GEOLOGY OF THE WASOOTCH CREEK
MAP-AREA ALBERTA

by

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We accept this thesis as conforming
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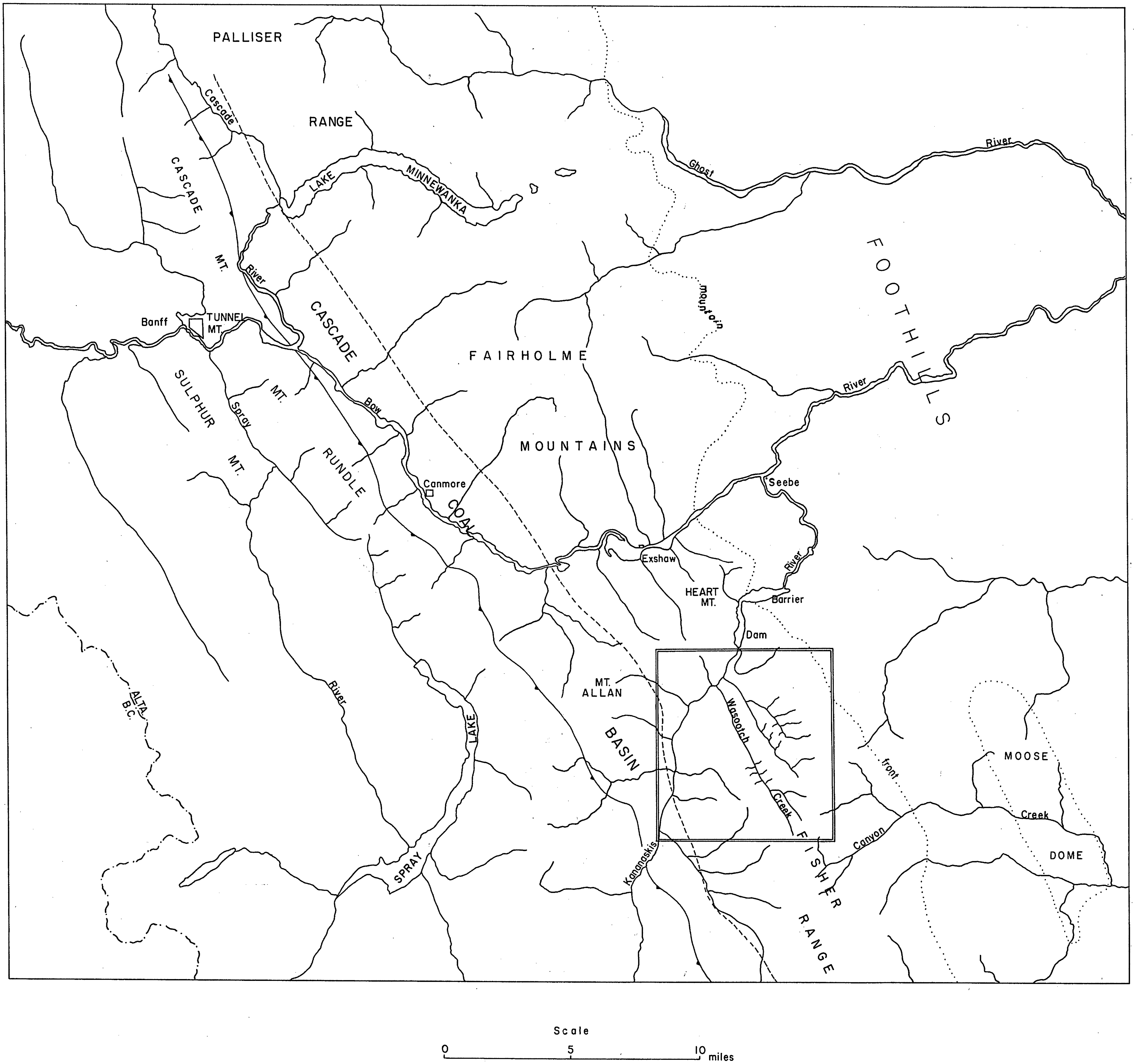
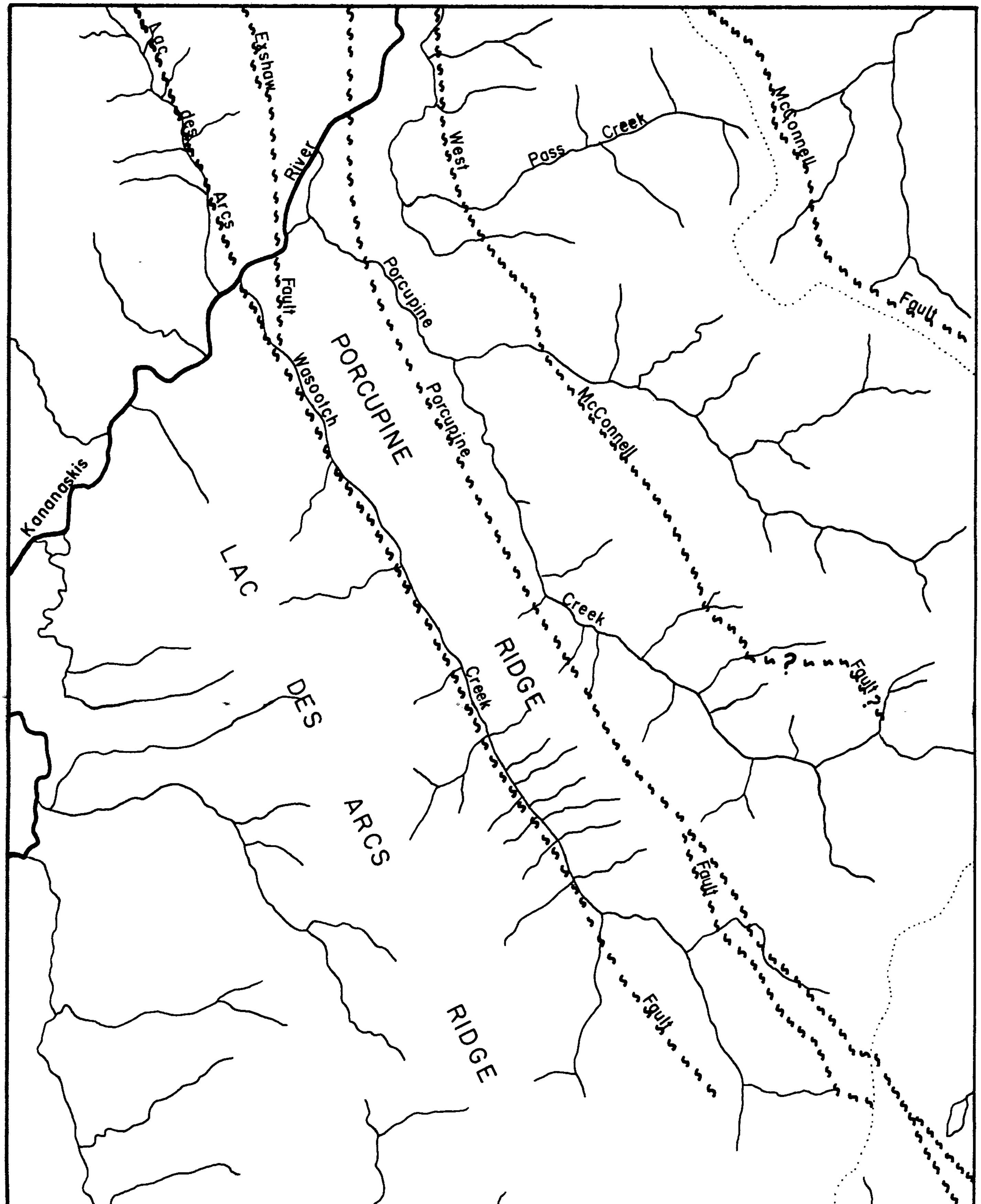


