically distinct from the basal sandstone in another area. No marine tongues have been identified within the Gates Formation south of the Wapiti River (Fig. 2), but one or more tongues are known to exist in some sections to the north. The exact southern limit of these tongues is not known at present. Tentatively, use of the name Torrens is extended as far north on the Wapiti River. Further work will be required to determine whether it can be extended farther north or must be restricted farther to the south.

Lithological characteristics

The Torrens Member is characterized by sandstone, from very fine-grained to very coarse-grained with beds of conglomerate. South of the type section, very fine to fine-grained sandstone predominates but coarser clast sizes are common. An overall upward increase in grain size was observed in most sections although the amount and manner of increase are highly variable. At the type section, two coarsening-upward sequences were observed (Fig. 3), the upper meter of the upper sequence containing pebble-size clasts. Above a thin recessive interval, a prominent fining-upward sequence forms the uppermost unit of the Torrens Member. This reversal of grain size trend was observed in several other sections, but is not a consistent feature. Some of the lateral variation may be seen in Figure 2.

Horizontal bedding and lamination is often well developed. Crossbedding was observed in nearly all sections, with shallow troughs and long, low-angle wedge sets predominant in the coarsening-upward sequences. Trough and planar crossbed sets were observed in the fining-upward sequence at the top of some sections. Cross-lamination was observed in most sections. Rip-up clasts, usually composed of

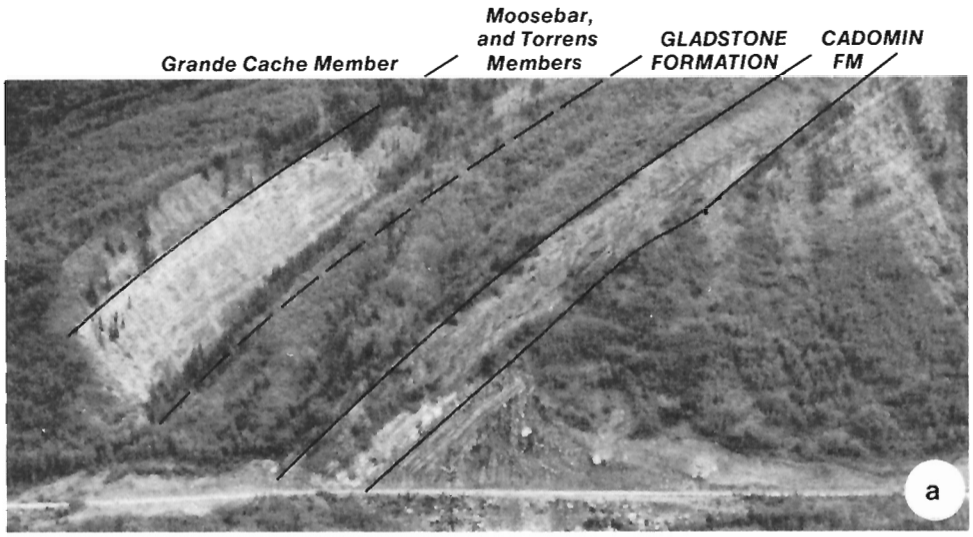


PLATE 4a. *Cadomin, Gladstone and Lower Malcolm Creek Formations, Grand Mountain, looking east across Smoky River. ISPG 1437-1.*

PLATE 4b. *Upper Moosebar Member, Torrens Member, and coal at base of Grande Cache Member, Malcolm Creek Formation. Ruby Creek section. ISPG 1356-8.*

angular to rounded fragments of mudstone, are a common constituent. Burrows and churned beds are common in the lower part of the member in most sections but are rare in the upper beds. A massive appearance characterizes some outcrop sections of the Torrens Member. This lack of apparent sedimentary structures appears to be due to a lack of the distinctive mineralogical differentiation which forms lamination and accentuates structures in other sections.

Age and correlation

No diagnostic fossils were collected from this member. However, its vertical and lateral gradational contact with the Moosebar Member implies contemporaneity and, therefore, a probable age of Middle Albian is indicated.

The Torrens Member correlates with the basal sandstone member of the Gates Formation and, as discussed above, the name appears to be applicable as far north as the Wapiti River (Fig. 1). It is also correlative with the basal part of the Grand Rapids Formation of the central to northern Plains of Alberta (Table 3).

Grande Cache Member

Definition

The type section (holostratotype of Hedberg, 1976) of the Grande Cache Member is in a prominent bulldozer cut along the base of Mount Hamell, just north of Gustavs Creek on the northwest side of the Smoky River near the town of

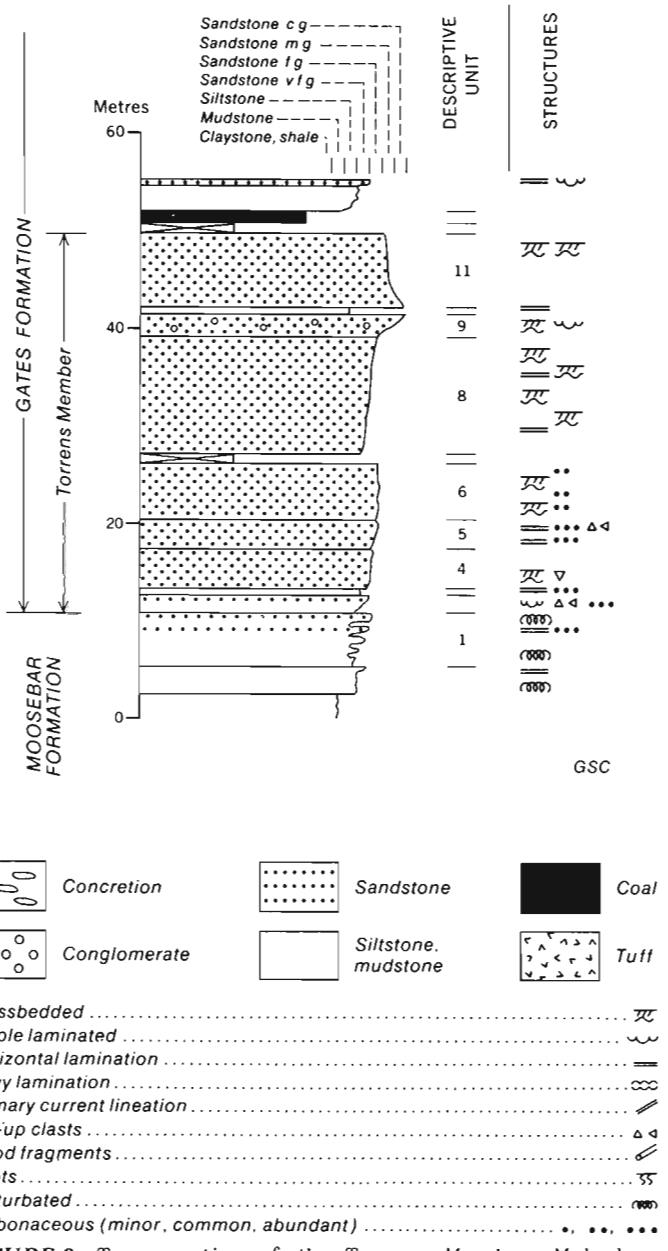


FIGURE 3. *Type section of the Torrens Member, Malcolm Creek and Gates Formations, Torrens Ridge section.*

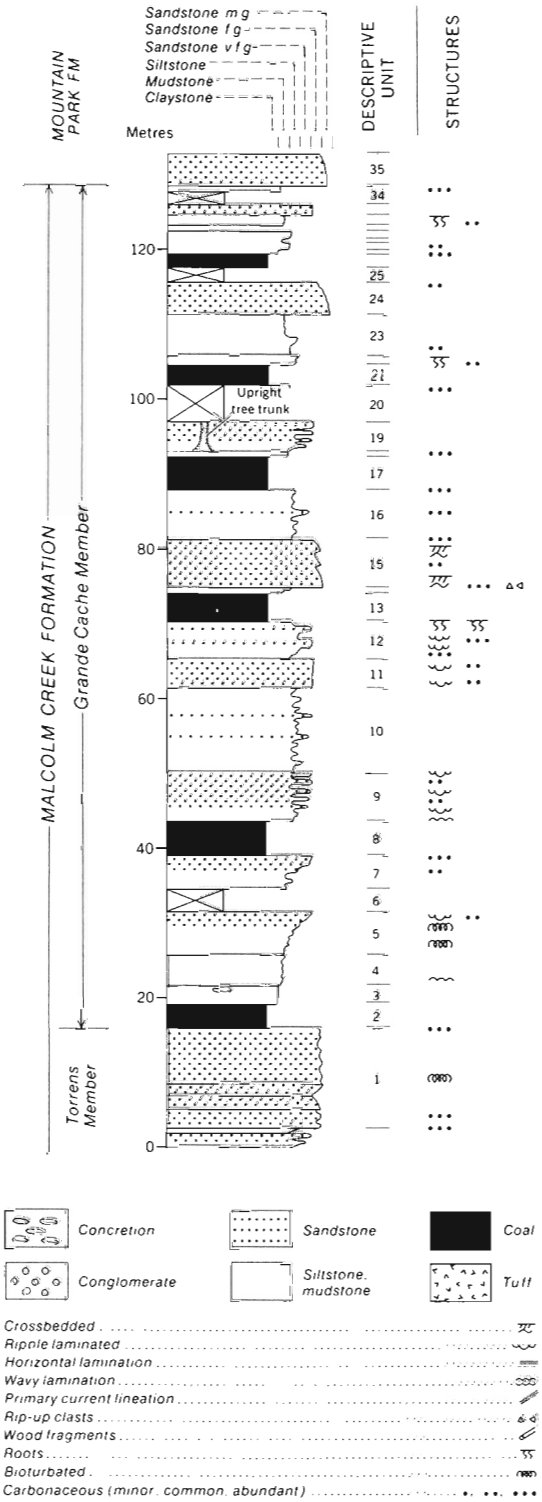


FIGURE 4. *Type section of the Grande Cache Member, Malcolm Creek Formation, Gustavs Flats section.*

Grande Cache (Fig. 1; Table 4). The cut was made during an exploration program by McIntyre Mines Ltd. and at least 7 adits were opened in 6 thick coal seams. The entire member is well exposed. Figure 4 shows a stratigraphic column of the type section. Some of the section is illustrated in Plates 5A, B and C. A written description of the section is given in Appendix A.

The Grande Cache Member overlies the Torrens Member abruptly but conformably. Sediments of the basal Grande Cache are finer grained on the whole and more recessive than the Torrens Member and, in many sections, a coal seam rests directly on the Torrens Member. The Grande Cache Member contains all of economically important coal seams south of the Grande Cache area (see Fig. 2 and the text on Geology of Coal Seams). The contact of the member, and therefore the top of the Malcolm Creek Formation, with the overlying Mountain Park Formation, is placed at the base of the first prominent sandstone unit with an abrupt basal contact and generally fining-upward grain size distribution, above the highest major seam (>0.6 m thick) in the Grande Cache Member. Reference to Figure 2 shows that this is a workable definition. Where outcrop sections are poorly exposed (as in the Cadomin Section) it may not be possible to delineate the contact with confidence because coal seams may not be exposed and prominent sandstone beds can occur within the coal measures as well as above them. However, in the author's experience, the contact can always be placed within workable limits.

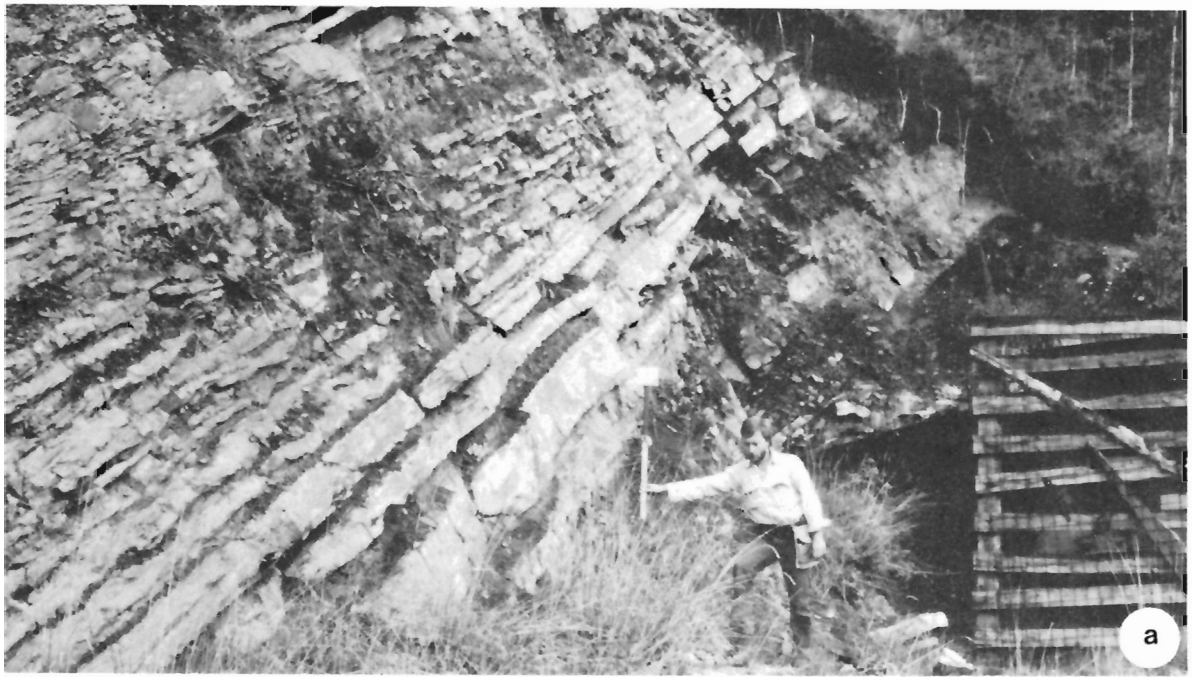


PLATE 5a. *Interbedded sandstone and mudstone overlying No. 4 seam in Grande Cache Member, Malcolm Creek Formation. Gustavs Flats section. ISPG 1356-7.*

PLATE 5b. *Channel sandstone scoured into mudstone overlying a thick coal seam, Grande Cache Member, Malcolm Creek Formation. Gustavs Flats section. ISPG 1356-4.*

PLATE 5c. *Upright tree trunk, 75 cm diameter and 5.2 m long, upper Grande Cache Member, Malcolm Creek Formation. Gustavs Flats section. ISPG 1356-2.*

Distribution and thickness

The Grande Cache Member is characterized by coal seams and is recognizable on this basis in the Foothills from the Alberta-British Columbia border in the northwest to Waiparous Creek (McLean, 1976) in the southeast (Fig. 2). South of Waiparous Creek, no coal has been observed and the Torrens and Moosebar Members have pinched out as well, so that the Malcolm Creek Formation is no longer recognized and the Mountain Park Formation occupies the entire interval from the top of the Gladstone Formation to the base of the Blackstone Formation. At this point the Beaver Mines Formation supplants both the Mountain Park and Malcolm Creek Formations (Table 2, Fig. 2).

The Grande Cache Member generally thins to the southeast, from 130 m at Torrens Ridge to 15 m at Waiparous Creek (Fig. 2) but there are numerous local variations in this trend. The member is generally thinner to the southwest, while there is a complementary thickening of the overlying Mountain Park Formation. However, the Grande Cache Member was never observed to pinch out entirely in the southwesterly direction as it does to the southeast.

Lithological characteristics

The Grande Cache Member is characterized primarily by thick coal seams interbedded with predominantly fine clastic sediments (mudstone, siltstones, and very fine-grained sandstones) (Plate 5A) and subordinate coarser grained clastic sediments (Plate 5B). Coal seams range in thickness from a few centimetres to 6 m and occasionally thicker. Both upper and lower contacts of the seams appear abrupt, but a very thin, argillaceous transition zone is commonly present at the base. Roots may occur in the underlying bed but often no roots were evident. Prominently rooted beds of mudstone to fine-grained sandstone without overlying coal seams are common. A few beds might be referred to as seat earths but these are uncommon. Very siliceous root zones were observed in a few places and these may be ganisters (siliceous seat earths).

Mudstones, siltstones and very fine-grained sandstones are ubiquitous and very variable in the relative proportions of each and in their interrelationships. Colours are generally sombre, greys and olive-greys being predominant, but prominent orange-weathering ferruginous beds are common. Fine horizontal lamination is abundant and cross lamination is frequently present in siltstone and very fine-grained sandstone beds. Many beds have a homogeneous appearance. Macerated carbonaceous debris is present in varying proportions throughout the Grande Cache Member and often is concentrated as thin laminations. Disarticulated pelecypod shells were observed in a few beds (Fig. 5) and locally may be useful in correlation. They are all fresh to brackish water forms. Coalified tree trunks in growth position were observed in a few sections. The largest one observed is in the type section where the measured length was over 5 m and the diameter 75 cm (Plate 5C). It extends through units 18 and 19 of Figure 4 and appears to be rooted in the underlying coal bed.

Age and correlation

No diagnostic fossils were collected from the Grande Cache Member. Its age range is limited by the determined ages of the Moosebar Member, Middle Albian, and the uppermost Mountain Park Formation, late Middle Albian or younger.

The Grande Cache Member correlates with part of the Gates Formation above the Torrens Member in the southeastern part of the northeastern British Columbia Foothills. It is homotaxial with part of the Grand Rapids Formation of the central and northern Alberta Plains (Table 3). Lithostratigraphically, it has no equivalent in the Beaver Mines Formation of the southern Alberta Foothills, but is a time equivalent of part of that formation.

Depositional environments

The basal pebble and glauconite unit of the Moosebar Formation records the transgression of the boreal sea southward. The bulk of the Moosebar Member, as well as the Torrens Member, records the regression of the Moosebar sea to the north and east. The presence of a marine fauna and of extensive bioturbation in the Moosebar indicates a shallow shelf setting (McLean and Wall, 1981). The increase in sand content upward indicates proximity of the strandline as it migrated seaward. The Torrens Member represents the relatively high energy shoreline environments from wave base to slightly above sea level. The coal and fine-grained sediments of the Grande Cache Member were deposited in the relatively low energy coastal or delta plain environment behind the shoreline deposits. Coarser grained sandstones in the Grande Cache Member represent delta distributary channels or proximal overbank sediments.

Mountain Park Formation

Definition

The name Mountain Park was first introduced by MacKay (1929a, b, c; 1930). The name is that of a mining town which was active until 1950, but which is now abandoned; little remains of this once thriving community (Ross, 1974).

MacKay (1930, p. 477) observed an apparent lithological difference between the upper beds (Mountain Park Formation) and the underlying coal-bearing beds (Grande Cache Member),

> . . . as expressed in the dark, olive-green and brick-red weathering appearance of the former, the presence in them of thick lenses of black chert conglomerate, their greater resistance to weathering and the absence in them of commercial coal seams; . . .

He was doubtful that any one horizon could be traced for any great distance over the area but suggested that the upper beds were sufficiently distinct from the underlying coal-bearing beds to warrant an attempt to delineate them as a separate mappable unit. Subsequent work by several geologists (Erdman, 1945, 1950; Henderson, 1945; Douglas, 1956a and b) has followed the lead of MacKay, particularly in the area between the North Saskatchewan River and the Cadomin-Luscar area (Fig. 1). The definition of Douglas (1956a, p. 20 and 22), as stated earlier seems to be the most useful definition.

The lower contact with the Grande Cache Member of the Malcolm Creek Formation was defined in a previous section. The major criteria are the paucity or absence of thick coal seams above and the presence of very thick sandstone beds characterized by abrupt bases and usually fining-upward grain size distribution. The greenish colouration is a useful subordinate characteristic in the type area but it is not definitive since greenish hues occur in the coal measures and only gradually intensify upward in the section. Attempts to pick a distinct colour break have been futile. The coal and sandstone criterion is much more useful and consistent for differentiation of the Mountain Park from the underlying beds. To the northwest along the trend of the Foothills (Fig. 2) the greenish colouration rises stratigraphically and diverges from the base of the Mountain Park Formation as used in this report.

It may happen that there are no distinct sandstone beds in a section which would serve as a base for the Mountain Park Formation. The reason for this is discussed under depositional environments. In such a case, the base of the formation must be placed at the top of the highest major seam (>0.6 m thick) in the Grande Cache Member.