INDEX MAP

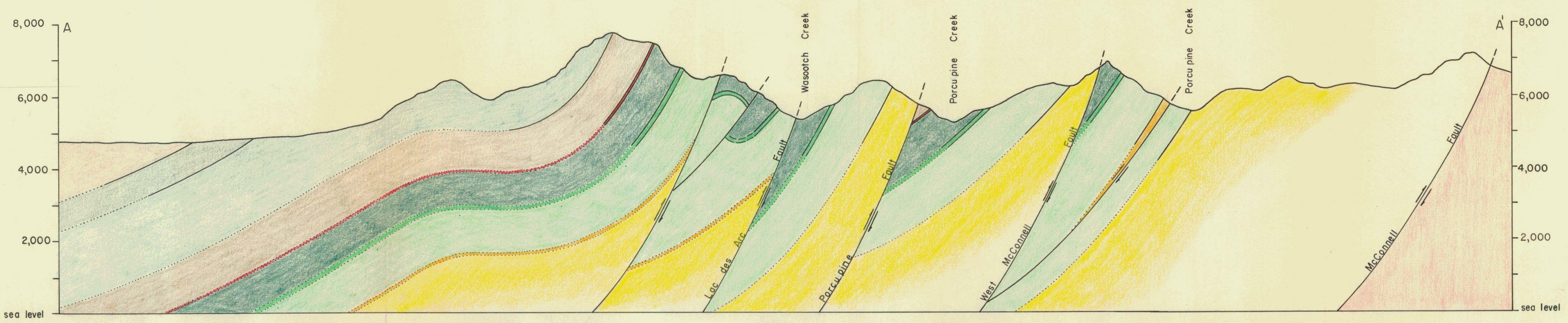
Figure 1

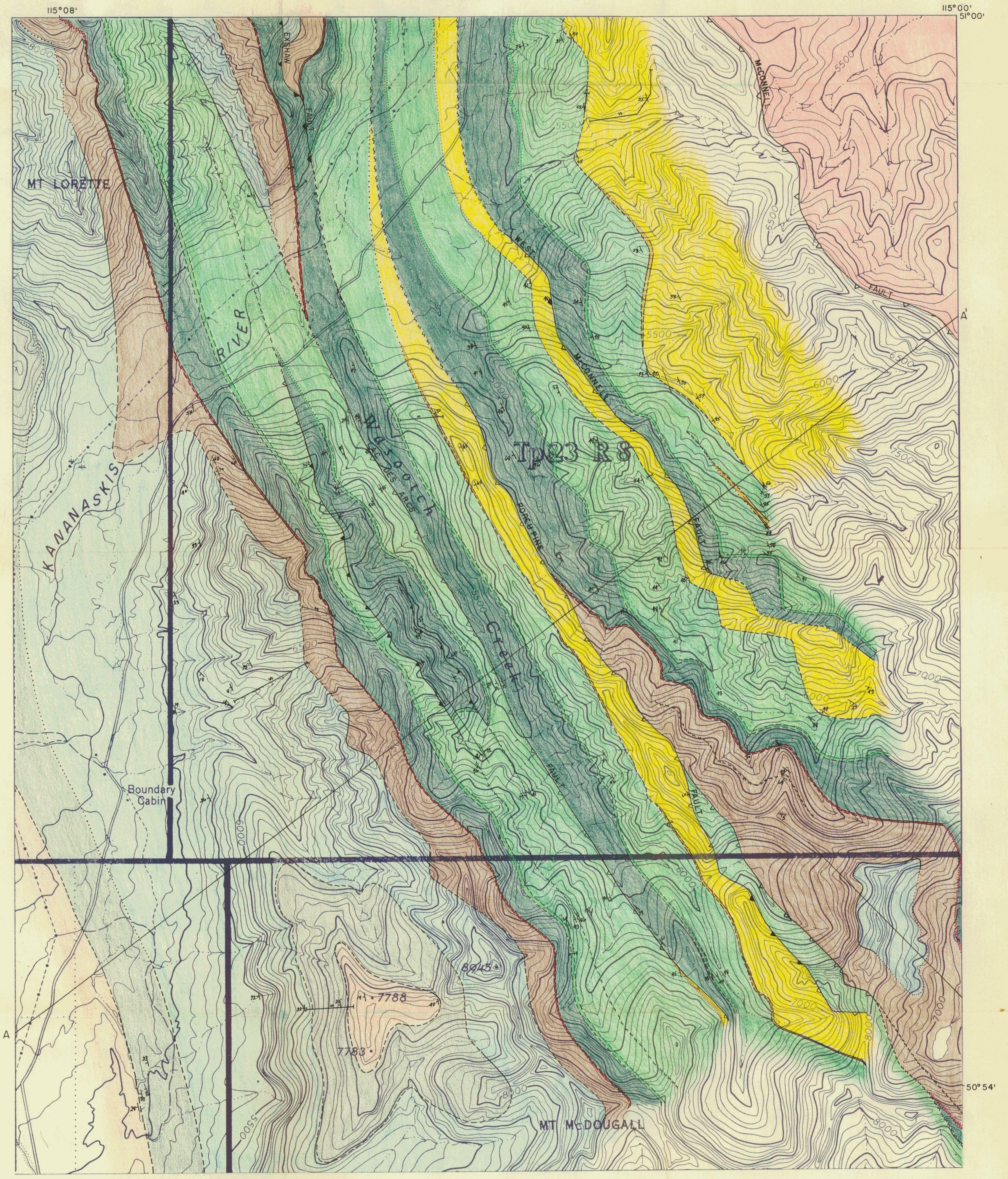


Scale

0 1 2 miles

Figure 3





LEGEND

MESOZOIC

CRETACEOUS
- UNDIVIDED

TRIASSIC
- SPRAY RIVER FORMATION

PALEOZOIC

PERMIAN
- ROCKY MOUNTAIN GROUP

MISSISSIPPIAN
- RUNDLE GROUP
- BANFF FORMATION
- EXSHAW FORMATION

DEVONIAN
- PALLISER FORMATION
- ALEXO FORMATION
- FAIRHOLME GROUP

CAMBRIAN
- GHOST RIVER (ARCTOMYS) FORMATION
- PIKA-ELDON FORMATION

Formation contact (defined, approximate, assumed)

Bedding (horizontal, inclined, overturned)

Fault, thrust (defined, approximate, assumed)

Anticlinal axis (with plunge)

Synclinal axis (with plunge)

Section traverse

WASOOTCH CREEK

Scale: One Inch = 2,000 feet

miles

0 1 2

ABSTRACT

The Wasootch Creek area is representative of the Rocky Mountain Front Range of southern Alberta. It is underlain by rocks of the Middle Cambrian, Upper Devonian, Mississippian, Permain and Lower Triassic, of which carbonates constitute the largest part. The Cambrian formations are correlated with the Eldon, Pika and Arctomys of the Bow Valley region. The Ghost River or Arctomys formation has on one fault block been removed by pre-Devonian erosion.

The area is bounded on the west by the Cascade Coal Basin and on the east by the McConnell fault. Between these two structures are several high angle, westward dipping, reverse faults named from west to east Lac des Arcs, Exshaw, Porcupine, and West McConnell. Mature disection of the fault blocks has produced excellent correlation of rock hardness with topography. The McConnell fault consists of two thrusts which merge at Kananaskis Gap. South of Kananaskis Gap the two thrusts are designated McConnell and West McConnell.

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Date April 15, 1959

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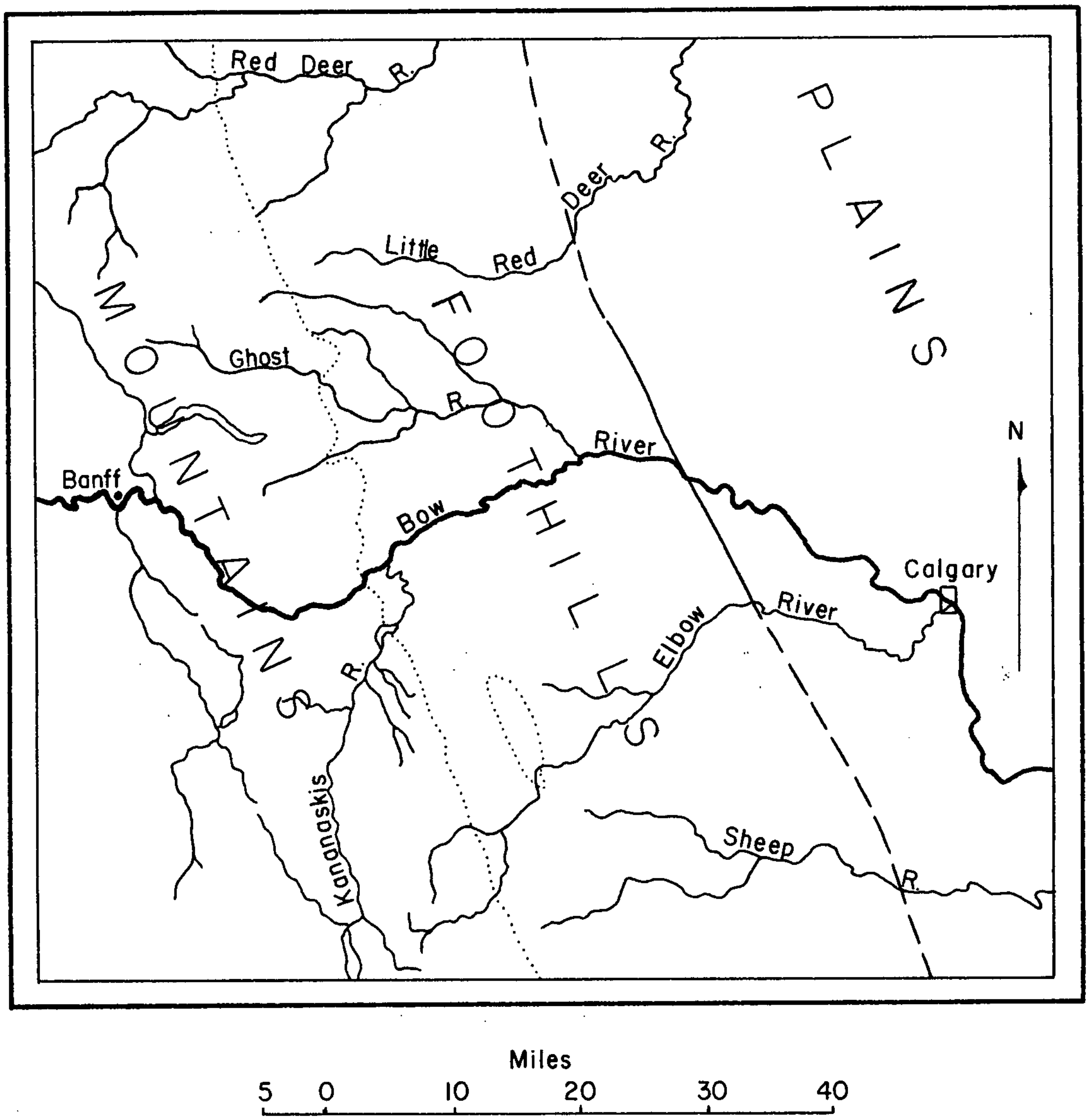
INTRODUCTION

Introductory Statement

This thesis deals principally with the stratigraphy and structural geology of a small area in the eastern part of the Front Range sub-province of the Rocky Mountains in southwestern Alberta. The area is underlain by sedimentary rocks of which limestone and dolomite constitute by far the greatest part. Formations ranging in age from Middle Cambrian to Lower Triassic were examined within four thrust blocks which include the major Paleozoic petroleum bearing formations of the Alberta Plains. No igneous or metamorphic rocks are present within the Front Range in southern Alberta.

It is hoped that this study will in some manner contribute to the practical use of this and the adjacent Bow Valley region by geologists, for by virtue of its proximity to Calgary, ready accessibility, excellence and clarity of stratigraphic, physiographic and structural features, every opportunity is provided for the geologist and student to acquire first-hand information that will equip him to work in any part of the Front Range of the southern Alberta Rocky Mountains.



Index Map

Figure 2

Location and Accessibility

The area under consideration embraces approximately 45 square miles that lie entirely within the mountains south of the Bow River and is bounded on the north by 51° 00' north latitude and on the south by 50° 54' north latitude. The Cascade Coal Basin forms the western boundary geologically and topographically. The map-area is traversed on the west and in the north by the Kananaskis River, and in the central part by northward flowing Wasootch and Porcupine Creeks, southern tributaries to the Kananaskis River. (Figures 1,2,3).