MacKay (1930, p. 128) suggested that the Mountain Park Formation thins markedly north of the Cadomin-Luscar area and is thin or absent at Brûlé (Fig. 1). Lang (1947) in the Brûlé area and Irish (1965) in the Foothills north of Brûlé did not recognize the Mountain Park but included all beds between the Cadomin and Blackstone Formations in the Luscar Formation. MacKay (1955) felt that the Mountain Park could be recognized in the Pocahontas area (Fig. 1), and Mountjoy differentiated the Mountain Park Formation from Luscar in the Miette area.

The cross-section (Fig. 2) along the Foothills shows that the Mountain Park Formation, as defined above, can be recognized as a distinct unit from Waiparous Creek to Torrens Ridge. Between the Athabasca River and Grande

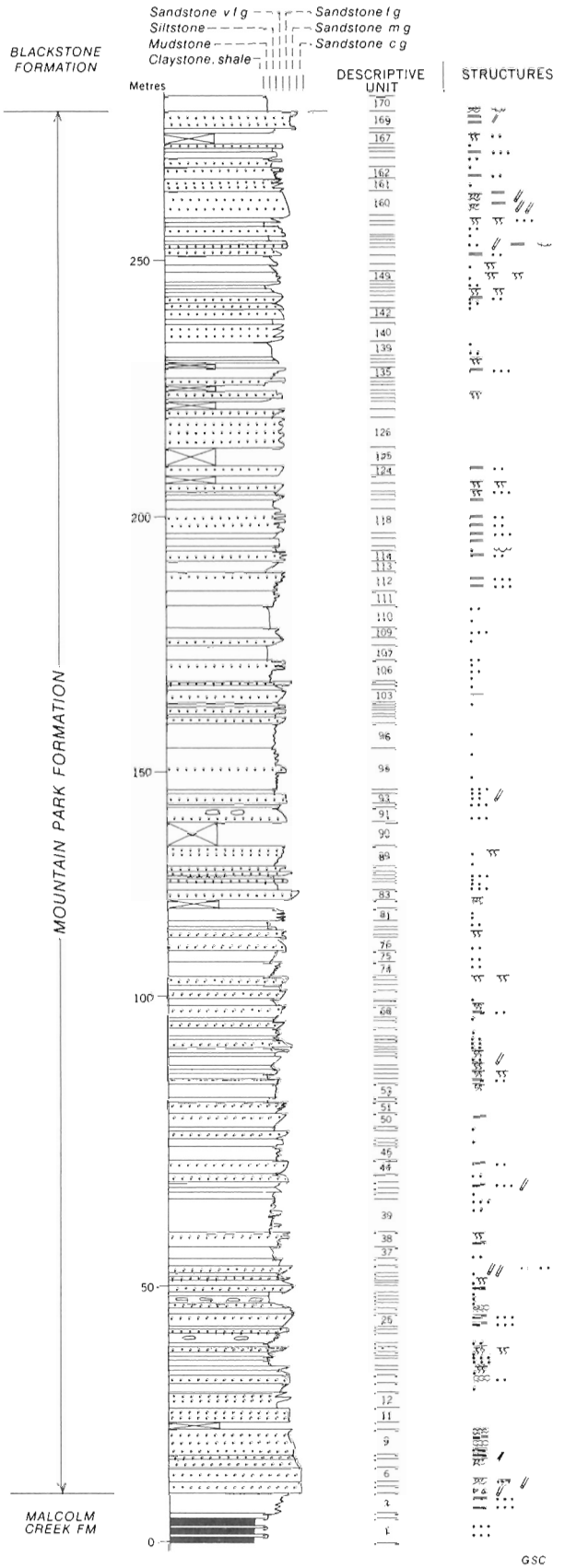


FIGURE 5. Hypostratotype of the Mountain Park Formation, Wapiabi Creek section.

Cache area, the Mountain Park Formation is not as well developed as it is to the south or north. The thick sandstone beds are poorly developed, resulting in a more subdued topographic expression for the unit as a whole and a scarcity of well-exposed sections. However, in the Little Berland River section (Fig. 2), the Mountain Park Formation contact with the underlying Malcolm Creek Formation is distinct. To the north, in the Grande Cache area, the Mountain Park is strongly developed with prominent thick sandstone beds above the coal measures as shown in the Malcolm Creek section (Fig. 2).

The Mountain Park Formation is overlain abruptly and disconformably by the Blackstone Formation, or Shaftesbury Formation north of the Athabasca River. The latter two are predominantly dark grey mudstones and siltstones in contrast to the lighter colours and coarser grained sediments of the Mountain Park.

A complete section of the Mountain Park Formation was not observed by the author in the type area and no type section was designated by MacKay (1930). Two reference sections (hypostratotypes of Hedberg, 1979) are presented here which exemplify the diagnostic characteristics of the formation. The Wapiabi Creek section (Fig. 1) is located in the Bighorn Basin, 20 km north of the North Saskatchewan River and 80 km south of the Mountain Park area. A stratigraphic log is shown in Figure 5, and a written description is present in Appendix A. The Malcolm Creek section (Fig. 1) is located just northwest of the Smoky River across the river from the town of Grande Cache. It is 180 km north of the Mountain Park area. A stratigraphic log is shown in Figure 2, and written description is presented in Appendix A.

Distribution and thickness

The Mountain Park Formation is recognized in the Foothills from Waiparous Creek to Torrens Ridge (Fig. 1 and 2), and is usually best developed in the more westerly sections. It is 275 m thick in the Wapiabi Creek reference section and 210 m thick in the Malcolm Creek section. Lateral variations can be observed in Figure 2. South of Waiparous Creek, the Mountain Park Formation is replaced by the Beaver Mines Formation and north of Torrens Ridge by the upper Gates, Hulcross, and part of the Boulder Creek Formations. Its use is confined to the Foothills.

Lithological characteristics

The most diagnostic lithology is sandstone in thick to massive beds, with abrupt bases and usually a decrease in mean grain size upward (Plate 6A and B). The top is often gradational with the overlying bed. Extraformational pebbles, rip-up clasts and coalspar (coalified wood fragments) commonly occur at the base. Grain size at the base may be very coarse to fine. Weathering colours range from greys to light brown and rusty orangish browns. In sections south of the type section (Fig. 1) and upward in the formation, greenish-grey colours are prominent. Fresh colours are predominantly greys and greenish-greys. Sedimentary structures in the sandstone include crossbedding, cross lamination, primary current lineation, flute marks, horizontal lamination, and minor load casts. Examples of lithological characteristics are shown in Figure 2 and in the two reference sections.

Between the sandstone units are thick sequences of interbedded mudstone, siltstone and sandstone with subordinate claystone and coal. Beds may be very thin to very thick and frequently are laminated. Weathering colours are predominantly greys to black, and shades of brown, but greenish-grey is prevalent in the more southerly sections and in the upper part of the formation in all sections. Fresh colours have a similar range and distribution pattern. Lithologies were observed in several associations with coarsening-upward sequences most common. Such sequences begin with a mudstone and progress upward without perceptible break to siltstone or very fine-grained sandstone. Often such successions are laminated, and siltstone laminae will gradually become dominant over mudstone laminae upward. There are many variations in this type of sequence. Fining-upward sequences of sandstone or siltstone to mudstone are also common. Carbonaceous mudstones and coal occur frequently in sections in which greenish-grey is not the predominant colour. Carbonaceous material is absent to rare in the more southerly sections and is less common upward in all sections. The absence of carbonaceous fragments in the more predominantly greenish-grey sedimentary sequences makes it very difficult to recognize primary sedimentary structures since it is the segregation of carbonaceous particles which usually produces lamination that defines these structures. Isolated outcrops in structurally disturbed areas may be difficult to orient due to a lack of structures which could indicate the order of superposition. Bentonite beds are not common but have been identified in a few sections.

The contact between the Mountain Park Formation and the overlying Blackstone or Shaftesbury Formation is abrupt and distinct (Plate 7A). Sandstone or greenish-grey mudstone is overlain by dark grey mudstone and often by a thin pebble bed which is included in the overlying formation (Plate 7A). Beds of quartzose siltstone or very fine grained sandstone, occasionally with pebble beds, are present above the contact and above dark mudstone beds in many sections. They are the upper units of coarsening-upward cycles in the Sunkay Member of the Blackstone Formation (Stott, 1963a).

Age

The lower age limit of the Mountain Park Formation is defined by the fauna in the Moosebar Member as Middle Albian. The upper age limit is slightly higher in the north than in the south, based on palynology studies by A.R. Sweet of the Geological Survey of Canada (pers. comm., 1979). Palynomorphs from the upper 50 m of the Mountain Park Formation at Malcolm Creek, and also from the Mount Louie section just south of the Smoky River (Fig. 1), have affinities to the dicotyledonous flora observed in the Hulcross and Boulder Creek Formation at Mount Belcourt (Fig. 1) by Mellon and Wall (1961, 1963) and Mellon, Wall and Stelck (1963). Samples from the upper beds of other sections in the northern and central Foothillls did not yield any comparable dicotyledonous flora.

It appears, therefore, that the upper part of the Mountain Park Formation in the vicinity of Grande Cache has an age of late Middle Albian or younger (A.R. Sweet, pers. comm., 1979) and a slightly older age in the remainder of the northern and central Foothills.

Depositional environment

The Mountain Park Formation is conformable with the Malcolm Creek Formation and represents an upslope facies of the overall regressive sequence represented by that formation. The thick, fining-upward sandstones are interpreted as fluvial channel deposits and the sediments between as floodplain deposits.

Because river channels migrated with time, the channel sandstones occur at different stratigraphic levels in different sections. Moreover, they do not normally migrate uniformly across the entire alluvial plain, so that certain locations may have several channel deposits whereas others may have none.

Relationship of the Malcolm Creek, Mountain Park, and Beaver Mines Formations

The stratigraphic sequence between the Gladstone and Blackstone Formations in the central and northern Alberta Foothills is in the same geometric position (homotaxially

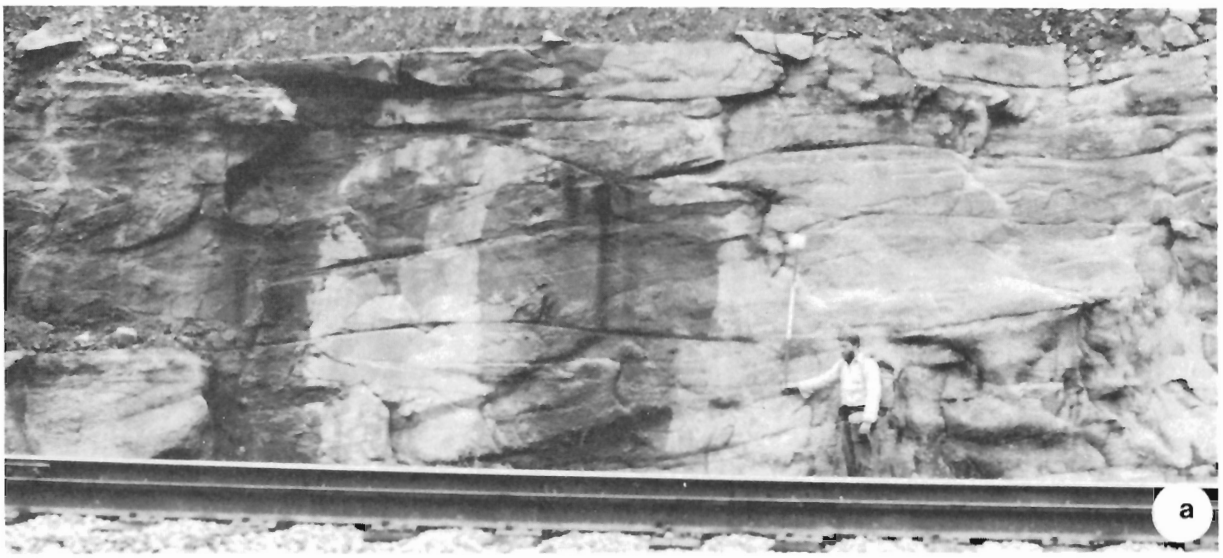


PLATE 6a. *Fluvial channel sandstone, showing thick planar tabular crossbed coset, in Mountain Park Formation. Along railroad, east side of Smoky River, opposite the McIntyre coal mine. ISPG 1356-13.*

PLATE 6b. *Prominent fluvial channel sandstones of the Mountain Park Formation overlying coal-bearing Malcolm Creek Formation. Bighorn River, west of Nordegg. ISPG 663-17.*

equivalent) as the Beaver Mines Formation in the southern Foothills. The Ma Butte and Crowsnest Formations which lie between the Beaver Mines and Blackstone Formations in the southern Foothills (Table 2) are known to be younger than the highest beds of the Mountain Park Formation (Mellon and Wall, 1963). It has been suggested by Mellon (1967) that the name Beaver Mines is applicable to the combined Malcolm Creek and Mountain Park Formations of this paper. However, this is not acceptable practice in lithostratigraphic nomenclature according to the widely used Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1970).

The type section of a formation constitutes the standard for the definition and recognition of that stratigraphic unit. The International Stratigraphic Guide (Hedberg, ed., 1976, p. 39) advises that, "A lithostratigraphic unit and its boundaries should be extended away from the type locality only as far as the definitive lithologic features on which the unit was based in its type section are known certainly to exist . . .". The lithologies present in the Malcolm Creek Formation are not represented in the type section of the Beaver Mines Formation and, therefore, that type section is completely inappropriate to the definition or recognition of the Malcolm Creek sequence.

Lithologically, the Mountain Park Formation is similar to the type Beaver Mines Formation, although the distinctive greenish-grey weathering colour of the Beaver Mines becomes more subdued, and in the Grande Cache area is almost entirely absent except in the highest beds.

It would be possible to use a single name for this unified Beaver Mines-Mountain Park interval, and Mountain Park has precedence. However, the name Beaver Mines has been used extensively in mapping between Sheep and Ram Rivers (Fig. 1) (Ollerenshaw, 1968, 1969, 1972a, 1979; Price and Ollerenshaw, 1971a, c) and it would be undesirable to drop a name which is both useful and entrenched. The Mountain Park Formation, likewise, has been shown to be a useful, mappable formation (MacKay, 1929a, 1940, 1943; Crombie and Erdman, 1946; Douglas, 1956a, 1958; Mountjoy, 1960b) and is firmly entrenched in the literature. Some difficulty was experienced by early geologists in mapping it north of the Athabasca River because of poor outcrop but, as shown above, it can be mapped up to the Alberta-British Columbia border using the definition of Douglas (1956a).

Ollerenshaw (1968, 1969), on maps already published between Waiparous Creek and Ram River (Fig. 1), used the name Beaver Mines Formation to encompass strata now included in the thin Grande Cache Formation (Fig. 2). This followed the proposed extension of the Beaver Mines Formation as far north as Cadomin by Mellon (1967). For the reasons stated above, the name Beaver Mines is not strictly valid in the region north of Waiparous Creek. However, it is possible that the thin Malcolm Creek Formation near its southern pinchout is not mappable, and since mappability is a primary prerequisite in establishing a formation (American Commission on Stratigraphic Nomenclature, 1970, article 6), it is suggested that an arbitrary boundary be set at Ram River (Fig. 1), south of which the remnant of the Malcolm Creek Formation could be included as an unmapped member of the Beaver Mines Formation. If it is found to be mappable separately in the future, then the name Beaver Mines should not be used and the name Mountain Park would be applied to the upper part of the sequence above the Malcolm Creek Formation. North of the Ram River, both the Malcolm Creek and Mountain Park Formations are mappable.

Correlation between Alberta and northeastern British Columbia

The Moosebar Member of the Malcolm Creek Formation (Table 2) is directly correlative with the Moosebar Formation of northeastern British Columbia but was reduced to member status because its mappability is uncertain in the Alberta Foothills.

The Torrens Member of the Malcolm Creek Formation is directly correlative with the basal sandstone member of the Gates Formation (Table 2). The name Torrens is equally applicable in northeastern British Columbia, as discussed previously.

The Grande Cache Member correlates with the lower, coal-bearing part of the Gates Formation above the Torrens Member. Preliminary study indicates that it encompasses the entire post-Torrens part of the Gates north of the Wapiti River. However, no formal subdivision of the Gates Formation above the Torrens is suggested at present.

The Mountain Park Formation occupies a stratigraphic interval between the Malcolm Creek and the Shaftesbury Formations in the Grande Cache area and is correlative with an upper part of the Gates Formation, plus the Hulcross and Boulder Creek Formations in northeastern British Columbia (Table 2). No break in sedimentation has been observed although floral evidence indicates that there are no time-equivalent beds to the Hulcross-Boulder Creek succession, south of the Grande Cache area. In any case, considerations of time properly play no part in lithostratigraphy. The lower boundary of the Mountain Park Formation can be seen to rise stratigraphically in the Gates Formation northward, and equivalent beds appear to be absent north of the Wapiti River.

Ma Butte Formation

Definition

The name Ma Butte Formation is herein proposed for the succession of interbedded mudstone, siltstone, and sandstone with subordinate conglomerate, agglomerate, tuff, and bentonite which occurs above the Beaver Mines Formation as defined by Mellon (1967) and below the Crowsnest Formation as defined by MacKenzie (1914), Douglas (1950), Norris (1964, 1978), and Pearce (1967). The name replaces the lower part of Mellon's (1967) Mill Creek Formation (Tables 1 and 2).

Mellon (1967, p. 23) distinguished his Mill Creek beds from the Beaver Mines Formation on the basis of sandstone composition and floral content. The sandstone compositional change is from feldspathic in the Beaver Mines Formation to quartzose in the Ma Butte Formation. The former usually has a greenish-grey colour whereas the latter tends to be light grey. The change in lithology was first noted by Douglas (1950, p. 25) and was described by Glaister (1959), but neither gave a separate name to the upper unit. Norris (1964) recognized the change and separated the two units, informally calling them middle and upper Blairmore respectively. He proposed the section on the east face of Ma Butte as the principal reference section for the entire Blairmore Group because (1) it is in the type area of earlier workers and is centrally located within the type area; (2) much of the group is well exposed; (3) the stratigraphic position of the upper and lower Blairmore floras are accurately located there. It is this same section which is proposed as the type section of the Ma Butte Formation (Table 4). Figure 6 is a stratigraphic log of the type section. A written description is given in Appendix A.

The floral break, while not legitimately a determining factor in lithostratigraphy (American Commission on Stratigraphic Nomenclature, 1970, Art. 4c and 4d) is of great interest. Two distinct floral groups, nondicotyledonous and dicotyledonous, were recognized by J.W. Dawson (1886) in the Crowsnest Pass area. He named the higher, dicotyledonous-bearing beds, the Mill Creek Series. Thus, the name Mill Creek was first used for a biostratigraphic unit. The distinct break in floral succession was recognized by McLearn (1916) and subsequent workers and was particularly emphasized by Mellon (1967) as a distinct break in the depositional history of the Crowsnest Pass area. The fact that there is a distinct break in the composition of sandstones at the change in flora makes this boundary an important lithostratigraphic horizon, and exceptionally useful in interpretation of depositional history.