Geographically the area lies 22 miles due east of the Alberta-British Columbia boundary at the 51st parallel, and 40 miles west and slightly south of Calgary. It lies entirely within the Bow River Provincial Forest Reserve, Kananaskis District, within the Provincial Game Preserve, and in part within the Dominion Government Forest Experimental Station.

The area is readily traversed in summer by means of the Kananaskis-Coleman Highway which leaves the Trans-Canada Highway at the village of Seebe, approximately 15 miles north of the map-area, and 50 miles west of Calgary. Except for a pack trail that leads from Lorette Creek through the Cascade Coal Basin to Canmore, and a trail in the northeast corner of the area which leads from the mountains out into the foothills, this is the only means of vehicular access to the area.

Early History

The first white men known to enter this part of the mountains were David Thompson and Duncan McGillivary who first arrived in the vicinity of Calgary in the fall of 1786 for the purpose of trade. They departed in the spring of 1787 and returned briefly in the fall of 1800 whereupon Thompson journeyed up the Bow River as far as the present town of Exshaw. (Figure 1). During 1840 the Rev. R.T. Rundle journeyed into the mountains and camped in front of the mountain since named in his honor. Later in 1840 Sir George Simpson passed through the Banff area on his way to the Columbia Valley. In 1845 Father P.J. De Smet crossed the summit of White Man Pass and camped where Canmore now stands. James Sinclair was reported to have travelled through Kananaskis Pass, at the head of the Kananaskis River, in 1848.

The most important explorers were Captain John Palliser and his group who approached from the northeast in July 1858 and camped at Bow Fort. On August 18, 1858 Palliser started across the mountains via the Kananaskis Pass to the Elk River. Dr. Hector, a geologist attached to Palliser's party and the first man to record geological observations in the region, entered the mountains on a round-trip to Fort Edmonton in 1858. In 1859 Hector once again entered the mountains in the Bow Valley. Palliser's map of this region is one of the earliest to have been compiled and many of the current geographic names were bestowed by members of this expedition. Palliser named Kananaskis Pass, and Palliser River; Dr. Hector named Cascade Mountain, and Mount Rundle; Mr. Bourgeau named Grotto, Pigeon and Windy Mountains, and Lac des Arcs Lake. The Fisher Range and Fairholme Mountains first appeared on Palliser's map.

Next came two men, George McDougall and his son the Rev. John McDougall in the 1860's, who established the settlement of Morleyville in 1864 and were a great influence among the Stony Indians.

In 1874 R.G.McConnell first visited the region of the Belly-Bow Rivers as a geologist for the Boundary Commission, but at that time was mainly confined to an area far to the south. In 1880 the first group of surveyors connected with the location of the Canadian Pacific Railroad camped in the vicinity of Banff. In 1881 McConnell traversed nearly to the position now occupied by the town of Canmore. During the years from 1881 to 1884 G.M. Dawson and R.G. McConnell ascended the Elbow and Bow Rivers and reported on the general geology. During this time Dawson gave some attention to the Cascade Coal Basin, believed to have been discovered in 1883, and called it the Cascade trough. In 1886 McConnell did reconnaissance work in the Fairholme Mountains and in areas to the north and west, where he recognized the true nature of the great overthrusts in the mountains, and subdivided the strata into essentially the subdivisions recognized at the present time (Table I). It is from this date that our knowledge of the geology of this area really dates.

Previous Detailed Geologic Work

The first detailed geological surveys of the region were made by D.B. Dowling beginning in 1903, who in 1907 published maps of the Cascade Coal Basin that included the area immediately to the west of the Wasootch Creek area. In 1912 J.A. Allan completed a geological section across the Rocky Mountains from Golden to the Cascade Coal Basin along the main line of the Canadian Pacific Railroad. In 1914 he worked in areas west of the Kananaskis region but did examine briefly the Lake Minnewanka area (Figure 1). He spent a short time in the Fairholme Mountains, the Sawback Range and near Simpson Pass in 1915.