The contact of the Ma Butte Formation with the Crowsnest Formation is conformable and gradational (Mackenzie, 1914; Pearce, 1967). Pearce (1967, p. 15) noted that there is interfingering of the Ma Butte and Crowsnest Formations and some mixing of lithologies on a limited scale. There is no single horizon at which the boundary can be placed throughout the area. Norris (1964, p. 530) indicated that "... there is commonly a gradation upwards from

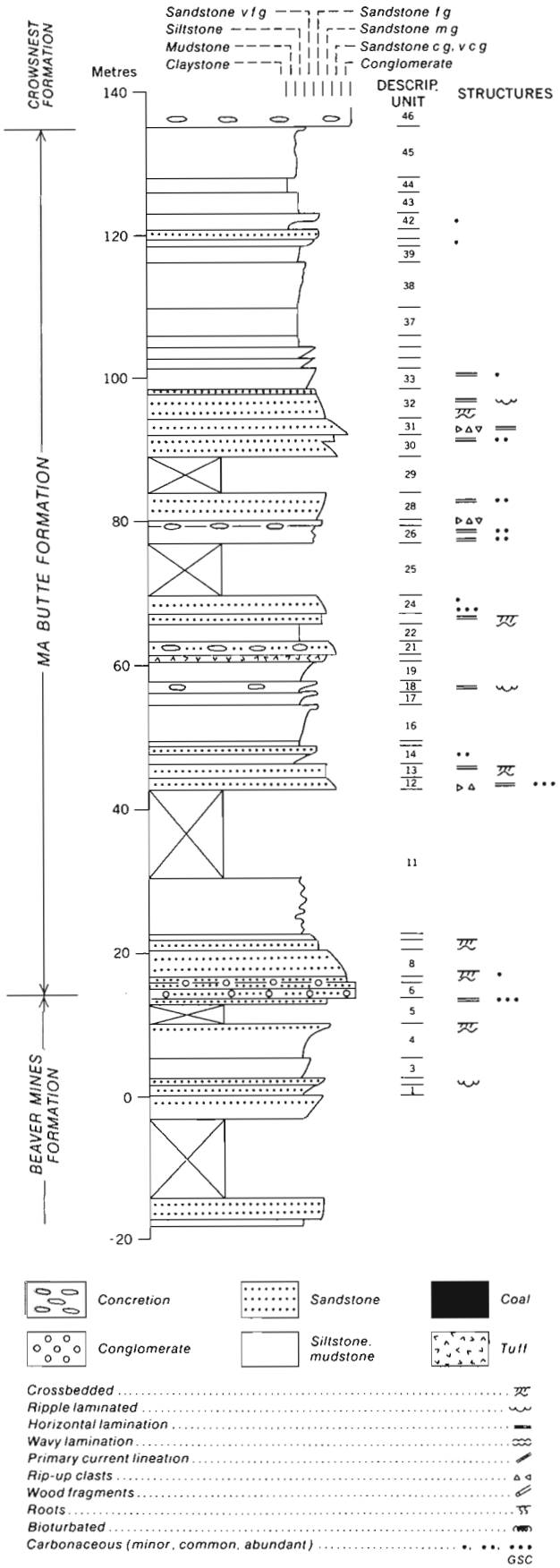


FIGURE 6. *Type section of the Ma Butte Formation, Ma Butte section.*

feldspathic sandstones of the Blairmore Group through sedimentary tuffs and volcanic conglomerates to typical tuffs, agglomerates and breccias of the Crowsnest Formation. Away from the source, Blairmore type sandstones are interbedded with Crowsnest Formation." He goes on to say, "The contact is therefore gradational and cannot be drawn at precisely the same bed regionally, because it is subjectively defined where there is an obvious decrease downwards in volcanic detritus."

Some intertonguing of volcanogenic sediments with the typical epiclastic sediments of the Ma Butte Formation can be seen in Figure 6 (units 20, 21, 27, 38, 43, 45). However, the distinctive change in lithology and induration comes at the base of unit 46 (also see Norris, 1978, Fig. 1), above which volcaniclastic sediments are predominant.

North of latitude 50°, the Crowsnest Formation is absent and the Blackstone Formation abruptly and disconformably overlies the Ma Butte Formation. The contact is usually marked by a thin but distinctive bed or discontinuous layer pebbles, commonly up to 6 or 8 cm in size. The dark grey mudstones of the basal Blackstone are distinct from the Ma Butte Formation which is characterized by shades of greenish-grey, olive-grey and sometimes red or purple.

Distribution and thickness

The distribution and thickness of beds herein included in the Ma Butte Formation have been reported on by previous authors (Douglas, 1950; Norris, 1964; Mellon, 1967) and no field work was carried out by the author on this unit outside the type area. A summary of their observations are included here.

The Ma Butte Formation is 120 m thick at its type section. Mellon (1967) reported 70 m on Mill Creek (Fig. 1), Norris (1964) 132 m on Slacker Creek and Mellon and Wall (1963) 132 m on Sheep River. The formation thins northward with thicknesses of 60 to 90 m between Sheep and Ghost River (Mellon, 1967). Thirty-two kilometres north of Ghost River at Burnt Timber Creek, Mellon (1967) reported that the formation is absent and the Blackstone Formation rests disconformably on the Beaver Mines Formation which contains a nondicotyledonous flora. The author's observations suggest that the uppermost, massive sandstone bed in the Burnt Timber outcrop section (Fig. 2) is distinctly atypical of the Beaver Mines Formation and is included in the Ma Butte Formation.

Eastward from the type area, the Ma Butte Formation has been equated with the Bow Island Formation (Glaister, 1959; Mellon, 1967) which is 90 to 120 m thick, similar to thicknesses in the Foothills outcrop belt. The Bow Island Formation consists, in part, of marine shales which increase in thickness to the east at the expense of the typical Ma Butte lithologies. The upper boundary of the Ma Butte - Bow Island succession is disconformable, being overlain by progressively older Blackstone strata to the east (Mellon, 1967). The name Ma Butte Formation can be used as far east as the first appearance of the dark shale which marks the first marine intertongue of the Bow Island Formation.

Lithological characteristics

The range of lithotypes encountered in the type section (Fig. 6 and type section description) is representative of the lithologies present everywhere in the Ma Butte Formation.

Thick beds of sandstone with abrupt, often scoured, bases and generally fining-upward grain size are volumetrically subordinate to finer-grained sediments, but are important ridge formers (Plate 7B). Intrabasinal gravel-sized clasts and wood casts are common along the base of these units and crossbedding, horizontal lamination and ripple lamination are often well developed. Units 7 to 9, 12 and 13, and 30 to 32 in Figure 6 are good examples of this lithology. Glaister (1959), Rapson (1964), and Mellon (1967) have done petrographic work on sandstones in this formation and the interested reader should refer to those works for details. Conglomerate beds are a minor but conspicuous component and appear to be associated with the sandstone beds discussed above, as in unit 6 of Figure 6. Some of these beds, investigated by Douglas (1950), Anderson (1951), Norris (1964) and Norris et. al., (1965), contain igneous pebbles which are conspicuously absent in lower conglomerate beds.

The greatest percentage of the formation consists of interbedded mudstone, siltstone and very fine-grained sandstone. Often these lithologies are gradational from one to the other, mostly as coarsening-upward sequences, or are thinly interbedded. There are numerous examples of the former in Figure 6, such as units 16 to 18, and 33 to 35. In some, horizontal lamination is clearly defined by finely comminuted carbonaceous debris, but such debris is not common and often these finer grained beds appear massive. Ripple lamination is present in a few beds. Colours are variable but are dominated by shades of greenish-grey, olive-grey and purple or red. A gradation from greenish-grey to purple is common (see description of the type section).

Several volcaniclastic units were observed in the type section (Fig. 6). Unit 20 is believed to be a tuff bed with a distinct amygdaloidal texture. "Speckled" mudstones are common towards the top of the formation in the type section (units 38, 43 and 45, Fig. 6). These mudstones are similar to other mudstone beds but contain green to reddish sand-sized crystals of unknown composition and are labelled "tuffaceous" by Mellon (1967, p. 28). Unit 44 of Figure 6 is a bentonite, with a very pale greenish grey colour. Recognizable volcanigenic sediments are less common in sections to the east and north.

Age and correlation

The Ma Butte Formation contains an abundant and varied flora of dicotyledons (flowering plants), distinct from the flora of the underlying Beaver Mines Formation. This difference has been recognized since the time of J.W. Dawson (1886). Bell (1956, p. 15) assigned an Albian age to this floral assemblage. Mellon (1967, p. 74) suggested an age of late Middle to Late Albian, which seems to be the most reliable determination available.

This flora is younger than any found in the Mountain Park or Boulder Creek Formations but is considered equivalent in age to the Bow Island Formation and the Viking and Joli Fou Formations in the Alberta Plains (Mellon, 1967, Fig. 16).

Depositional environment

The thick, abrupt-based, fining-upward sandstone beds are interpreted as fluvial channel deposits. Finer grained beds between are overbank floodplain deposits. The presence of tuff and bentonite beds indicates that sediment was partially airborne but the relative proportions of airborne to waterborne sediment is unknown. The reddish colouration of many mudstones indicates that floodplain deposits were often exposed to oxidation.

The alluvial plain deposition setting has been suggested by several previous authors (Glaister, 1959; Norris, 1964; Rapson, 1964; Mellon, 1967). Vincent (1977) did a detailed analysis of sections of the entire Blairmore Group on Mill Creek, Sheep River and Burnt Timber Creek. His conclusions for the entire Group including strata now incorporated within the Ma Butte Formation were: (1) fluvial channels were intermediate between meandering and braided; (2) position of channels was stable for extended periods of time producing multi-storied sand bodies and thick overbank sequences; (3) the climate was semiarid to sub-humid with little vegetation on the floodplain. These conclusions appear to be consistent with the author's observations, except that the meandering river model is preferred over the braided river model.

STRATIGRAPHIC SETTING OF COAL SEAMS IN THE MALCOLM CREEK FORMATION

This study indicates that coal seams of present economic interest occur almost exclusively in the Grande Cache Member of the Malcolm Creek Formation. In some sections, seams occur below in the Gladstone Formation and above in the Mountain Park Formation, but are, with few exceptions, thin and economically unattractive. Previous reports by MacKay (1930, 1955) and Mountjoy (1960a) suggested major seams in stratigraphic positions which would place them below the position of the Moosebar Member. It is believed that these seams were mislocated relative to the Cadomin Formation due to structural complexity in a few areas and that they are, in fact, above the Moosebar and Torrens, in the Grande Cache Member.

Figure 7 shows the distribution of seams, determined during this study, in vertical sections from Prairie Creek in the south (approximately latitude 52°, Fig. 1) to the Smoky River in the north (approximately latitude 54°, Fig. 1). The base of the Moosebar Member is the datum. Seam names are indicated where they are in common use in an area.

The lowest coal seam occurs immediately above the top of the Torrens Member, or only a short distance above it, in all sections. This in no way suggests a time equivalence but there is a facies equivalence. These seams may be laterally continuous with one another but this cannot be demonstrated with the outcrop data available and the present limited drilling coverage. This applies equally to the higher seams which can be seen (Fig. 7) to vary in number and spacing from one area to another. Great care must be exercised in correlating seams even over short distances. Figure 8 shows a well documented example of a prominent change in the relative stratigraphic position of coal seams over a distance of only 3 km. Approximately 45 m of strata present in the most southeasterly section are absent 3 km to the northwest. Thus, relative stratigraphic position cannot always be used as a reliable criterion for correlation.

Geological work on the Lower Cretaceous coal measures in the Foothills of Alberta prior to 1930 was summarized by MacKay (1930). Figure 9 is a reproduction of two cross sections by MacKay (1930, Fig. 5) showing schematic vertical sections relating the position of coal seams to the Cadomin Formation in twelve areas between the North Saskatchewan and Smoky Rivers. The approximate location of the base of the Moosebar Member has been added to each section, based on the author's field observations.

The distribution of seams on the Smoky River (Fig. 9) is similar to that observed at Gustavs Flats (Fig. 2), although fewer seams were observed by MacKay (1930). There are several thick seams below the Moosebar Member and, as discussed above, the name Gething Formation is applied in this area. The location of coal seams in sections at Solomon, Brûlé, Prairie Creek, Luscar, Cadomin and Muskiki Lake (Fig. 9) correspond well with information obtained during this study. All seams lie above the Moosebar Member. However,

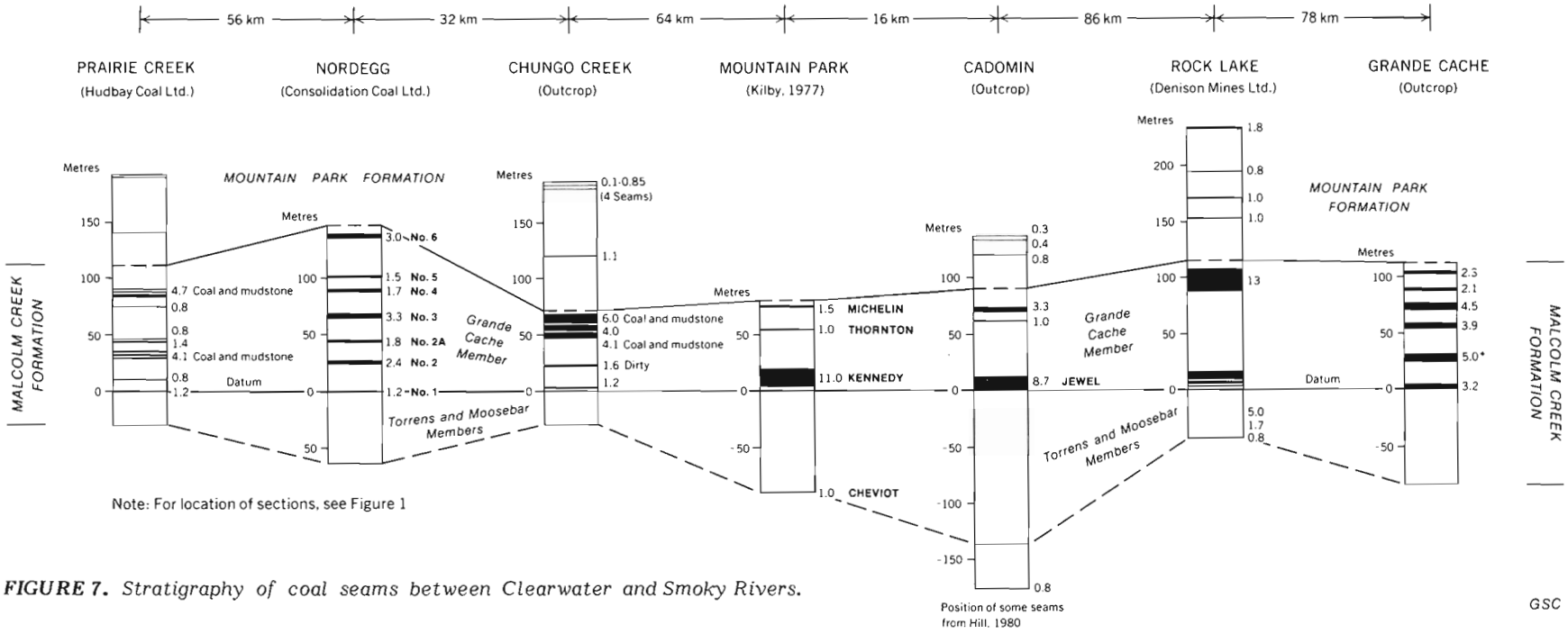


FIGURE 7. *Stratigraphy of coal seams between Clearwater and Smoky Rivers.*

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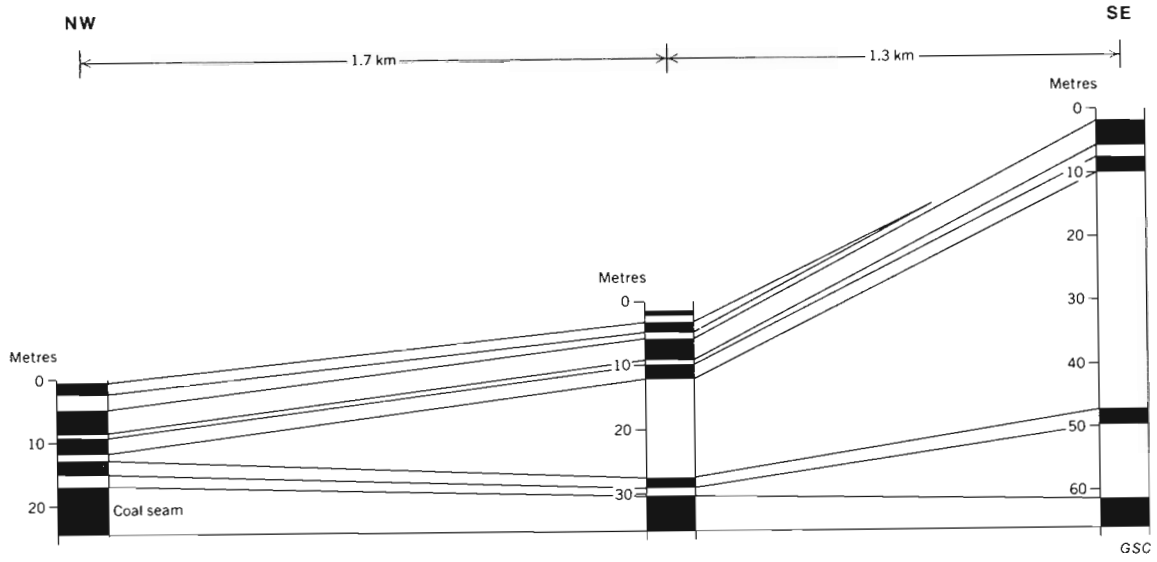

FIGURE 8. *Variation in seam stratigraphy over short distance in the Grande Cache area.*

sections by MacKay (1930) for Muskeg River, Thoreau Creek, Pocahontas-Moosehorn (see also MacKay, 1955), Mountain Park and Bighorn (Fig. 9) show thick seams below the Moosebar Member as well as above. Data from this study as well as other geological work suggests that the lower seams may be mislocated due to repetition of seams by faulting or to poor outcrop which did not allow accurate determination of the stratigraphic positions of the seams.

Kilby (1978) has demonstrated by the use of detailed subsurface correlation that the section at Mountain Park is much less complex that that shown by MacKay (1930). Figure 10 contrasts the two interpretations. All but the 1 m thick Cheviot Seam and the three shaly coals just above the Cadomin are above the Moosebar and Torrens Members. A 0.8 m seam was observed below the Moosebar Tongue in the author's Cadomin section as well.

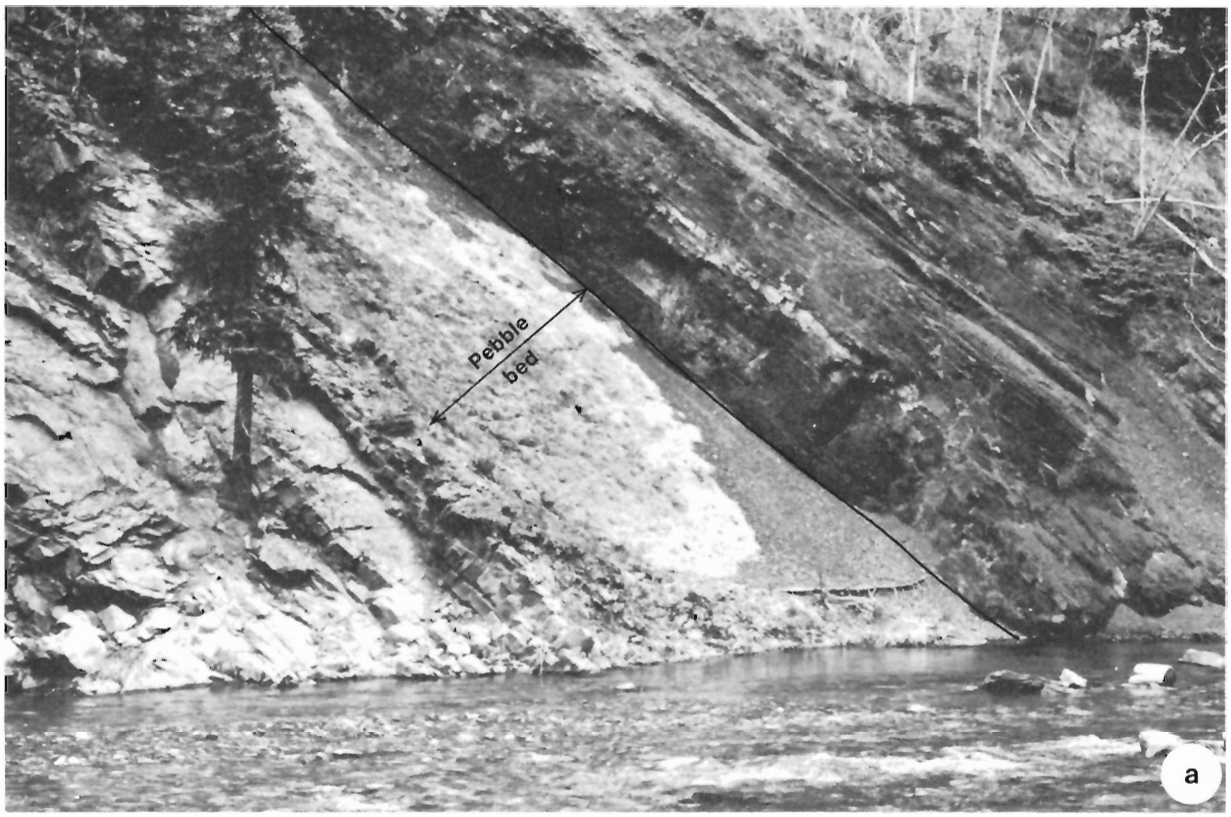

PLATE 7a. *Abrupt, disconformable contact between the Beaver Mines Formation and the overlying Blackstone Formation. Pebble bed exposed along bedding plane is at the base of the Blackstone Formation. Burnt Timber Creek section. ISPG 1356-22.*