H.W. Shimer (1911, 1913) reported on the geology of the Lake Minnewanka area. In 1924 E.M. Kindle proposed new terms for some of the upper Paleozoic formations in the Bow Valley area (Table I). Shimer continued work in the Lake Minnewanka area and in 1926 published a number of Paleozoic sections. P.S. Warren in 1923 made a survey of the geology and thermal springs of the Banff area but did not publish the report until 1927. B.R. McKay (1935) published two maps of the Canmore area which dealt mainly with the coal measures associated with the Cascade Coal Basin.

H.H. Beach (1943) published a report on the Moose

Mountain and Morely areas which largely lie in the Foothills, the western boundary of which forms the eastern border of the Wasootch Creek area. J.A. Allan and J.L. Carr in 1947 completed the detailed geology of the Highwood-Elbow area that deals with a Mesozoic coal basin which is a southern continuation of the Cascade Coal Basin.

The latest published work is that of Clark (1949) who mapped the area between the Kananaskis and Bow Rivers and an equal distance north of the Bow Valley, from the mountain front to the Second Range. Clark first used the names McConnell, Exshaw, Lac des Arcs and Rundle for the four major faults in this region.

Field Work and Maps

This thesis is based on field work carried out during part of May and the first two weeks of September 1958. Because the work was carried out unassisted a certain amount of detail was by necessity sacrificed and it was decided that a somewhat generalized program would be adopted.

For use in the field a topographic base map was enlarged from a National Topographic Series 1:50,000, Evans-Thomas Creek, west of the fifth meridian Alberta, 82 J/14 East Half, First Edition. In conjunction with this topographic map, aerial photographs were used extensively. The final map is enlarged from a part of the Evans-Thomas Creek sheet to a scale of 1" = 2,000 feet.

Acknowledgments

The writer is indebted to Shell Oil Company of Canada Limited for the use of geologic equipment, and also to Mr. P. Gordy for his help regarding topographic maps.

To Dr. Okulitch special thanks are due for his constructive criticism of the manuscripts, and for instruction in micro-photography. I am very grateful to Mr. R. Greggs for his many suggestions and thought-provoking discussions.

PHYSIOGRAPHY

Topography

The surface of this region has a maximum topographic relief of approximately 4,400 feet, the lowest elevation being in the northern part of the area in the Kananaskis Valley which is 4,500 feet above sea level. The highest points are the peaks of Mt. McDougall and the first major peak north of it which are slightly over 8,900 feet and Mt. Lorette which is 8,100 feet. The average relief of the mapped area is near 2,500 feet.

The most prominent topographic feature of the region are the several elongate, sub-parallel, dominantly westward sloping mountain ridges (Figure 3, 4). Individual mountains such as Lorette and McDougall occur as isolated peaks on these ridges and owe their origin to the resistant nature of the formations composing them and the height to which they have been raised through faulting. These linear ridges are the direct result of the thrusting of large slices and the subsequent differential erosion of them. Mature disection has reduced the interstream areas to narrow, often knife-like ridges, and because of the markedly different resistences to erosion offered by the various lithologic units, every degree of relative hardness is now distinctly marked topographically (Figure 5, 6). The ridges are carved from massive limestones and dolomites of the Livingstone, Palliser, Fairholme and

Eldon formations. These ridges are characterized by precipitous eastern faces with slopes varying considerably according to the resistance of the rock. The west slopes are more gentle, corresponding roughly to the dip of the underlying strata, and the higher peaks are often easily reached by these western slopes. The general strike of these ridges is 20 degrees west of north. The valleys are usually occupied by either relatively non-resistant formations or by faults which may weaken highly resistant rocks.

A striking and abrupt change in the topography occurs at the southern and eastern border of the area. The Wasootch Creek area consists essentially of three prominent, linear, sub-parallel ridges (Figure 3, 4) which retain their character within the watersheds of Wasootch and Porcupine Creeks. South of this area in the watershed of Canyon Creek and Elbow River, the conspicuous lineation is entirely lost and the area consists of numerous high peaked, irregularly distributed, interstream mountains with no particular orientation. This abrupt change probably reflects a change and complication in the structure.