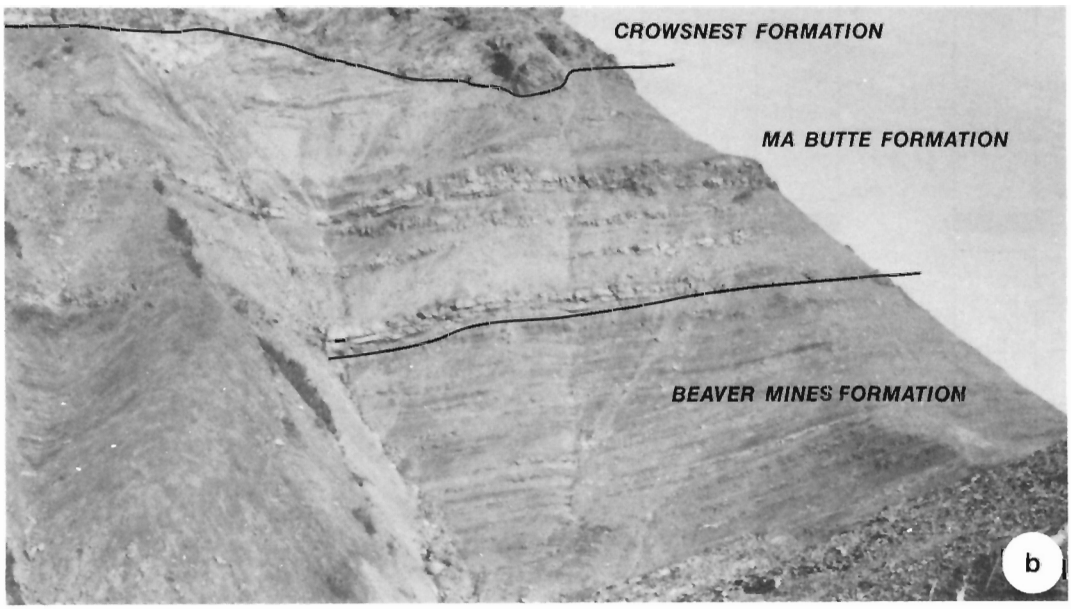

PLATE 7b. *Type section of the Ma Butte Formation with upper part of underlying Beaver Mines Formation and lower part of overlying Crowsnest Formation. Ma Butte section. ISPG 1356-6.*

FIGURE 9. *MacKay's (1930) stratigraphy of coal seams in the Luscar Formation.*

The disposition of seams in the Bighorn Basin is not well documented and MacKay's (1930) information appears to have been derived primarily from the work of Malloch (1911). Two sections, at Wapiabi and Chungo Creeks, were examined during this study and no coal was observed below the Moosebar Tongue. The 4.0 and 0.6 m seams of MacKay (1930) are believed to have been incorrectly located relative to the Cadomin Formation (Fig. 9). The coal measures at Nordegg shown in Figure 7 are slightly farther east, but here again all of the coal seams of current economic interest are above the Moosebar Tongue.

The Pocahontas-Moosehorn area (Fig. 1) was actively mined at one time but is now in Jasper National Park where mining is not allowed. The Gladstone and Malcolm Creek Formations are poorly exposed in the area and the Park authorities will not allow any geological work other than surface examination. As a result, no good sections of the coal measures were obtained. Figure 11 shows two interpretations by MacKay (1930, 1955) of the position of coal seams relative to the Cadomin Formation. The Pocahontas-Moosehorn area is on strike with the Rock Lake - Wildhay River coal area and the Mountain Park areas (Fig. 1). The position of the seams at Rock Lake also is shown in Figure 11. The Mountain Park section is illustrated in Figure 10. The section at Rock Lake, from a bulldozer cut made by Denison Mines, shows two major coal seams, both of which are above the Moosebar and Torrens Members of the Malcolm Creek Formation. Only minor seams are present below. By comparison, the 2.7 to 3.9 m Tunnel seam and the 3.0 to 4.2 m seam higher in the section in the Pocahontas area are definitely above the Moosebar Tongue. Thicknesses of lower seams are not consistent in the two sections of MacKay. Structural complications and heavy drift cover render measured distance above the Cadomin unreliable in many cases. In addition, the absence of any thick seams laterally at Rock Lake and Mountain Park, suggests that it is unlikely there are seams as thick as 1.5 or 2.6 m at Pocahontas - Moosehorn. The possibility of seams of this thickness cannot be ruled out, however, as more precise data are not available.

Mountjoy (1960a) indicated that coal seams in the Pocahontas area are in his lower division of the Luscar Formation. To the east, in the Folding Mountain area (Fig. 1) he indicated coal seams in both the upper part of the lower, and lower part of the upper, division of the Luscar Formation. A section measured and sampled by the author on Folding Mountain showed that the conglomeratic sandstone unit which marks the base of Mountjoy's (1960a, b) upper Luscar is the Torrens Member of the current nomenclature with a thick Moosebar section below. The section terminates at the top of the Torrens Member, so the possible occurrence of seams directly above is uncertain. However, slightly farther east, on the flank of Folding Mountain, Mountjoy (1960a, p. 115) indicated that all coal seams, except for very thin coal bands occur between 6.4 and 32.1 m (21 and 106 ft) above the conglomerate or sandstone at the base of the upper Luscar unit. This is in agreement with the findings of this study and with the location of seams in the sections laterally along strike in the Foothills.

Elsewhere, Mountjoy (1960a, p. 115) indicated that coal seams on Folding Mountain occur near the top of the lower unit. In this, he seems to be in error, or perhaps the conglomerate-sandstone unit taken as the base of the upper Luscar is not the same bed in all cases. It is suggested that this is the case, particularly farther to the west in Pocahontas area where there is a prominent sandstone unit approximately 330 m (1100 ft) above the Cadomin Formation and above the major coal seams, which may have been taken as the basal unit of the upper Luscar and correlated with the Torrens Member to the east. It lies approximately 150 m (500 ft) above the Torrens Member.

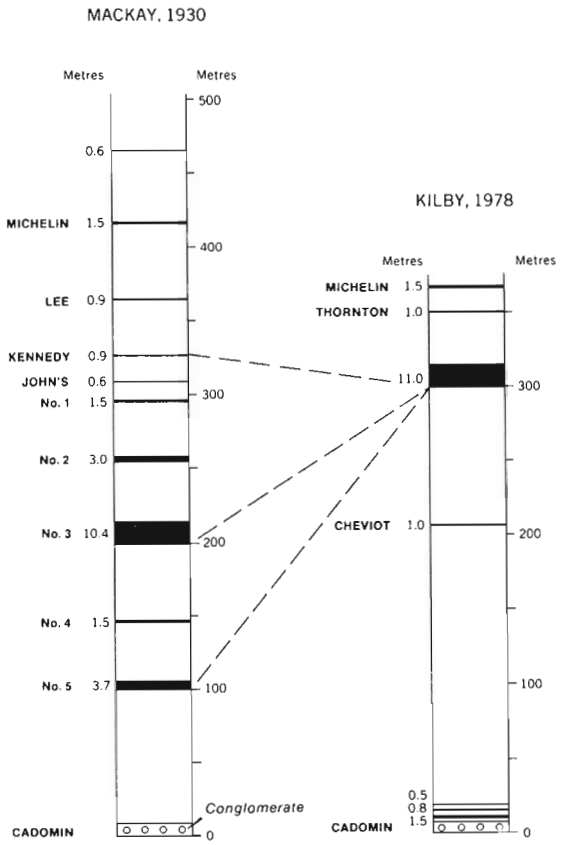

FIGURE 10. Comparison of coal measures at Mountain Park by Mackay (1930) and Kilby (1978).

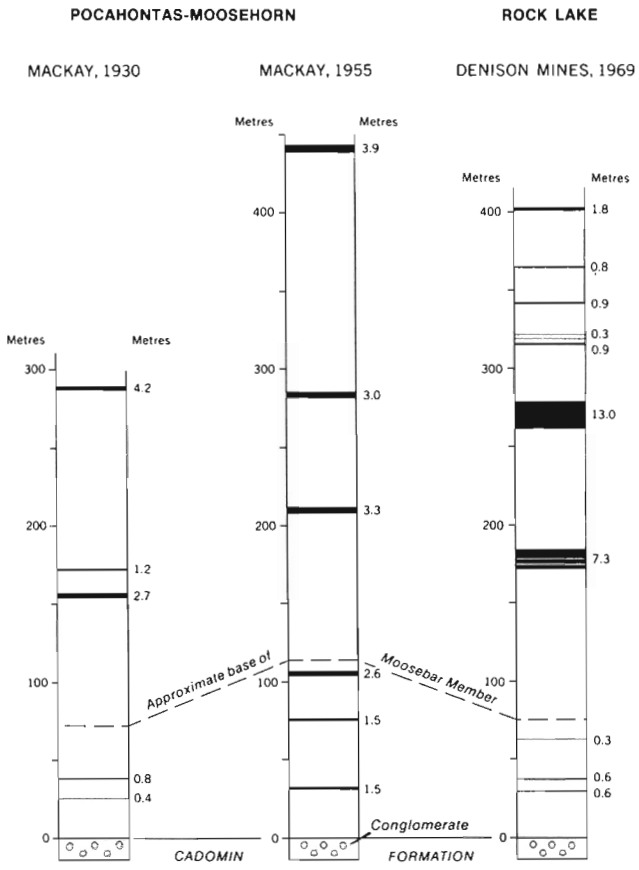

FIGURE 11. Comparison of stratigraphic position of coal seams at Pocahontas-Moosehorn and Rock Lake.

The section at Rock Lake (Fig. 11) is considered more reliable than the nearby Thoreau Creek section shown by MacKay (1930, Fig. 5) which is reproduced in Figure 9. The former was entirely exposed in a bulldozer cut, whereas the latter is a composite from poor outcrop. The major 12.1 m seam lies above the Moosebar and Torrens Member and, according to Pearson (1960, p.40) is the only thick coal seam present in that area. It lies approximately 200 m above the Cadomin Formation as measured by the author in a poorly exposed section at Thoreau Creek.

Evidence from the author's observations and from other sources mentioned above indicate that the great majority of seams of current economic interest in the Lower Cretaceous succession in the Alberta Foothills lie above the Moosebar marine tongue, in the Grande Cache Member of the Malcolm Creek Formation. However, seams up to 1 m thick are known to occur in the Gladstone Formation and it appears that these are in sections closer to the southwestern edge of the Foothills belt than those which have thin, or no, coal seams. Evidence cited above suggests that the thick seams in the Pocahontas - Moosehorn area are above the Moosebar Member, but this evidence is not unequivocal and some, or all, of these seams may be in the Gladstone Formation. The coal explorationist should not ignore this lower part of the Blairmore Group unless the absence of coal has been satisfactorially demonstrated.

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APPENDIX

TYPE SECTION

GLADSTONE FORMATION

Unit	Description	Unit Thickness (metres)	Height above base (metres)
37	Sandstone, very fine grained, light green-grey with medium light grey weathering, slightly calcareous, abundant fine carbonaceous debris as horizontal laminae. Overlies 36 abruptly.	1.45	91.15
	Contact Beaver Mines Formation		
36	Limestone, silty, medium dark grey with very light grey weathering, discontinuous platy weathering, few fossils.	0.9	89.70
35	Limestone, massive appearance but prominent horizontal to slightly wavy laminae on weathered surface. More resistant than below. Overlies 34 gradationally.	0.9	88.80
34	Limestone, shaly, colours as below, shells are numerous, discontinuous platy weathering, one rusty purplish concretion with abundant shell debris.	0.2	87.90
33	Covered interval. One small exposure of limestone with two thin very fossiliferous laminae.	2.7	87.70
32	Shale, very calcareous, thin platy weathering, dark grey with light cream-grey weathering. Bioclastic limestone, 5 cm thick in middle of unit.	0.5	85.00
31	Limestone, medium dark grey with very light cream-grey weathering, aphanitic, small irregular blocky to platy weathering, silty and very fine laminated in part, a breccia lense 20 cm thick and 60 cm long, fragments up to 2 cm, some rounded. Ten centimetres of very sandy limestone at top, wavy appearance, with shell fragments common. Overlies 30 abruptly.	1.5	84.50
30	Siltstone, very calcareous, clayey, colours as below, very recessive relative to adjacent beds.	2.5	83.00
29	Limestone, medium dark grey with very light grey weathering, sucrose, flaggy to blocky weathering, large horizontal burrows (?) (5 cm wide, 3 cm deep) along base. Minor bioturbation elsewhere. Overlies 28 abruptly.	3.3	80.5
28	Siltstone, very calcareous, medium light olive-grey with very light grey weathering, irregular platy. Overlies 27 gradationally.	0.4	77.20
27	Sandstone, very fine grained very calcareous, beds 2-10 cm, wavy bedding, colours as below, few asymmetrical ripples.	0.7	76.80
26	Siltstone, very calcareous, colours as below, very fine horizontal lamination, possible desiccation cracks.	1.2	76.10
25	Shale, very calcareous to limestone, very silty upward. Colours as below, colour lamination in upper part, few concretions with shell debris. Lower contact irregular due to irregularities on surface of underlying bed. Overlies 24 abruptly.	0.5	74.90
24	Limestone, aphanitic, dark grey with very light grey weathering, minor bioclastic fragments, massive. Gradational with 23.	0.6	74.40
23	Shale, very calcareous, platy, very dark grey with medium light grey weathering. Overlies 22 abruptly.	0.4	73.80
22	Limestone, bioclastic, dark grey with very light grey weathering, platy.	0.5	73.40
21	Siltstone, calcareous, dark grey with cream weathering, in lower 30 cm, few pelecypod valves, overlain by a massive mudstone-claystone unit as in 20. Overlies 20 gradationally.	2.0	72.90
20	Mudstone and claystone, dark olive-grey to greenish-grey, lighter colour upward, then darker in upper 100 cm, non-calcareous, massive, scattered calcareous concretions, irregular bulbous microconcretions (very coarse sand size) in upper part. Small pelecypods near top. Overlies 19 gradationally.	6.2	70.90
19	Mudstone, meduum dark green-grey, olive-grey to rusty weathering, slightly purplish in lower few decimetres, non-calcareous massive, scattered irregular to elliptical concretions (10-20 cm long), very calcareous.	6.5	64.70
18	Claystone, medium olive-grey, slightly purplish in part, sandy-silty in part, non-calcareous, massive. Overlies 17 gradationally.	4.9	58.20
17	Mudstone, very silty, medium light green-grey, non-calcareous, with small, irregularly distributed nodules, very calcareous, light grey with rusty brown weathering. Overlies 16 gradationally.	1.3	53.30
16	Mudstone, maroon coloured throughout, non-calcareous, concretionary in part, very calcareous, brecciated appearance. Upper 1 m, gradually changes to predominantly medium olive-grey. Overlies 15 abruptly.	4.1	52.00
15	Claystone to mudstone to sandstone, very fine grained upward, light green-grey with rusty brown-orange stain, non-calcareous except in upper 20-30 cm where very calcareous and ferruginous. Appears to be paleosol.	2.7	47.90
14	Sandstone, very fine grained to mudstone upward. Light green-grey with very patchy appearance at top. Non-calcareous at base to strongly calcareous at top. Possible caliche.	2.0	45.20
13	Mudstone, . light green-grey becoming predominantly maroon upward. Overlain gradationally by siltstone to very fine grained sandstone upward; light green-grey, massive. Overlain abruptly by mudstone, green-grey with maroon patches. Overlies 12 abruptly.	6.1	43.20
12	Concretion bed; very light grey with rusty orange weathering, aphanitic, non-calcareous. Deformed underlying unit slightly.	0.3	37.10
11	Claystone, mottled light green-grey and maroon, becoming predominantly maroon-coloured upward but with green patches. Mostly green in upper 10 cm. Non-calcareous, massive.	1.7	36.80
10	Siltstone, very clayey, medium olive-grey with distinct green hue upward, rusty concretionary appearance. Laterally gradational to sandstone, very fine grained.	1.0	35.10
9	Sandstone to mudstone, similar to 8. Overlies 8 abruptly. One set cross laminae.	2.2	34.10
8	Sandstone, fine grained at base to siltstone at top, medium dark grey, non-calcareous, massive. Overlies 7 abruptly. Upward to very silty mudstone, massive.	1.6	31.90
7	Siltstone to mudstone upward, similar to unit 4. Overlies 6 abruptly.	0.3	30.30
6	Mudstone, sideritic, concretionary, non-calcareous, rusty orange weathering.	0.3	30.00

Unit	Description	Unit Thickness (metres)	Height above base (metres)
5	Sandstone, fine to very fine grained upward. Light grey, salt-and-pepper appearance. Faint trough cross-bedding near base, cross lamination upward, load casts on base. Siderite grains common upward. Slightly calcareous. Very rusty, nodular, purplish-brown weathering unit below-probable paleossol.	4.3	29.70
4	Interbedded sandstone, siltstone and mudstone. Beds 2 to 40 cm thick, colours as below with some light greenish-grey. Series of predominantly coarsening upward cycles.	2.9	25.40
3	Covered interval. One poor exposure of sandstone, argillaceous, medium grey, minor carbonaceous fragments, few pelecypod clasts.	6.5	22.50
2	Interbedded mudstone, medium grey to olive-grey, non-calcareous, and sandstone, very fine grained, to siltstone, medium olive-grey to light orange-brown (fresh) non-calcareous to moderately calcareous, horizontal laminae. Interval poorly exposed.	8.0	16.00
	Cadomin Formation		
1	Sandstone, medium-grained at base, fine and very fine grained upward, medium dark grey, silica cement, load casts along base, massive appearance.	8.0	8.00

TYPE SECTION (HOLOSTRATOTYPE) - MALCOLM CREEK FORMATION

Located on Malcolm Creek

Unit	Description	Unit Thickness (metres)	Height above base (metres)
76	Sandstone, very coarse to coarse grained, non-calcareous, very light grey with light grey weathering, erosional base, shale rip-up clasts and wood casts at base, horizontal bedding.	4.2	211.5
	TOP OF MALCOLM CREEK FORMATION		
	Top of Grande Cache Member		
75	Shale, as below.	3.5	207.3
	Note: Units 64 to 75 form a prominent valley and collectively are a very recessive unit.		
74	Siltstone and concretion, cream to deep rusty weathering, pale yellowish-brown to medium light grey fresh, non-calcareous, a few interbeds of mudstone, 3 to 5 cm thick.	1.4	203.8
73	Shale, very dark grey, abundant carbonaceous fragments, coaly in part, recessive, one concretion near base, aphanitic, non-calcareous, very rusty weathering, very hard.	5.4	202.4
72	Covered.	4.2	197.0
71	Shale, very dark grey, massive.	4.5	192.8
70	Siltstone, argillaceous, non-calcareous, moderately hard, very rusty weathering.	0.4	188.3
69	Shale, very dark grey, slightly silty, non-calcareous, three thin concretion beds (less than 5 cm), appears very carbonaceous and coaly at base. Overlies unit 68 abruptly.	3.2	187.9
68	Mudstone, to siltstone upward, light rusty weathering, moderately strongly calcareous, thin horizontal lamination in part.	1.7	184.7
67	Shale, very carbonaceous, recessive.	0.4	183.0
66	Covered.	3.2	182.6
65	Coal, very weathered and recessive, overlain by 20 cm of dark shale.	0.7	179.4
64	Shale, very carbonaceous, very dark grey, recessive. Overlies unit 63 abruptly.	0.6	178.7
63	Siltstone and sandstone, very fine grained, 30 to 100 cm thick, interbedded with mudstone, 20 to 45 cm thick, moderately strongly calcareous, root zones prominent. Mudstone, very recessive, medium grey with dark olive-grey weathering. Contacts between beds appear sharp. Laterally, upper beds are trough crossbedded, fine grained sandstone, with a 12 cm very ferruginous concretion bed at top.	3.1	178.1
62	Shale, dark grey, non-calcareous, medium light grey weathering, plant debris common throughout, one 20 cm coal seam near base.	3.0	175.0
61	Mudstone, very calcareous, moderately hard, resistant unit, light rusty weathering. Overlies unit 60 gradationally.	0.7	172.0
60	Claystone, slightly silty, olive-grey, very calcareous, few plant fragments and roots, recessive.	1.0	171.3
59	Sandstone, very fine to fine grained, transitional with unit 58, medium dark grey with light rusty weathering, horizontal and ripple lamination common. Laterally, sandstone lies abruptly on silstone-mudstone and is channelled several metres into them. Wood fragments common, trough cross lamination common in lower part, horizontal lamination upward.	5.1	170.3
58	Mudstone with siltstone and minor coal, thin horizontal bedding abundant plant impressions, brownish-grey to dark greyish-red, very calcareous. Overlies unit 57 abruptly.	1.7	165.2
57	Shale, very dark grey, very carbonaceous, abundant roots through shale and into underlying siltstone. Overlain by coal, prominent dull and bright banded, a 10 cm silty bed in centre.	1.7	163.5
56	Sandstone, very fine grained and siltstone, massive to faint horizontal lamination, beds 4 cm to 1 cm thick interbedded with mudstone, beds 2 to 30 cm thick, slightly to moderately strongly calcareous, minor carbonaceous fragments, mudstone more abundant upward. Abrupt on unit 55.	12.0	161.8

Unit	Description	Unit Thickness (metres)	Height above base (metres)
55	Coal, argillaceous, very crumbly, recessive, overlain by 10 cm of mudstone, dark grey, moderately hard.	0.4	149.8
54	Recessive, no exposure. Small trench of carbonaceous mudstone near top.	2.2	149.4
53	Mudstone, brownish-grey with light grey weathering, moderately calcareous. Grades upward from siltstone to sandstone, fine grained, weak to moderately calcareous, medium light grey and rusty weathering. Upper 1 m is a second coarsening upward sequence. May be gradational with unit 52.	3.3	147.2
52	Sandstone, very fine grained, medium light grey with light rusty weathering, moderately calcareous, prominent ripple lamination throughout, carbonaceous-rich and ferruginous lamination. More silty and argillaceous upward, burrows common, one mud cracked surface observed.	2.9	143.9
51	Shale, very dark grey, upward to siltstone, similar to unit 50. Overlies unit 50 abruptly.	1.8	141.0
50	Coal and shale, very carbonaceous at base, upward to brownish-grey silty mudstone and siltstone, medium grey with pale yellowish-brown weathering, moderately calcareous, very hard. Very recessive, poorly exposed unit.	1.8	139.2
49	Mudstone, dark grey with medium light grey and rusty weathering, a distinct colour banded appearance due to more and less ferruginous beds (up to 5 cm thick), minor carbonaceous fragments and plant impressions on bedding planes. Upward to siltstone in upper 50 cm with irregular 'brick-work' appearance. A hard, aphanitic, moderately calcareous concretion bed at top. Overlies unit 48 abruptly.	1.8	137.4
48	Sandstone, very fine grained and siltstone 20 to 50 cm beds, moderately-strongly calcareous, interbedded with mudstone, carbonaceous, 2 - 20 cm beds. An upright tree trunk 110 cm long. Gradational with unit 47.	2.3	135.6
47	Sandstone, very fine grained, gradational with unit 46, light rusty weathering, beds 10 - 30 cm thick, occasionally 70 cm. Horizontal and ripple lamination common. Interbedded siltstone, argillaceous, recessive, 5 - 30 cm thick. Forms a prominent ridge and narrow chute along creek.	4.8	133.3
46	Mudstone and siltstone, prominent thin bedded (2 to 10 cm), medium dark brownish-grey with buff and rusty weathering, minor burrows. Abrupt basal contact.	2.5	128.5
45	Mudstone, carbonaceous fragments and plant fragments common, brownish-grey weathering, noncalcareous. Upward more silty and calcareous to siltstone, buff weathering, moderately calcareous, cross lamination, a few gastropod casts near base. Overlies unit 44 abruptly.	2.0	126.0
44	Coal, dull with subordinate bright lenses.	3.6	124.0
43	Shale, black, very carbonaceous, overlies unit 42 abruptly. Gradational upward to unit 44.	0.3	120.4
42	Sandstone, fine to medium grained, medium grey with medium to dark yellowish-orange weathering, moderately strongly calcareous, platy to slabby weathering with some megaripple cross lamination but predominantly ripple lamination, with abundant ripple trains on bedding surfaces, horizontal lamination prominent at base and near top. Interbedded mudstone, medium dark grey and siltstone, argillaceous at top, recessive, plant fragments common, non-calcareous. Gradational with unit 41 over a short interval.	5.6	120.1
41	Coarsening upward unit, mudstone to siltstone to sandstone, very fine grained. light olive-grey with light rusty weathering, a prominent rusty concretion bed at base, central part of unit has concretionary weathering appearance, very hard and has ellipsoidal pattern on surface, calcareous. Upward, thin, slabby weathering sandstone with ripple lamination in part.	1.1	114.5
40	Mudstone - shale, dark grey, with silty lenses exhibiting cross lamination, non-calcareous to moderately calcareous in siltstone, disarticulated pelecypods common in lower 2 m and in discontinuous concretionary beds. Foraminifera and ostracodes present.	6.8	113.4
39	Recessive. Coal excavated near base but exact thickness unknown. Given thickness is a maximum.	3.0	106.6
	Base of Grande Cache Member		
	Top of Torrens Member		
38	Sandstone, fine grained to rarely medium grained, very light grey weathering, non-calcareous, horizontal lamination, vague low angle crossbedding in part, slabby weathering. Forms lower end of canyon.	3.3	103.6
37	Mudstone, dark grey with siltstone, ferruginous, horizontal lamination, thin interbedded (1-4 cm). Recessive unit between 2 prominent sandstone units.	0.4	100.3
36	Sandstone, prominent canyon-forming unit, fine- to occasionally medium grained, light grey to faintly rusty weathering, beds 5 to 25 cm thick, a few recessive units as in unit 35, horizontal lamination abundant, upward have more massive beds, carbonaceous material common on bedding planes, few siderite grain laminae particularly near base, a few concretions as in unit 34, non-calcareous to weakly calcareous.	6.3	99.9
35	Sandstone, fine grained, prominent carbonaceous laminae, non-calcareous, recessive.	0.3	93.6
34	Sandstone, very fine and fine grained, light grey with some rusty weathering, thin to medium bedded (2-20 cm), horizontal and ripple lamination common, platy to slabby weathering, numerous thin discontinuous, concretionary beds separate sandstone beds, very rusty, aphanitic, non-calcareous, in places are infilling ripple troughs. Carbonaceous fragments along many bedding planes, siderite grain (medium to coarse grained size) laminae common. An irregular, ferruginous vertical cylindrical concretion, 1 cm diameter, probably burrow.	6.1	93.3
33	Siltstone and sandstone, very fine grained, argillaceous, abundant carbonaceous-rich laminae, pale yellowish-brown weathering, non-calcareous, recessive. Overlies unit 32 abruptly.	0.3	87.2
32	Sandstone, fine to very fine grained upward, two fining upward cycles, abrupt base, mudstone rip-up clasts at base, vague trough crossbedding in lower part and horizontal lamination in upper part of both units.	3.3	86.9
31	Siltstone, interbedded with mudstone, dark grey (30%) and sandstone, very fine grained (20%), grey to brownish-grey weathering to rusty weathering of some sandstone beds. Upper and lower contacts of sandstone abrupt, ripple and horizontal lamination common, sole marking common. Overlies unit 30 abruptly.	2.4	83.6
30	Sandstone, very fine to medium grained upward with some coarse grained near top, gradational with unit 29, lower 90 cm is horizontally bedded, trough crossbedded above, non-calcareous, light grey with dark yellowish-orange weathering.	6.0	81.2

Unit	Description	Unit Thickness (metres)	Height above base (metres)
	Base of Torrens Member		
	Top of Moosebar Member		
29	Thin bedded unit, similar to unit 26. Mudstone beds are thicker (up to 20 cm) than other lithologies.	2.3	75.2
28	Sandstone, fine grained, slightly to moderately calcareous, abrupt channelled base, trough crossbeds at base, prominent horizontal bedding above, asymmetrical ripples, ripples on upper surface, mudstone rip-up clasts in one bed, wood and carbonaceous fragments common. A discontinuous ironstone concretion bed in centre.	1.8	72.9
27	Mudstone and siltstone, thin bedded as below with greater proportion of sandstone beds (50 to 75%), fine grained, horizontal lamination, several load casts with well developed concentric pattern.	1.5	71.1
26	Prominent thin bedded unit consisting of (1) mudstone, silty, medium dark grey, contains foraminifera; (2) mudstone, very silty, medium light grey; (3) siltstone, lighter grey, weakly calcareous; (4) sandstone, very fine grained, light rusty weathering, moderately calcareous occur as individuual ripple trains with abrupt base and top; (5) concretion beds very silty-sandy, medium light grey with prominent rusty weathering, some cross lamination, few small pyrite nodules, non-calcareous. Overlies unit 25 abruptly.	7.0	69.6
25	Sandstone, very fine grained, similar to below, horizontal lamination with prominent platy weathering. Units 19 to 25 form a resistant ridge and are much more prominent than underlying units.	0.4	62.6
24	Siltstone, argillaceous, moderately calcareous, light olive-grey with brownish-grey weathering, very finely laminated.	0.3	62.2
23	Sandstone, as in unit 19.	0.4	61.9
22	Siltstone and mudstone, as in unit 20, cross lamination in some siltstone beds.	0.3	61.5
21	Sandstone, as in unit 19, abundant carbonaceous-rich lamination.	0.7	61.2
20	Siltstone, argillaceous and mudstone, light to medium grey weathering, moderately calcareous, faint horizontal lamination.	0.2	60.5
19	Sandstone, very fine grained, medium grey with light rusty weathering, weakly calcareous, prominent horizontal lamination. Abrupt base.	0.5	60.5
18	Mudstone, interbedded with siltstone and very fine grained, argillaceous sandstone 1-4 cm usual thickness, up to 15 cm, ripple lamination common in sandstone beds, a break in middle of unit where have a 15 cm bed of platy weathering sandstone similar to top of previous unit. Abrupt base.	2.4	59.8
17	Siltstone, argillaceous and sandstone, very fine grained, thin interbedded, interbedded with cleaner sandstone beds as below, medium grey to pale yellowish-brown, beds 1-10 cm thick. At top, prominent platy weathering sandstone, horizontal lamination and low angle crossbedding, weakly calcareous. Upper 10 cm, silty concretion bed, moderately calcareous, laminated, distinct rectangular weathering pattern.	2.6	57.4
16	Sandstone, very fine grained, ripple laminated, with 'faecal pellets' as below, often beds are 3 cm or less thick, interbedded with thicker units of sandstone-siltstone, horizontally laminated. Overlies unit 15 gradationally.	3.5	54.8
15	Mudstone, similar to below with abundant 'faecal pellets' upward to sandstone, very fine grained, silty and argillaceous, some ripple lamination, moderately calcareous, one large ironstone concretion, 12 cm thick and 2 m long. Overlies 14 abruptly.	7.8	51.3
14	Mudstone, as below becoming more silty and more calcareous upward, at top sandstone, very fine grained, rusty weathering, ripple laminated, moderately calcareous, some 'faecal pellets' but less abundant than below.	7.4	43.5
13	Mudstone and siltstone, argillaceous, medium grey with light grey weathering (in marked contrast to ferruginous beds below), with few laminae of siltstone, abundant pods (1 mm diameter and several millimetres long) of darker colour, probably faecal pellets. Lies abruptly on unit 12.	2.9	36.1
12	Mudstone, medium grey with buff weathering, upward into laminated siltstone and very fine grained sandstone, ripple to horizontal lamination, non-calcareous to moderately calcareous, extensive bioturbation in upper 10 to 15 cm.	2.5	33.2
11	Mudstone, variably silty to siltstone, argillaceous in part, dusky yellowish-brown with dark yellowish-brown weathering, thin (2-10 cm) bedded, faintly laminated, slightly calcareous, a few concretion beds, hard, aphanitic, non-calcareous, medium light grey with dark yellowish-orange weathering. Contains foraminifera fauna.	5.6	30.7
10	Covered. No outcrop.	7.5	25.1
	Base of Moosebar Member		
	BASE OF MALCOLM CREEK FORMATION		
9	Mudstone, dark grey upward to siltstone, prominently ripple laminated, overlain abruptly by sandstone, very fine grained, crossbedded, finer grained and cross laminated upward, medium grey with medium light grey weathering, minor interbedded argillaceous siltstone, carbonaceous, slightly calcareous.	2.0	17.6
8	Covered interval.	1.7	15.6
7	Sandstone, very fine grained, medium light grey with light rusty weathering, moderately calcareous, no lamination observed.	1.8	13.9
6	Recessive, poorly exposed interval. Shale upward to very fine grained sandstone.	1.7	12.1
5	Siltstone and sandstone, very fine grained, with mudstone interbeds (5-15 cm thick), beds several cm thick, prominent ripple lamination, moderately calcareous, bioturbated of few sand-filled burrows in mudstone. Gradational with unit 4.	4.3	10.4
4	Claystone, dark brownish-grey, carbonaceous, overlain by claystone, rusty weathering, massive.	1.0	6.1
3	Coarsening upward sequence similar to unit 2, 80 cm of coal overlain by 30 cm of shale and mudstone and 20 cm of predominantly siltstone and sandstone. Overlies unit 2 abruptly.	1.3	5.1
2	Coarsening upward sequence similar to unit 1. Coal, very crumbly at base, to very carbonaceous shale to mudstone, yellowish-grey, very calcareous, trace carbonaceous, to siltstone and very fine grained sandstone, ripple laminated, moderately calcareous, root penetrated. Overlies unit 1 abruptly.	1.4	3.8
1	Shale, coaly, upward to carbonaceous mudstone with fine horizontal lamination, moderately calcareous, upward to sandstone, fine grained to very fine grained upward, light grey with medium light grey to pale rusty weathering, slabby to blocky weathering, carbonaceous fragments common, moderately calcareous. Lense of pebbles, up to 1 cm diameter, at top appears to be discontinuous, only 3 cm thick.	2.4	2.4

TYPE SECTION
TORRENS MEMBER

Unit	Description	Unit Thickness (metres)	Height above base (metres)
13	Coal, hard, bright lustre, recessive	1.40	46.50
12	Covered. Very recessive	1.35	45.10
	Top Torrens Member		
11	Sandstone, coarse to fine grained upward, light grey with rusty laminae, noncalcareous, massive at base, crossbeds common upward. Overlies unit 10 abruptly.	7.40	43.75
10	Siltstone, very argillaceous, dark grey with rust-stained laminae, noncalcareous. Overlies unit 9 abruptly.	0.45	36.35
9	Sandstone, fine to coarse grained upward, pebbles up to 1 cm scattered throughout, gradational with unit 8, low angle crossbed sets, ripples at top, platy to blocky habit upward.	1.00	35.90
8	Sandstone, very fine to fine grained upward, more resistant upward, moderately strongly calcareous, medium light grey with light rusty weathering, abundant low angle crossbedding. Blocky to platy upward. Overlies unit 7 abruptly.	13.60	34.90
7	Covered. Very recessive unit.	1.05	21.30
6	Sandstone, very fine to fine grained, medium light grey and brownish-grey with light rusty weathering, moderately to moderately strongly calcareous upward, crossbedded in part, carbonaceous throughout.	5.40	20.25
5	Sandstone, very fine to fine grained upward, overlies unit 4 abruptly, similar to unit 4 but prominent horizontal bedding with dark, carbonaceous-rich laminae in upper 50 cm.	3.00	14.85
4	Sandstone, very fine grained, medium dark grey with rusty weathering, overlies unit 3 abruptly, moderately calcareous, blocky weathering, faint crossbedding, minor mudstone rip-up clasts.	4.20	11.85
3	Sandstone, very fine grained to siltstone, medium dark grey, very carbonaceous, thin platy habit. More recessive than unit 2.	1.00	7.65
2	Sandstone, very fine grained, slight coarsening upward, overlies unit 1 abruptly, medium light grey, moderately calcareous, more calcareous upward, carbonaceous-rich laminae common low angle crossbed sets. Asymmetrical ripples on upper surface. Rounded mudstone rip-up clasts near base.	1.85	6.65
	Top Moosebar Member		
1	Sandstone and mudstone interbedded, 1 to 10 cm thick, Mudstone, dark grey to olive-grey, very calcareous, bioturbated. Sandstone, very fine grained to fine grained upward, medium dark grey with rusty weathering, moderately calcareous, gradational base and abrupt top, bioturbated at base, carbonaceous lamination and cross-lamination upward.	4.80	4.80

TYPE SECTION
GRANDE CACHE MEMBER
Located at Gustavs Flats

Unit	Description	Unit Thickness (metres)	Height above base (metres)
35	Sandstone, medium grained to fine grained upward, non-calcareous, massive, hard, cream to light rusty weathering, siderite grains give 'freckled' appearance.	4.0	128.3
	TOP OF GRANDE CACHE MEMBER		
34	Covered interval. Small exposure just below unit 35 of shale, dark grey, very carbonaceous.	2.4	124.3
33	Sandstone, very fine grained, silty, very calcareous, very hard, rusty weathering, carbonaceous fragments common, possible roots.	0.7	121.9
32	Covered interval.	1.1	121.2
31	Shale, as in unit 29.	1.0	120.1
30	Mudstone, dark yellow-brown, very calcareous, massive, abrupt lower contact.	1.4	119.1
29	Shale, dark grey with bluish-grey weathering, non-calcareous, abrupt lower contact.	0.5	117.7
28	Mudstone, very silty, very calcareous, carbonaceous fragments common, overlies unit 27 abruptly.	0.9	117.2
27	Shale, dark grey, carbonaceous, coaly in part, with 5 cm thick concretion bed, rusty weathering, discontinuous. Overlies unit 26 abruptly.	0.5	116.3
26	Coal, not well exposed, old adit entrance.	2.3	115.8
25	Covered interval.	2.0	113.5
24	Sandstone, fine to medium grained at base to very fine grained upward, light grey, slightly calcareous, carbonaceous fragments common, siderite grains give 'freckled' appearance.	4.3	111.5
23	Mudstone and shale, olive-grey, silty in lower part, with carbonaceous fragments common, to dark grey, rusty weathering shale upward. A prominent concretion bed at base, very silty, very calcareous, very hard, medium dark grey fresh with light grey and cream coloured weathering.	5.9	107.2
22	Mudstone, dark grey, prominent medium-light grey with bluish tinge weathering, upward more silty, less carbonaceous and more calcareous to siltstone, common plant and carbonaceous fragments, roots common.	1.1	101.3

Unit	Description	Unit Thickness (metres)	Height above base (metres)
21	Coal, old adit collapsed, no exposure of seam.	2.1	100.2
20	Covered interval. Small exposure of shale, very carbonaceous, at top.	4.9	98.1
19	Sandstone, very fine grained, moderately to very calcareous, gradational with unit 18 in part, scoured into unit 18 in part, horizontal lamination and ripple lamination common, carbonaceous fragments common, a prominent upright tree trunk, rooted at top of unit 17, 5.2 m high, 75 cm wide.	3.2	93.2
18	Shale, dark grey, very carbonaceous, small coal lenses, upward to mudstone, silty, slightly calcareous.	1.0	90.0
17	Coal, very fractured and oxidized, contains several concretions, light brown weathering, medium grey fresh, non-calcareous, very hard, up to 1 m long, 30-45 cm thick. Old adit entrance.	4.5	89.0
16	Mudstone with very subordinate siltstone or sandstone, very recessive and mostly covered, carbonaceous fragments abundant, black fissile shale at top gradationally upward to unit 17.	6.3	84.5
15	Sandstone, fine to very fine grained, very calcareous, scoured into unit 14, wood casts and carbonaceous fragments common at base, very hard to moderately friable in part, some interbedded siltstone, very carbonaceous, overlies unit 14 abruptly.	6.9	78.2
14	Shale, very dark grey, non-calcareous, upward in few centimetres to mudstone, silty, very calcareous, rusty brown weathering, only minor carbonaceous fragments.	0.4	71.3
13	Coal, very fractured and oxidized, adit, McIntyre Mines No. 5 seam.	3.9	70.9
12	Mudstone, dark grey, carbonaceous with siltstone and very fine grained sandstone, calcareous throughout, roots prominent in some sandstone beds, minor coal seams, ripple lamination in some sandstone beds.	5.2	67.0
11	Sandstone, very fine grained, very ferruginous, orange weathering, prominent ripple lamination throughout, carbonaceous fragments common, overlies 10 abruptly.	3.3	61.8
10	Mudstone and siltstone with subordinate sandstone, recessive unit, beds 5 cm to 1 m, sandstone beds up to 30 cm, horizontal lamination common, few cross laminae.	11.2	58.5
9	Sandstone, very fine grained, with mudstone, silty, beds 5 to 80 cm, overall thinner bedded upward, prominent banded appearance. Sandstones have abrupt base and top, abundant cross lamination, carbonaceous fragments common throughout. Small load casts common. Mudstone, dark grey and olive-grey, very calcareous, a few pelecypod shells observed in one bed. Overlies coal abruptly.	6.5	47.3
8	Coal, a thin bed of very carbonaceous shale at base, overlain abruptly by coal; poorly exposed, No. 4 seam of McIntyre Mines.	5.1	40.8
7	Mudstone, interbedded with siltstone, becoming sandstone, very fine grained in upper 3 m, very calcareous, irregular laminae in lower 1 m, platy to massive sandstone, abundant carbonaceous-rich laminae, very ferruginous.	4.1	35.7
6	Covered interval.	3.0	31.6
5	Siltstone and mudstone, with some very fine grained sandstone upward, very calcareous, thin bedded and horizontal lamination, minor bioturbation, prominent yellowish-orange weathering, carbonaceous fragments common throughout, cross lamination in sandstone. Overlies shale gradationally.	5.3	28.6
4	Shale, very silty in part, very calcareous, a pelecypod-rich concretion bed 1 m above base, shells abraded.	4.3	23.3
3	Shale, very dark grey, slightly calcareous, a 30 cm thick ironstone concretion bed at top. Overlies coal abruptly.	2.3	19.0
2	Coal, No. 3 seam of McIntyre Mine Ltd., old adit, overlies sandstone abruptly.	3.2	16.7
	BASE OF GRANDE CACHE MEMBER		
1	Sandstone, very fine and fine grained, non-calcareous, siderite grains common giving 'freckled' appearance, very light grey weathering, bioturbated in lower part, cross bedded in upper two metres. Abundant carbonaceous fragments in upper decimetre.	13.5	13.5

WAPIABI CREEK SECTION

Hypostratotype of Mountain Park Formation

Unit	Description	Unit Thickness (metres)	Height above base (metres)
170	Mostly covered. Trenched shale, dark grey, silty.	3.0	282.9
	TOP OF MOUNTAIN PARK MOUNTAIN		
169	Sandstone, medium grained at base, fine grained throughout most of section, pale greenish-grey with light rusty yellow weathering, non-calcareous, predominantly horizontal bedding, some primary current lineation. Upper 50 cm is medium grained, moderately strongly calcareous, trough crossbedded, few rippies along bed tops.	3.3	279.9
168	Mudstone to siltstone, medium dark greenish-grey, rusty weathering in part, structureless, much more resistant than below. Overlies unit 167 abruptly.	1.1	276.6
167	Covered. Few small exposures of mudstone, medium light greenish-grey, carbonaceous fragments common, few rootlets.	2.1	275.5
166	Sandstone, very fine grained, medium light greenish-grey, slightly carbonaceous and micaceous, platy habit. Overlies 165 abruptly.	0.6	27 4

Unit	Description	Unit Thickness (metres)	Height above base (metres)
165	Siltstone and mudstone, alternately slightly more or less resistant, light to medium light greenish-grey with rusty orangish-brown weathering.	1.1	272.8
164	Siltstone, medium dark olive-grey to light greenish-grey upward, abundant carbonaceous fragments along some planes.	0.8	271.7
163	Mudstones, medum light greenish-grey with greenish-grey and reddish-brown weathering, structureless. Near top, sandstone, light greenish grey, 40 cm thick, overlain by 20 cm of claystone, carbonaceous. Overlies unit 162 abruptly.	2.2	270.9
162	Claystone and mudstone, light greenish-grey with medium dark olive-grey weathering, trace carbonaceous, upward to siltstone and sandstone, very fine to fine grained, carbonaceous lamination at base, massive upward. Sandstone at top channelled into underlying beds.	1.9	268.7
161	Siltstone and mudstone, medium light greenish-grey, trace carbonaceous, transitional with unit 160. Upward to 3 coarsening upward units, 30, 60 and 70 cm thick, to very fine grained sandstone at top, medium greenish-grey.	2.8	266.8
160	Sandstone, fine grained at base, to medium grained in short distance, and to fine grained upward, light greenish-grey and non-calcareous at base to moderately calcareous with rusty weathering upward, trough crossbedded and platy, horizontal bedding in part, wood fragments common throughout.	5.2	264.0
159	Sandstone, very fine grained, structureless, overlain by mudstone breccia medium greenish-grey with light rusty yellowish-orange weathering, fragments up to granule size, probable abundant root penetration, upward to shale, very carbonaceous and coaly.	1.1	258.8
158	Clay, very soft, olive grey, possibly bentonite.	0.1	257.7
157	Sandstone, fine to very fine grained upward, medium grey with light rusty yellow weathering, non-calcareous, minor mica and carbonaceous fragments throughout, becomes siltstone upward, darker colours. Overlies unit 156 abruptly.	2.6	257.6
156	Claystone, medium dark grey to olive-grey, non-calcareous, slightly harder and more resistant upward.	0.2	255.0
155	Mudstone, light greenish-grey with prominent rusty weathering.	0.3	254.8
154	Sandstone, argillaceous, greenish-grey, upward to claystone, medium grey, slightly carbonaceous. Overlies 153 gradationally.	0.8	254.5
153	Sandstone, very fine to fine grained, medium light greenish-grey, carbonaceous and small wood fragments common, faint lamination and cross lamination, a few roots near top.	0.8	253.7
152	Sandstone, very fine grained, platy, carbonaceous lamination, upward to siltstone and mudstone, medium greenish-grey, structureless.	1.7	252.9
151	Siltstone, medium greenish-grey with prominent rusty orange weathering, non-calcareous, upward to a series of claystone, mudstone and shale, medium dark olive-grey to medium greenish-grey, carbonaceous, massive. Overlies unit 150 abruptly.	1.7	251.2
150	Siltstone to mudstone, light greenish-grey, minor carbonaceous fragments, trace roots, upward to mudstone-claystone, medium dark grey, darker in upper 5 cm. Overlies unit 149 gradationally.	1.2	249.5
149	Siltstone to very fine grained sandstone, medium greenish-grey with rusty orange to maroon weathering, trace carbonaceous, root penetrated throughout, more recessive upward.	3.0	248.3
148	Mudstone, medium light greenish-grey, structureless, slightly more resistant than unit 147.	0.2	245.3
147	Claystone, medium dark grey, carbonaceous.	0.4	245.1
146	Mudstone, light greenish-grey, soft, recessive. Gradational with unit 145.	0.3	244.7
145	Sandstone, very fine grained, massive, upward to very weathered sandstone and mudstone sequence, abundant roots penetrating whole unit.	1.2	244.4
144	Siltstone, argillaceous, medium dark greenish-grey, carbonaceous fragments common, upward to sandstone, very fine grained, moderately calcareous, faint horizontal lamination throughout. Overlies unit 143 abruptly.	1.1	243.2
143	Sandstone, very fine grained, massive, to siltstone and mudstone upward, medium greenish-grey, becoming darker upward and more carbonaceous. Overlies 142 abruptly.	1.2	242.1
142	Sandstone, very fine grained, to siltstone upward, platy but no structure observed, medium greenish-grey. Overlies unit 141 abruptly.	2.2	240.9
141	Mudstone, very recessive.	0.7	238.7
140	Mudstone to siltstone to sandstone, very fine grained, greenish-grey with maroon weathering, three coarsening upward units 75, 150, and 140 cm thick.	3.7	238.0
139	Mudstone, medium greenish-grey, hard lower 10 cm, overlain by claystone, carbonaceous but less upward, structureless.	2.9	234.3
138	Covered, appears to be claystone, very soft, medium dark olive-grey. Probably transitional with unit 137.	0.9	231.4
137	Siltstone, medium greenish-grey with light greenish-grey and maroon weathering, few rootlets.	0.4	230.5
136	Covered.	0.9	230.1
135	Mudstone to siltstone and mudstone to sandstone, very fine grained, medium greenish-grey (mudstone slightly darker), rusty maroon weathering, trace carbonaceous. Upper 50 cm is prominent platy sandstone with common carbonaceous fragments and minor mica flakes. Overlies unit 144 abruptly.	2.4	229.2
134	Sandstone, very fine grained, medium greenish-grey, structureless. Overlies unit 133 abruptly.	0.4	226.8
133	Shale, medium dark olive-grey with medium dark grey and rusty orange weathering, non-calcareous.	0.5	226.4
132	Covered.	1.2	225.9
131	Siltstone, argillaceous, medium greenish-grey, very rusty and concretionaary at top. Abrupt base.	0.9	224.7
130	Sandstone, argillaceous, very fine grained, medium greenish-grey, roots common, otherwise structureless. Lies abruptly on unit 129.	0.7	223.8
129	Claystone to mudstone, medium dark greenish-grey, massive.	0.7	223.1
128	Covered.	1.3	222.4

Unit	Description	Unit Thickness (metres)	Height above base (metres)
127	Mudstone to siltstone to sandstone, very fine grained, medium grey (greenish-grey wet), structureless and bedding is obscure, overall coarsening upward.	1.6	221.1
	Note: Folding and the necessity to offset along strike due to a sharp bend in the river makes correlation imprecise. May be a short repetition of beds.		
126	Siltstone and sandstone, very fine grained, medium greenish-grey to medium dark grey with medium olive-grey to light rusty brown weathering, structureless, bedding obscure.	6.1	219.5
125	Covered.	3.4	213.4
124	Mudstone to siltstone to sandstone, very fine grained, medium greenish-grey, non-calcareous to moderately calcareous upward, minor carbonaceous lamination at top.	1.9	210.0
123	Covered. Partially mudstone, greenish-grey.	1.6	208.1
122	Siltstone to sandstone, very fine grained upward, medium light greenish-grey, rootlets throughout.	1.9	206.5
121	Siltstone, argillaceous, medium greenish-grey weathering, a few roots, upper 5 cm very recessive, carbonaceous mudstone.	0.6	204.6
120	Siltstone and sandstone, very fine grained, medium greenish-grey, structureless to very faintly laminated. Transitional with unit 119.	1.4	204.6
119	Mudstone to siltstone upward, medium greenish-grey with maroon weathering, structureless to faintly laminated upward, recessive.	1.1	202.6
118	Sandstone, very fine grained, medium greenish-grey, moderately weakly calcareous, very fine carbonaceous lamination in part, interbedded with more recessive siltstone and mudstone, non-calcareous, structureless. Sandstone bed 10-15 cm, siltstone less that 10 cm. Overlies unit 117 gradationally.	4.8	201.5
117	Mudstone to siltstone upward, medium greenish-grey, very fine carbonaceous lamination, platy to slabby weathering, rusty maroon weathering. Overlies unit 116 abruptly.	1.1	196.7
116	Siltstone, medium dark grey with prominent rusty orangish-brown weathering, minor lamination, very calcareous, prominent rusty bed. Overlies unit 115 abruptly.	1.2	195.6
115	Mudstone and siltstone, medium greenish-grey, minor carbonaceous fragments, ripple lamination near top.	1.1	194.4
114	Siltstone and sandstone, very fine grained, medium greenish-grey to medium light grey with light greyish-brown and rusty weathering, beds 2 to 25 cm, faint carbonaceous lamination in part, non-calcareous except moderately strongly calcareous at top, very ferruginous concretionary siltstone. Overlies unit 113 abruptly.	2.3	193.3
113	Claystone, medium greenish-grey, structureless, recessive, upward to siltstone, argillaceous, medium greenish-grey. Overlain by 90 cm of siltstone, argillaceous, medium light greenish-grey with medium greenish-grey and maroon weathering.	1.9	191.0
112	Mudstone and siltstone, medium dark greenish-grey to siltstone and very fine grained sandstone, medium light grey with rusty orange-brown weathering in part, very fine carbonaceous lamination in part, non-calcareous to moderately calcareous in most resistant part of bed to non-calcareous upward.	3.9	189.1
111	Mudstone, medium light greenish-grey, with very rusty weathering, some siltstone interbeds upward. Mostly heavily covered.	2.5	185.2
110	Shale, medium dark olive-grey, non-calcareous, more recessive and more carbonaceous upward with some greenish grey interbeds. Abrupt lower contact.	4.4	182.7
109	Siltstone and mudstone, fining upward, light to dark greenish-grey, with some very carbonaceous shale, appears to coarsen slightly near top.	2.1	178.3
108	Siltstone to sandstone, very fine grained upward, medium to light greenish-grey with rusty maroon-brown weathering, minor carbonaceous and mica flakes give platy to thin slabby weathering appearance. Gradational with unit 107.	1.3	176.2
107	Shale, medium dark to medium olive-grey, non-calcareous. Overlies unit 106 abruptly.	2.8	174.9
106	Mudstone and claystone, light greenish-grey, recessive, massive, minor to common carbonaceous fragments. Two sandstone beds in upper 90 cm, very fine grained, medium light greenish grey, structureless.	4.5	172.1
105	Sandstone, very fine to fine grained upward, medium to light greenish-grey with greenish-grey and maroon weathering. Abrupt lower contact.	0.9	167.6
104	Siltstone to mudstone upward, medium greenish-grey, trace carbonaceous. Gradational with unit 103.	0.5	166.7
103	Siltstone to sandstone, very fine grained, medium greenish-grey with rusty orange-brown weathering, bedding obscure but seems to be interbedded with platy weathering. Gradational with unit 102.	2.7	166.2
102	Siltstone, medium dark greenish-grey, trace carbonaceous, recessive, poorly exposed. Overlies unit 101 abruptly.	0.8	163.5
101	Sandstone, as in unit 99.	0.5	162.7
100	Mudstone, dark greenish-grey, platy, recessive.	0.1	162.2
99	Sandstone, very fine grained, as below, structureless. Appears to be channelled into unit 98.	0.4	162.1
98	Mudstone, more silty upward, medium dark grey. Overlies unit 97 abruptly.	1.0	161.7
97	Siltstone to sandstone, very fine grained, medium to medium dark greenish-grey with greenish-grey and maroon weathering.	0.9	160.7
96	Similar to below but very poorly exposed. May be slight structural disturbance.	5.1	159.8
95	Mudstone and siltstone, medium greenish-grey to medium grey, trace carbonaceous, recessive. Lenses of sandstone, very fine to fine grained, up to 2 m thick, appear to be scoured into mudstone-siltstone.	8.5	154.7
94	Mudstone, medium greenish-grey with a thin bed of a very carbonaceous black shale in middle.	0.3	146.2
93	Sandstone, very fine grained, medium greenish-grey to medium grey upward, moderately to non-calcareous upward, carbonaceous throughout with a few wood fragment impressions.	2.4	145.9
92	Siltstone, very carbonaceous, platy medium dark grey, recessive.	0.1	143.5

Unit	Description	Unit Thickness (metres)	Height above base (metres)
91	Sandstone, very fine grained, medium grey with grey to rusty brown weathering, abundant carbonaceous fragments along bedding planes, moderately strongly calcareous in lower few centimetres, non-calcareous above. Upward to siltstone and mudstone, medium grey, darker upward, a few ironstone concretions up to 5 cm thick, 10 cm long.	3.0	143.4
90	Covered.	4.9	140.4
89	Mudstone, medium light greenish-grey, upward to siltstone, medium dark greenish-grey with maroon weathering, upward to sandstone, very fine grained, medium greenish-grey with light greenish-grey weathering, minor carbonaceous, trace roots.	3.9	135.5
88	Siltstone to sandstone, as in unit 87. Sandstone only in upper 20 cm, appears to rest abruptly on siltstone. Overlies unit 87 abruptly.	1.1	131.6
87	Siltstone to sandstone, very fine to fine grained upward, medium greenish-grey to light grey upward, non-calcareous light rusty to dirty brownish-grey weathering, structureless. Overlies unit 86 abruptly.	0.9	130.5
86	Mudstone, very carbonaceous, medium dark olive-grey, recessive.	0.6	129.6
85	Sandstone, very fine grained, medium greenish-grey, structureless. Abrupt lower contact. Minor carbonaceous and mica flakes along bedding planes.	0.5	129.0
84	Siltstone and mudstone, medium greenish-grey with abundant carbonaceous fragments at base, less carbonaceous and more argillaceous upward. Abrupt lower contact.	1.5	128.5
83	Sandstone, very fine grained to medium grained upward, light greenish-grey with medium light greenish-grey to maroon weathering, non-calcareous at base to very calcareous upward, platy with low angle crossbeds at base to massive and slabby upward.	2.4	127.0
82	Covered.	1.3	124.6
81	Mudstone and siltstone to very fine grained sandstone upward, three coarsening upward units, then fines upward into overlying unit, greenish-grey colours, minor carbonaceous fragments, structureless as below.	2.9	123.3
80	Claystone, medium dark olive-green, carbonaceous, recessive, structureless.	0.9	120.4
79	Mudstone, very silty, pistachio-green very recessive.	0.5	119.5
78	Siltstone to very fine grained sandstone, medium dark to medium light greenish-grey, non-calcareous, root penetrated. Gradational with unit 77.	1.3	119.0
77	Sandstone, very fine grained, moderately to strongly calcareous, more resistant than adjacent beds, a large ironstone concretion 60 cm by 75 cm long.	0.3	117.7
76	Sandstone, very fine grained, medium greenish-grey with minor carbonaceous fragments, green and maroon weathering, upward to siltstone and mudstone, medium greenish-grey, structureless. Abrupt base.	2.3	117.4
75	Shale, medium dark grey, carbonaceous, rusty maroon weathering, upward to mudstone, medium dark greenish-grey with rusty orange to maroon weathering, structureless, darker towards top again. Abrupt contact.	2.5	115.1
74	Claystone-mudstone to mudstone-siltstone upward, medium dark to medium greenish-grey upward, some darker more carbonaceous units. Recessive, poorly exposed.	2.7	112.6
73	Sandstone, as below but more recessive, crumbly appearance due to abundant root penetration.	0.7	109.9
72	Sandstone, very fine grained medium light greenish-grey with light rusty to maroon weathering, structureless. May be gradational with unit 71.	0.9	109.2
71	Siltstone, greenish-grey, slightly more recessive.	0.6	108.3
70	Siltstone to very fine grained sandstone upward, similar to lower units.	2.1	107.7
69	Mudstone and claystone, medium to light greenish-grey with minor carbonaceous fragments, to medium grey claystone becoming darker upward. Overlies unit 68 gradationally.	1.1	105.6
68	Mudstone, dark greenish-grey, above lower 20 cm to siltstone, and very fine grained sandstone, medium greenish-grey, carbonaceous-rich lamination in part, roots common in upper 50 cm. Abrupt lower contact.	2.6	104.5
67	Claystone, medium greenish-grey to medium dark grey and carbonaceous upward.	0.3	101.9
66	Siltstone to very fine grained sandstone upward, medium greenish-grey with rusty orange to maroon weathering, structureless. Overlies unit 65 abruptly.	1.3	101.6
65	Siltstone and mudstone, slightly finer upward, medium light greenish-grey with rusty purplish weathering, trace carbonaceous, structureless. Overlies unit 64 abruptly.	2.1	100.3
64	Mudstone, soft, recessive, medium dark olive grey to medium dark grey upward.	0.3	98.2
63	Sandstone, similar to below.	0.8	97.9
62	Sandstone, fine grained, light greenish-grey with grey and maroon weathering, carbonaceous fragments common, to mudstone, silty, 30 cm thick concretionary, abundant plant fragments to mudstone, very carbonaceous in upper 20 cm. Overlies unit 61 abruptly.	1.0	97.1
61	Claystone, medium greenish-grey with medium orangish-brown weathering, trace carbonaceous, upward to shale, carbonaceous and coaly, medium dark grey.	0.7	96.1
60	Sandstone, fine grained, medium light grey, rusty weathering at base, less upward, a few roots and more carbonaceous upward.	0.5	95.4
59	Mudstone, medium greenish-grey, structureless. Abrupt contact.	0.3	94.9
58	Mudstone, more silty upward, medium dark grey with medium rusty orange weathering, carbonaceous fragments and wood impressions common, few small ironstone concretions. Finer upward at top to mudstone, carbonaceous, medium dark grey. Abrupt lower contact.	2.1	94.6
57	Shale, dark grey, very carbonaceous at base, upward predominantly clay, soft, medium olive-grey, slightly more carbonaceous upward, possible bentonite. Rootlets at top. Abrupt contact with unit 56.	0.8	92.5
56	Mudstone, dark olive-grey to siltstone, medium greenish-grey, structureless but with abundant root penetration.	0.7	91.7
55	Clay, very light grey, soft, probable bentonite.	1.0	91.0
54	Mudstone, medium dark grey, to platy siltstone, medium greenish-grey to slabby sandstone, similar colour, non-calcareous, beds up to 10 cm thick, carbonaceous fragments common in siltstone and sandstone as fine laminae.	1.0	90.0

Unit	Description	Unit Thickness (metres)	Height above base (metres)
53	Mudstone, medium grey, mottled appearance, bioturbated (?) probably by roots. Slight scour into unit 52.	2.7	89.0
52	Mudstone, light greenish-grey, upward to clay, very light greenish-grey, soft probable bentonite.	0.7	86.3
51	Mudstone-siltstone to siltstone-sandstone, very fine grained upward, similar to below. A 35 cm concretion bed near base, light greenish-grey with reddish-brown weathering, moderately strongly calcareous.	2.2	85.6
50	Mudstone to very fine grained sandstone upward, medium light greenish-grey with medium dark maroon brown weathering, very faint lamination in part, non-calcareous. Gradational with unit 49.	2.8	83.4
49	Claystone, to mudstone upward, medium light greenish-grey, trace carbonaceous, structureless. Abrupt lower contact.	0.8	80.6
48	Mudstone to siltstone and very fine grained sandstone, appears gradational throughout, light greenish-grey.	1.4	79.8
47	Siltstone, argillaceous, medium greenish-grey, non-calcareous, trace carbonaceous, structureless. Lies abruptly on unit 46.	0.9	78.4
46	Mudstone, medium light greenish-grey, more recessive, massive.	0.3	77.5
45	Mudstone, medium greenish-grey with maroon weathering, more silty in some beds, structureless. Overlies 44 abruptly.	2.9	77.2
44	Siltstone, very argillaceous, medium dark greenish-grey, very fine lamination, platy. Upward to sandstone, very fine grained, light greenish-grey weakly developed carbonaceous-rich lamination, non-calcareous. Abrupt lower contact.	2.8	74.3
43	Sandstone, very fine grained, to siltstone and silty mudstone upward, medium dark greenish-grey, non-calcareous, minor carbonaceous fragments throughout. Dark grey carbonaceous shale in upper 2 to 3 cm. Abrupt lower contact.	1.7	71.5
42	Siltstone, medium dark greenish-grey, non-calcareous, very thin carbonaceous-rich lamination common, a few wood fragment impressions. Gradational with unit 41.	1.4	69.8
41	Siltstone to mudstone, medium dark greenish-grey, with rusty concretionary appearance. Overlies unit 40 abruptly.	0.6	68.4
40	Mudstone with claystone and siltstone, greenish-grey, minor carbonaceous fragments in part, light rusty weathering. Abrupt lower contact.	1.1	67.8
39	Mudstone, claystone, shale with subordinate siltstone, dark olive-grey to medium greenish-grey, rusty orange to maroon weathering common. Structureless and bedding surfaces often obscure, beds less than 10 cm to 100 cm. A few carbonaceous-rich beds and upper 100 cm is very carbonaceous coaly shale. Transitional lower contact.	6.7	66.7
38	Siltstone to sandstone, very fine grained upward, medium greenish-grey, massive but with faint lamination in part. Sandstone beds, 10 to 20 cm thick in upper 1 m separated by more recessive siltstone (1 cm). Rootlets in upper 40 cm, ferruginous towards top. Abrupt lower contact.	2.9	60.0
37	Mudstone, greenish-grey with maroon weathering, carbonaceous in lower 30 cm, to claystone upward.	2.1	57.1
36	Siltstone, argillaceous to siltstone, medium greenish-grey, with rusty orangish-brown weathering, structureless. Abrupt on unit 35.	1.2	55.0
35	Siltstone, medium dark grey with light orangish-grey weathering, non-calcareous, hard, abundant wood fragments along base. To sandstone, very fine to fine grained, medium greenish-grey non-calcareous, faint carbonaceous lamination in part. Overlies unit 34 abruptly.	1.7	53.8
34	Mudstone, medium dark greenish grey, hard, massive. More siltstone upward but less indurated, minor carbonaceous fragments. Overlies unit 33 abruptly.	0.5	52.1
33	Siltstone to sandstone, very fine grained upward, greenish-grey, with rusty yellowish-orange weathering, minor rootlets. Upward appears transitional to siltstone and mudstone, greenish-grey with maroon-brown weathering, structureless.	1.1	51.6
32	Sandstone-siltstone, more argillaceous upward, medium greenish-grey, 2 cm of carbonaceous sandy clay at top.	0.3	50.5
31	Siltstone to very fine to fine grained sandstone upward and then to very fine grained at top, medium to light greenish-grey, non-calcareous to moderately calcareous to non-calcareous upward, structureless except faint lamination in part. Overlies unit 30 abruptly.	1.9	50.2
30	Mudstone and claystone, medium greenish-grey, very recessive, carbonaceous in part. A 5 cm bed of clay, very soft, cream colour, probable bentonite.	0.7	48.3
29	Concretion, silty, light olive-grey with light rusty orange weathering, non-calcareous, hard.	0.3	47.6
28	Clay, very soft, recessive, light olive-grey, trace carbonaceous, very ferruginous in upper 15 cm.	0.8	47.3
27	Siltstone and mudstone, fining upward, medium light greenish-grey, trace carbonaceous. Very rusty claystone with large (medium grained) siderite grains in upper 20 cm. Gradational with unit 26.	1.3	46.5
26	Sandstone, fine grained as below interbedded (10-20 cm) with sandstone, very fine grained with wavy, platy weathering. Contact both abrupt and gradational.	0.7	45.2
25	Siltstone to sandstone, very fine grained, medium greenish-grey, carbonaceous-rich lamination give sandstone a platy appearance, becoming fine grained upward, blocky weathering and less carbonaceous. Overlies unit 24 abruptly.	3.1	44.5
24	Siltstone, greenish-grey, structureless. Abrupt contact.	0.5	41.4
23	Sandstone, very fine grained, medium greenish-grey, structureless, more indurated than below.	0.3	40.9
22	Mudstone to siltstone, medium greenish-grey with medium orangish-brown weathering, non-calcareous, structureless, a few ironstone concretion nodules. Gradational with unit 21.	2.1	40.6
21	Shale, very coaly, black to claystone, carbonaceous, dark olive-grey, upward slightly more resistant upward. Overlies unit 20 abruptly.	0.6	38.5
20	Siltstone, argillaceous to sandstone, very fine grained, medium greenish-grey with light rusty weathering, abundant roots penetrate through unit, upper 20 cm is very weathered very ferruginous, possible paleosol. Overlies unit 19 gradationally.	1.0	37.9
19	Mudstone, silty, medium dark olive-grey to claystone upward, dark grey, trace carbonaceous, structureless. Overlies unit 18 abruptly.	1.1	36.9
18	Shale, coaly lenses and very carbonaceous throughout.	0.2	35.8

Unit	Description	Unit Thickness (metres)	Height above base (metres)
17	Mudstone, carbonaceous with coal, argillaceous and shale, coaly, beds 3 to 10 cm, dark grey to olive grey.	1.3	35.6
16	Siltstone and mudstone upward to predominantly sandstone, very fine grained, medium greenish-grey to olive-grey with medium dark orangish-brown weathering, upper 35 cm harder and very ferruginous with abundant roots.	1.0	34.3
15	Siltstone and mudstone, fining upward, medium greenish-grey to dark grey, trace carbonaceous, crumbly, recessive unit. Overlies unit 14 gradationally.	0.6	33.3
14	Sandstone, very fine grained, slightly more resistant than below, a 5 cm ironstone concretion bed at base, non-calcareous, medium greenish-grey, minor wavy carbonaceous lamination.	1.8	32.7
13	Siltstone, argillaceous, medium greenish-grey, trace carbonaceous, structureless, upward to sandstone, very fine grained, silty, may be gradational with unit 12.	1.5	30.9
12	Mudstone to siltstone, argillaceous, non-calcareous, structureless, with two sandstone beds, very fine grained, 80 and 60 cm thick, appear to be upper members of coarsening upward sequences.	3.5	29.4
11	Sandstone, very fine grained, light grey to light greenish-grey, non-calcareous, massive, flaggy to irregular platy weathering.	2.7	25.9
10	Covered.	0.9	23.2
9	Sandstone, fine grained to very fine grained upward, light grey to greenish-grey, rusty weathering, horizontal to wavy lamination. Upper 150 cm slightly coarser again and is moderately calcareous in part. Units 4 to 9 represent a channel deposit. Laterally, it cuts down into underlying beds at least several metres.	5.6	22.3
8	Sandstone, fine grained, very pale greenish-grey with light maroon weathering, horizontal bedding, good primary current lineation on some bedding planes, very calcareous. Overlies unit 7 abruptly.	0.4	16.7
7	Sandstone, medium to fine grained, weakly to moderately calcareous, faint crossbedding, prominent platy weathering. Overlies unit 6 abruptly.	1.8	16.3
6	Sandstone, medium grained, moderately calcareous and light grey at base, upward to rusty weathering and very calcareous. Overlies unit 5 abruptly.	2.6	14.5
5	Sandstone, medium grained, non-calcareous and moderately hard at base, strongly calcareous and moderately friable upward, faint crossbedding, horizontal bedding in part, a few large wood impressions, more rusty weathering upward. Overlies unit 4 abruptly and scours into it slightly.	1.3	11.9
4	Sandstone, medium grained, light grey with light rusty yellowish-orange weathering, moderately to weakly calcareous, a few mudstone rip-up clasts and wood fragment impressions along base. Abrupt base and scoured into underlying beds.	1.2	10.6
	TOP OF MALCOLM CREEK FORMATION		
3	Mudstone and siltstone, thin interbedded medium dark grey with medium olive-grey and rusty orange weathering, upward to sandstone, very fine grained, abundant carbonaceous-rich laminae, thin platy weathering. Overlies unit 2 abruptly.	4.2	9.4
2	Claystone, dark olive-grey, non-calcareous, a few small (1-2 cm) elongate ironstone concretions. Overlies unit 1 abruptly.	0.7	5.2
1	Coal with thin interbeds of claystone and shale, very carbonaceous and coaly.	4.5	4.5

MALCOLM CREEK SECTION

Hypostratotype of Mountain Park Formation

Unit	Description	Unit Thickness (metres)	Height above base (metres)
119	Shale, silty, dark grey, with deep rusty to purplish staining on fractures.		
118	Covered interval.	26.5	241.3
	TOP OF MOUNTAIN PARK FORMATION		
117	Siltstone to sandstone, very fine grained upward, very calcareous, pale yellowish-brown to light brown, concretions in lower part, very fine horizontal laminae in upper part. Overlies unit 116 gradationally.	4.2	214.8
116	Claystone, dusky yellowish-brown to greenish-grey upward, non-calcareous, carbonaceous material common to minor upward, soft recessive.	4.2	210.6
115	Concretionary bed, grey with rusty weathering, aphanitic, non-calcareous, in siltstone and mudstone, very carbonaceous at top.	0.5	206.4
114	Sandstone, similar to below but less indurated, more silty and argillaceous upward to black shale at top, greenish-grey to dark grey upward.	1.7	205.9
113	Mudstone, dark grey, very carbonaceous, upward to siltstone and sandstone, very fine grained, greenish-grey, non-calcareous with scattered plant fragments.	0.9	204.2
112	Clay, yellowish-grey, soft, possible bentonite.	0.2	203.3
111	Coal, weathered, very crumbly, dull, recessive.	0.2	203.1
110	Siltstone and mudstone, very recessive, non-calcareous, more carbonaceous upward.	0.6	202.9
109	Siltstone and sandstone, very fine grained, hard, resistant, very carbonaceous at base, non-calcareous, very fine lamination, minor interbedded mudstone. Abrupt base.	1.0	202.3
108	Recessive, mostly covered interval. Greenish-grey mudstone at base, 10 cm of very argillaceous coal higher, and very carbonaceous mudstone above.	2.2	201.3
107	Sandstone, very fine grained to siltstone to mudstone upward, greenish-grey, non-calcareous, massive, a few roots near top. Abrupt contact with unit 106.	1.9	199.1

Unit	Description	Unit Thickness (metres)	Height above base (metres)
106	Siltstone to mudstone upward, pale greenish-grey, becomes darker and greyer upward, massive, scattered ferruginous concretions.	0.7	197.2
105	Siltstone to sandstone, very fine grained medium light grey with light rusty weathering, very calcareous, irregular slabby weathering. Gradational with unit 104.	0.8	196.5
104	Mudstone, dusky yellowish-green weathering, non-calcareous, massive to claystone, light olive-grey upward.	1.2	195.7
103	Sandstone, very fine grained, silty, greenish-grey, crossbedded in part, non-calcareous, moderately recessive.	2.5	194.5
102	Sandstone, fine to medium grained in part, crossbedded at base, non-calcareous to moderately calcareous upward, cream weathering at base to rusty weathering upward. Abrupt base.	2.8	192.0
101	Siltstone, abundant carbonaceous-rich laminae, non-calcareous, moderately recessive, abrupt base.	0.4	189.2
100	Sandstone, very fine grained, to siltstone and silty mudstone upward pale greenish-grey, more carbonaceous and darker upward, non-calcareous throughout. Gradational with unit 99.	1.1	188.8
99	Sandstone, fine to very fine grained upward, light grey (slightly greenish) with medium rusty weathering, non-calcareous. large wood fragments, trough crossbedding common in lower 2 m, climbing ripples common at top, carbonaceous-rich laminae common, blocky to platy weathering. Abrupt base.	8.6	187.7
98	Claystone, greenish-grey, massive.	0.6	179.1
97	Sandstone, fine and very fine grained, greenish grey with light rusty weathering, non-calcareous. A series of massive beds overlain by platy weathering beds, each couplet 40 to 100 cm thick, carbonaceous-rich lamination. Abrupt base.	2.2	178.5
96	Mudstone to siltstone to sandstone, very fine grained, upward, non-calcareous, increase in carbonaceous material upward, unit is moderately recessive.	5.4	176.3
95	Sandstone, very fine grained, non-calcareous faint lamination, abundant carbonaceous and wood fragments, grades upward into increasingly finer material with greenish-grey colour. Rusty concretions along upper contact.	0.6	170.9
94	Shale, dark grey, coaly in part. Recessive and poorly exposed.	0.5	170.3
93	Sandstone, medium to very fine grained upward, very light grey with light rusty weathering, trough crossbedded, wood fragment impressions common on bedding planes. Overlies unit 92 abruptly.	0.9	169.8
92	Mudstone, dark grey, carbonaceous, scattered concretions to mudstone and siltstone, greenish-grey in upper half, non-calcareous, thin bedded, platy.	1.7	168.9
91	Siltstone to very fine grained sandstone, very light grey with about 10 percent rusty siderite grains; 75 cm above base, into festoon bedded sandstone, fine grained, massive to platy upward, very calcareous to non-calcareous upward, very ferruginous at top. Abrupt lower contact.	2.6	167.2
90	Mudstone, greenish-grey, non-calcareous, more carbonaceous with minor coal upward with shale, silty, olive-grey at top. Gradational with unit 89.	1.5	164.6
89	Siltstone and sandstone, very fine grained, medium light grey with medium grey and rusty weathering, non-calcareous, prominent grey and orange colour banded in part (1-2 cm bands), faint lamination throughout.	1.5	163.1
88	Shale, very carbonaceous becoming coaly upward. Abrupt lower contact.	0.4	161.6
87	Sandstone, fine grained, fining upward, rusty weathering, prominent cross lamination, carbonaceous-rich lamination, roots common. Abrupt base.	0.4	161.2
86	Mudstone, light olive grey, moderately recessive, more carbonaceous upward to few centimetres of argillaceous coal and back to mudstone at top, moderately calcareous in lower part.	0.4	160.8
85	Sandstone, very fine grained, massive at base to thinly laminated upward, prominent roots extend through unit. Abrupt base.	0.2	160.4
84	Sandstone, argillaceous, very fine grained, slightly recessive, very calcareous.	0.2	160.2
83	Sandstone, very fine grained, calcareous, faint horizontal lamination, rusty weathering. Abrupt lower contact.	0.3	160.0
82	Sandstone, very fine grained, friable, recessive, more argillaceous upward to very carbonaceous shale and shaly coal, then back to brown, carbonaceous, calcareous, argillaceous siltstone at top.	0.6	159.7
81	Sandstone, very fine grained and siltstone, thin interbedded and laminated. Upward to prominent, massive bed with horizontal lamination and low angle cross lamination, normal graded beds with some coarse grained sand at base but predominantly very fine to fine grained. An upright tree trunk 75 cm from base of unit. Overlies unit 80 abruptly.	1.3	159.1
80	Siltstone, argillaceous, very carbonaceous to mudstone, dark grey, non-calcareous upward. Appears gradational with unit 79.	0.6	157.8
79	Sandstone, fine grained, moderately calcareous, 15 percent siderite grains, concretionary at base with prominent rectangular jointing. Gradational with unit 78.	1.5	157.2
78	Mudstone and siltstone to sandstone, very fine grained at top, scattered ferruginous concretions, minor carbonaceous throughout, non-calcareous.	2.9	155.7
77	Concretion bed, medium grey with rusty weathering, non-calcareous, with possible root casts.	0.4	152.8
76	Mudstone, carbonaceous, dusky yellowish-brown, non-calcareous, massive.	2.4	152.4
75	Coal, very recessive to brown carbonaceous silty clay to hard mudstone upward. Overlies unit 74 abruptly.	0.4	150.0
74	Mudstone to siltstone, greyish-brown with cream to light rusty weathering, carbonaceous throughout, moderately strongly calcareous to non-calcareous at top, very finely laminated at top.	1.7	149.6
73	Sandstone, very fine grained, friable, to siltstone, mudstone and shale upward, all non-calcareous, minor carbonaceous fragments, mudstones are greenish-grey. Upward, moderately indurated silty mudstone, with abundant carbonaceous material and a 30 cm coal bed, argillaceous. Whole unit recessive and poorly exposed.	3.6	147.9
72	Sandstone, similar to unit 70, rootlets penetrate entire bed.	0.4	144.3
71	Sandstone, similar to unit 69, friable.	0.6	143.9

Unit	Description	Unit Thickness (metres)	Height above base (metres)
70	Sandstone, very fine grained, very hard, quartzose, medium light grey with light grey weathering.	0.5	143.3
69	Sandstone, very fine grained, silty, slightly argillaceous, medium grey, trace calcareous. Overlies unit 68 abruptly.	0.4	142.8
68	Sandstone, medium to very fine grained upward, strongly calcareous, lower 30 cm contains abundant wood fragments, plant debris and ironstone pebbles, trough crossbedded in part, minor ripple lamination upward, very light grey with buff to light rusty weathering. Overlies 67 abruptly. A prominent resistant unit.	7.0	142.4
67	Coal, highly sheared.	0.2	135.4
66	Sandstone, very fine grained, plant fragments common, pale greenish-grey, non-calcareous, recessive.	0.9	135.2
65	Series of fining-upward units as in 64 and 63, all non-calcareous, all have a greenish colouration when wet.	1.7	134.3
64	Sandstone, as in 63, becoming more argillaceous upward, faint lamination.	0.7	132.6
63	Sandstone, fine to very fine grained upward, massive to platy upward, to siltstone and mudstone, recessive, at top.	0.8	131.9
62	Sandstone, very fine to fine grained upward, light grey, non-calcareous, to moderately calcareous to non-calcareous upward, platy to massive upward, faintly laminated, some faint trough crossbedding. A 30 cm recessive zone at top, silty mudstone to siltstone upward, light olive-grey, non-calcareous. Gradational with unit 61.	2.8	131.1
61	Interbedded mudstone and siltstone, medium grey, non-calcareous, recessive, poorly exposed. Overlies unit 60 abruptly.	1.5	128.3
60	Sandstone, very fine grained, light grey with medium light grey weathering, non-calcareous. Becomes fine grained upward, markedly calcareous, with prominent light brown weathering, prominent horizontal lamination throughout. Overlain by fine grained, non-calcareous sandstone, abundant carbonaceous lamination. Overlain abruptly by a very calcareous, rusty concretion bed with very calcareous fine grained sandstone above.	5.2	126.8
59	Shale, carbonaceous, very dark grey, a few silty, more resistent interbeds, non-calcareous.	2.0	121.6
58	Covered.	2.4	119.6
57	Siltstone upward to mudstone, dark grey, very carbonaceous, non-calcareous, upward to claystone medium greenish-grey, minor carbonaceous fragments.	1.5	117.2
56	Sandstone, fine to medium grained upward, medium light grey with dark rusty weathering, slightly greenish when wet, abundant carbonaceous fragments often as laminae, horizontal lamination to low angle crossbedding, massive to thick slabby weathering. A greenish, friable sandstone at top. Abrupt base.	2.9	115.7
55	Shale, slightly silty, very dark grey, non-calcareous. Overlies unit 54 abruptly.	2.2	112.8
54	Coal, dull, very fractured and weathered. Overlies unit 53 gradationally.	0.7	110.6
53	Claystone, silty, light olive grey, very calcareous, rusty weathering, massive, more carbonaceous upward.	1.5	109.9
52	Shale, very carbonaceous and coaly.	0.4	108.4
51	Sandstone, very fine grained, horizontal lamination with abundant roots towards top, more argillaceous interbeds upward and abundantly carbonaceous at top. A 3 cm bed of soft coal at top. Abrupt base.	1.2	108.0
50	Claystone, greenish-grey, upward to darker, more carbonaceous claystone. A few concretionary lenses, very rusty weathering, 50 cm long and up to 20 cm thick.	2.9	106.8
49	Sandstone, very fine to fine grained upward, sharp lower contact with very ferruginous concretions, carbonaceous-rich laminae, light rusty to light grey weathering upward, upper 20 cm moderately friable.	1.1	103.9
48	Shale, light olive-grey with dark blue-grey weathering, bluish manganese (?) stain, carbonaceous material common, non-calcareous. Overlies unit 47 abruptly.	2.3	102.8
47	Mudstone, medium dark grey, upward to sandstone, very fine grained, non-calcareous with a thin concretionary bed at top.	0.5	100.5
46	Covered.	4.2	100.0
45	Claystone, greenish-grey, may be a bentonite. Upward to more resistant mudstone, medium grey, non-calcareous, very fine horizontal lamination. Upward to siltstone, rusty weathering, very calcareous.	1.7	95.8
44	Sandstone, very fine grained, slightly coarser upward, concretions at base, horizontal lamination to ripple laminated upward.	0.5	94.1
43	Claystone, dark greenish-grey with medium greenish-grey weathering, darker, probably more carbonaceous upward.	1.8	93.6
42	Covered.	2.7	91.8
41	Sandstone, very fine grained, light grey with light rusty weathering, traces of ripple lamination but most is destroyed by burrowing. No lamination in upper few decimetres.	1.5	89.1
40	Siltstone, calcareous, to siltstone, argillaceous upward, more recessive upward, carbonaceous, very calcareous. Gradational with unit 39.	0.8	87.6
39	Sandstone, very fine grained, silty to fine grained upward, medium brownish-grey with light rusty weathering, very calcareous, minor horizontal lamination at base, prominent upward. Minor bioturbation at top. Gradational with unit 38.	1.9	86.8
38	Mudstone, dusky yellowish-brown, very calcareous, trace carbonaceous, upward to siltstone, rusty weathering, very calcareous with more argillaceous interbeds. Overlies unit 37 abruptly.	2.2	84.9
37	Sandstone, very fine grained, light rusty weathering, prominent climbing ripples. Two sandstone beds 45 and 40 cm thick separated by 5 cm recessive bed.	0.9	82.7
36	Sandstone, very fine grained, silty, light grey weathering, moderately strongly calcareous. Overlies unit 35 abruptly.	0.4	81.8
35	Sandstone, medium to very fine grained upward, small trough crossbeds to climbing ripples upward, massive at top, moderately calcareous. Overlies unit 34 gradationally.	4.2	81.4
34	Sandstone, very coarse grained to medium grained upward, buff weathering, scoured base with mudstone and concretion rip-up clasts, extra formational pebbles usually less than 1 cm, up to 4 cm, trough crossbedded, primary current lineation along few surfaces. Overlies unit abruptly.	1.3	77.2
33	Sandstone, very fine grained, horizontal lamination, overlain abruptly by a few cm of medium grained sandstone.	0.2	75.9
32	Heavy cover. No exposure.	11.6	75.7

Unit	Description	Unit Thickness (metres)	Height above base (metres)
31	Sandstone, very fine grained, cream-coloured with siderite specks, rusty weathering, non-calcareous. Gradational with unit 30 over short interval but much better indurated and resistant to weathering.	2.7	64.1
30	Mudstone, dark grey, very carbonaceous, upward to siltier mudstone and siltstone, olive-grey with rusty weathering, non-calcareous, carbonaceous fragments common. Overlies unit 29 abruptly.	1.7	61.4
29	Thin interbedded siltstone, sandstone and concretions similar to unit 27. Lower boundaries of sandstone beds are gradational, upper boundaries are sharp. Roots penetrate entire unit.	0.7	59.7
28	Mudstone, dark grey, with a prominent septarian concretion bed up to 1 m thick, but usually less than 10 cm, discontinuous, very calcareous, rusty weathering, aphanitic.	1.2	59.0
27	Siltstone to very fine grained sandstone and rusty concretionary interbeds, slightly to moderately calcareous. Overlies unit 26 gradationally.	0.9	57.8
26	Mudstone, dark grey with medium grey weathering, non-calcareous, more silty and laminated upward. An 8 cm bed of sandstone 50 m above base, very fine grained, argillaceous, with abundant shell fragments. Overlies unit 25 abruptly.	2.0	56.9
25	Mudstone, brownish-grey, with rootlets and rusty concretions in lower 40 cm. Overlain abruptly by claystone, very dark grey, gradationally upward to sandstone, very fine grained, non-calcareous, horizontal thin bedded, pale brown with prominent rusty concretion beds 5 to 15 cm thick, moderately calcareous. Overlies unit 24 abruptly.	1.7	54.9
24	Sandstone, very fine grained, moderately calcareous, cream to moderately rusty weathering, faint lamination. Interbedded siltstone and mudstone 7 to 10 cm thick. Prominent root zone at top. Overlies unit 23 gradationally.	1.7	53.2
23	Mudstone, dark grey, carbonaceous upward to lighter coloured siltstone, non-calcareous to moderately strongly calcareous upward. Overlies unit 22 abruptly.	0.5	51.5
22	Sandstone, very fine grained, prominent yellowish-orange weathering, moderately strongly calcareous. Overlies unit 21 abruptly.	0.9	51.0
21	Shale, dark grey, recessive, poorly exposed.	1.2	50.1
20	Sandstone, very fine grained, pale brownish-grey with light brown weathering, moderately strongly calcareous, carbonaceous fragments common, some plant impressions. Overlies unit 19 abruptly.	1.0	48.9
19	Shale, dark grey with medium dark grey weathering, minor rusty stain. Overlies unit 18 abruptly.	2.9	47.9
18	Sandstone, very fine grained, very carbonaceous at base with wood casts. Overlies unit 17 abruptly. Appears to be a lense.	0.6	45.0
17	Coal, argillaceous to claystone, dusky yellowish-brown upward. Recessive, poorly exposed.	1.7	44.4
16	Siltstone, concretionary at base, moderately calcareous, light brown to rusty brown, minor carbonaceous fragments. Upward to sandstone, very fine grained, light grey and rusty weathering, moderately strongly calcareous, horizontal lamination and low angle cross lamination, roots near top. Overlies unit 15 abruptly.	2.1	42.7
15	Mudstone, medium dark brownish-grey, carbonaceous throughout, coaly near top. Overlies unit 14 abruptly.	2.7	40.6
14	Siltstone to fine grained sandstone upward, medium light grey to rusty weathering, non-calcareous, faint lamination in part, two silty mudstone interbeds. Root penetration of 50 cm in one sandstone bed. Gradational with unit 13.	2.6	37.9
13	Mudstone, very carbonaceous, very dark grey, very coaly with thin coal lenses in part. Upward lighter grey, more silty, non-calcareous. Six distinct ironstone concretion beds, non-calcareous prominent rusty weathering. Overlies unit 12 abruptly.	8.9	35.3
12	Sandstone, fine to very fine grained upward, light grey with buff to rusty weathering, ferruginous laminae and specks; abrupt, scoured base, some crossbeds. Laterally is represented by distinctly laminated siltstone and claystone, horizontal and ripple laminated, contorted at base, abundantly bioturbated upward. More carbonaceous with roots at top.	3.2	26.4
11	Siltstone, argillaceous, very carbonaceous, most very recessive and covered. Mudstone, medium dark grey, non-calcareous at top.	3.7	23.2
10	Sandstone, fine grained, slightly finer upward, light grey with light brown weathering, non-calcareous, minor mudstone rip-up clasts, one large erratic block 80 cm thick, some trough crossbedding. Laterally in short distance, thickens and cuts downsection to the unit 2 to 6 sequence. Abrupt, scoured base.	4.5	19.5
9	Sandstone, very fine grained, medium light grey with light grey weathering, a few small mudstone rip-up clasts, prominent cross lamination, slightly calcareous. Overlies unit 8 abruptly.	0.7	15.0
8	Mudstone, silty, very carbonaceous and coaly, particularly in lower few decimetres, siltier upward. Overlies unit 7 abruptly.	2.8	14.3
7	Sandstone, very fine grained, medium light grey fresh and weathered, non-calcareous, abundant roots, more carbonaceous and brownish coloured upward.	0.5	11.5
6	Sandstone, very fine grained, colours as below, moderately calcareous, prominent ripple drift lamination, moderately carbonaceous, root penetration at least 30 cm. Units 2 to 6 are part of a fining-upward sequence which thins laterally.	0.6	11.0
5	Sandstone, very fine grained, horizontal laminae, distinct platy weathering. Overlies unit 4 abruptly.	0.3	10.4
4	Sandstone, fine grained, light grey with pale rusty weathering, shale rip-up clasts at base, moderately calcareous, vague megaripples. Overlies unit 3 abruptly.	0.8	10.1
3	Sandstone, gradational with unit 2, fining upward to fine grained, weakly calcareous, light rusty weathering, discontinuous carbonaceous laminae.	1.6	9.3
2	Sandstone, very coarse to coarse grained, non-calcareous, very light grey with light grey weathering, erosional base, shale rip-up clasts and wood casts at base, horizontal bedding.	4.2	7.7
	BASE OF MOUNTAIN PARK FORMATION		
1	Shale, very dark grey, abundant carbonaceous fragments, recessive.	3.5	3.5

TYPE SECTION OF THE MA BUTTE FORMATION

Unit	Description	Unit Thickness (metres)	Height above base (metres)
46	Agglomerate, volcanoclastic fragments up to 10 cm, colours are shades of brown, olive and green. Very prominent resistant unit. Overlies unit 45 abruptly.		
	Top of Ma Butte Formation		
45	Mudstone, soft to very hard in part, medium to dark greenish-grey, non-calcareous, very recessive. Very sandy at top with pink and green grains. Probable tuff.	7.1	133.8
44	Clay, very light greenish grey, very soft, minor silt including some biotite. Probable bentonite.	2.3	126.7
43	Mudstone, greyish-purple with some greenish mottling at top and bottom, in places have vitreous green grains in mudstone. Probably a tuff.	2.7	124.4
42	Claystone, maroon colour throughout, upward in a few centimetres to mottled maroon and greenish grey and then to greenish-grey. Overlain abruptly by sandstone, very fine grained, medium greenish-grey with light greenish-grey weathering, carbonaceous fragments common, moderately hard to friable upward. Overlies unit 41 abruptly.	2.3	121.7
41	Sandstone, very fine grained, medium dark greenish-grey with purplish weathering, moderately strongly calcareous, less resistant upward but without grain size change. Overlies unit 40 abruptly.	1.3	119.4
40	Siltstone to very fine grained sandstone upward, medium greenish-grey, moderately to non-calcareous upward, minor carbonaceous fragments. Overlies unit 40 gradationally.	0.9	118.1
39	Mudstone, very dark greenish-grey, non-calcareous, massive, becoming siltier upward. Overlies unit 38 abruptly.	2.3	117.2
38	Mudstone, dark greenish-grey, crumbly, similar to below. More sandy near top with reddish (heulandite?) grains. Probably tuffaceous. Very rusty weathering at top.	6.9	114.9
37	Mudstone, medium greenish-grey, very recessive, crumbly weathering, rusty weathering at top. Overlies unit 36 abruptly.	3.7	108.0
36	Mudstone, prominent maroon weathering colour at base, to medium greenish-grey with purple weathering and then to dark purplish-grey at top, massive. Overlies unit 35 abruptly.	1.5	104.3
35	Mudstone to siltstone upward, similar to unit 34 but non-calcareous throughout.	1.5	102.8
34	Mudstone to very fine grained sandstone upward, dark to light greenish-grey upward, moderately calcareous with rusty brown weathering at top.	1.2	101.3
33	Siltstone to very fine grained sandstone upward, medium dark to medium greenish-grey upward, non-calcareous, minor carbonaceous fragments give weak lamination. Overlies unit 32 abruptly.	3.3	100.1
32	Sandstone, fine to very fine grained upward, medium light greenish-grey, non-calcareous except upper 65 cm which is moderately strongly calcareous and weathers a distinct purplish-brown colour, horizontal lamination and some primary current lineation, some crossbeds and ripple lamination. Overlies unit 31 abruptly.	4.0	96.8
31	Sandstone, very coarse grained with rip-up clasts along base, medium to fine grained above lower 20 cm, light grey, non-calcareous, prominent horizontal lamination, 20 to 75 cm, massive above. Overlies abruptly and is scoured into unit 30.	1.4	92.8
30	Sandstone, coarse and medium grained at base to fine and very fine grained upward, light grey with grey-orange-pink weathering, non-calcareous, horizontal lamination common, carbonaceous-rich in upper few decimetres. A shallow trough of medium grained sandstone at top. Overlies unit 29 abruptly.	2.9	91.4
29	Claystone, becoming very fine grained sandstone upward, very recessive, rubble-covered slope.	5.2	88.5
28	Sandstone, very fine to fine grained upward, more resistant upward, very light grey to slightly greenish-grey upward; very fine, horizontal, carbonaceous-rich laminae, deformed bedding in part with some overturned laminae.	3.8	83.3
27	Sandstone breccia, very fine grained, non-calcareous, with abundant angular siltstone and mudstone rip-up clasts.	0.7	79.5
26	Sandstone, very fine grained, non-calcareous, medium greenish-grey, horizontal carbonaceous-rich laminae common.	2.4	78.8
25	Mudstone to sandstone, very fine grained, upward. Dark greenish-grey to light olive-grey colours, massive. Recessive and poorly exposed.	7.6	76.4
24	Sandstone, fine to very fine grained upward, non-calcareous, medium greenish-grey, very rusty at base to light orange weathering upward, abundant carbonaceous fragments in lower part, less upward. Channeled into unit 23.	2.3	68.8
23	Sandstone, fine grained, very light grey moderately calcareous, quartzose, very fine horizontal lamination (1-3 mm thick), minor crossbedding. Overlies unit 22 abruptly.	1.4	66.5
22	Mudstone, sandy, olive-grey, non-calcareous massive.	2.2	65.1
21	Sandstone, breccia, medium grained, non-calcareous, light grey with abundant fragments of very fine grained sandstone and fewer fragments, sandstone is fine grained, medium greenish-grey, moderately calcareous, massive.	2.2	62.9
20	Tuff(?), amygdaloidal, dark grey with medium dark green anydules, rusty brown weathering, amydules 5 per cent, up to 8 mm diameter, roughly spherical, one pyrite-infilled amygdule observed, becomes medium grained sandy upward, moderately calcareous.	1.3	60.7
19	Mudstone to very fine grained sandstone, poorly exposed, no internal structure observed, similar to unit 16.	2.6	59.4
18	Mudstone, medium dark grey, with rusty brown weathering, upward to siltstone and very fine grained sandstone, medium light grey becoming greenish-grey upward, less calcareous upward, very faint lamination, ripple lamination and some climbing ripples in upper part. Several small weathered out spherical concretions (2 cm diameter), probably pyrite. Overlies unit 17 abruptly.	1.6	56.8
17	Mudstone to sandstone, similar to unit 16. Overlies unit 16 abruptly.	1.8	55.2
16	Mudstone to siltstone, coarsening upward, dark greenish-grey with purple weathering in lower few decimetres and mottles green and purple near top. Upward to sandstone, in upper 60 cm, very fine grained, coarsening upward, medium dark greenish-grey, patchy green and purple weathering, crumbly weathering no sedimentary structures observed. Overlies unit 15 abruptly.	4.9	53.4

Unit	Description	Unit Thickness (metres)	Height above base (metres)
15	Mudstone to siltstone, coarsening-upward unit, light to very pale greenish-grey upward, crumbly, no sedimentary structures observed.	0.7	48.5
14	Mudstone, silty, very carbonaceous, overlain gradationally by sandstone, argillaceous, carbonaceous, soft, recessive. Upward more resistant sandstone, very fine grained, medium dark greenish-grey (fresh), massive, carbonaceous fragments minor to common, very crumbly in upper 20 cm, possible paleosol. Overlies unit 13 abruptly.	2.4	47.8
13	Sandstone, fine grained, massive weathering very resistant unit, light to medium grey (slightly purplish in part), non-calcareous, horizontal lamination with some planar crossbedding.	2.1	45.4
12	Sandstone, medium to fine grained upward abundant mudstone clasts at base, light olive-grey to greenish-grey, non-calcarous, prominent horizontal, carbonaceous-rich laminae. Overlies unit 11 abruptly.	1.7	43.3
11	Very poorly exposed. Series of recessive mudstones, siltstones, medium to dark greenish-grey, non-calcareous, crumbly weathering with no sedimentary structures observed.	20.1	41.6
10	Sandstone, very fine grained to siltstone, dark greenish-grey with reddish-orange weathering, non-calcareous, very ferruginous.	1.0	21.5
9	Sandstone, very fine grained medium dark greenish-grey, platy weathering, some crossbedding.	1.5	20.5
8	Sandstone, medium to fine grained upward, no pebbles, medium grey to weakly greenish-grey upward, massive.	3.6	19.0
7	Sandstone, medium to coarse grained with discontinuous beds and lenses of pebbles plus isolated pebbles, orange weathering, a few truncated lenses of very fine grained sandstone, carbonaceous fragments common along bedding planes.	1.0	15.4
6	Conglomerate, scoured into unit 5 with at least 1 m relief (appears to be several metres laterally), pebbles mostly less than 1 cm up to 2 cm common, 5.5 cm maximum observed, medium to very coarse grained sandstone matrix, hard, siliceous, thins and is absent laterally.	0.7	14.4
	Base of Ma Butte Formation		
5	Very poorly exposed. Appears to mudstone to siltstone sequence as below. Small exposure at top of sandstone, fine grained becoming very fine grained upward, moderately calcareous, medium light greenish-grey, a few pebbles (up to 1 cm) at base, horizontal, carbonaceous-rich laminae abundant at top.	4.1	13.7
4	Mudstone and siltstone, very poorly exposed, similar to below, upward to more resistant sandstone, very fine to fine grained upward, very calcareous, irregular platy weathering with some crossbedding.	4.7	9.6
3	Mudstone to siltstone upward, greenish-grey, similar to unit 1.	2.5	4.9
2	Sandstone, very fine to fine grained upward, medium to light greenish-grey throughout, non-calcareous to very calcareous upward, faint ripple lamination near top. Overlies unit 1 abruptly.	0.9	2.4
1	Claystone, dark greenish-grey, gradationally upward to siltstone and very fine grained sandstone, medium light greenish-grey.	1.5	1.5

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