The entire area is bounded on the west by a structurally controlled, low lying area, in part occupied by the Kananaskis River. This area is trough-like topographically and in part owes its low position to the nature of the bedrock which consists of Mesozoic sandstones and shales whereas the walls are composed of Paleozoic limestones and dolomites which are relatively much more resistant so that differential erosion has caused the Paleozoic strata to stand out in relief, several thousand feet above the valley. Structurally this trough is a syncline, typically with an overturned west limb where Paleozoic strata were thrust from the southwest along the Rundle fault (Figure 1). The syncline is a southern continuation of the Cascade Coal Basin that is well developed in the Bow Valley and once extensively developed for its coal. The strata of the east flank which is named Lac des Arcs Ridge dip westward from 75 to 15 degrees. Mt. Allan occupies an axial position in the syncline between Bow and Kananaskis Rivers and has given its name to the structure in this region (Crockford 1949).

The depth of erosion has removed all of the Mesozoic beds from the area except for those in the syncline which have been preserved by reason of their downfolded position. Post-Mississippian and Triassic beds have been mostly eroded from the western slopes of Lac des Arcs Ridge but on the crestal area of a small anticlinal flexure on the west side a few outliers of Rocky Mountain and Sulphur Mountain formations remain.

Drainage

Drainage within the area is accomplished entirely by the Kananaskis River which empties into Bow River at Seebe. The river, though not large, has been dammed at several points by Calgary Power Limited, and serves as a source of power for much of the surround area. The nearest dam to this area is Barrier Dam which is located at Kananaskis Gap (Figure 1). The head of this dam lies just north of the northern edge of the map sheet. Within the map area the Kananaskis River has a grade of 1%.

The two major tributary streams to the river are Wasootch Creek and Porcupine Creek. These are northward flowing, sub-parallel, subsequent streams which are in a state of late youth in some parts and early maturity in others. They originate in snowfields and springs on the higher ridges and flow only weakly throughout most of the year. In the main branch of Wasootch Creek the valley floor is evenly alluviated and almost immediately soaks up any water delivered to it from its tributaries, and thus even in spring the fast flowing east tributary failed to produce a flow of water along the main branch. During the fall of 1958 Porcupine Creek contained water in the lower reaches of both forks, between their junction and the highway, and in the headwaters of the west branch.

The subsequent nature of these two streams is well displayed, particularly by Wasootch Creek which is straight for almost 6 miles (Figure 3, 4), and controlled by a fault as much as by lithology. Along the main branch, lower Fairholme dolomite has been thrust over Palliser limestone. The Fairholme is much less resistant than the Palliser and this weakness coupled with the faulting has served to produce a belt of weakness along which the stream is following, and slowly migrating in a westward direction.

Because the region is being eroded at a rapid rate due to the high maximum relief, small streams are cutting innumerable gullies into every slope. Streams which flow in an eastward direction, tributary to the two main creeks, and opposite to the dip of the beds, have been termed obsequent streams. These are short with steep gradients and in this area are almost always dry. Those streams flowing in the direction of the dips are designated resequent streams. These resequent and obsequent streams flowing into Wasootch Creek form an excellent example of trellis type of stream pattern near the head of the main branch, (Figure 3, 4).

The Kananaskis River in its northward flowing course is a subsequent stream, occupying the Mt. Allan syncline, and further south it occupies a subsequent valley in the Second Range. Periodically however it turns sharply and cuts transversely across the faults and fault-blocks. This is well demonstrated in the Wasootch Creek area (Figure 4), where the Kananaskis River flows northward along the western border of the area, then turns abruptly and flows in a northeastward direction to a point just past the mouth of Porcupine Creek, where it bends slightly northward to parallel the structure again until Kananaskis Gap is reached, whereupon it turns abruptly eastward at right angles to the front of the mountains and enters the foothills. The origin of these transverse valleys poses a difficult question and it has not been decided whether they are due to an antecedent or superimposed stream.

Because of the relatively youthful stages of the tributary streams to the Kananaskis River no terraces have been built by them, the only terraces present are those in the main river valley. Terraces are not too well developed in the valley at the western side of the area but in the transverse valley south of Mt. Lorette they are quite conspicuous. The river here is cutting its southern bank where only a narrow terrace is present. A higher, older terrace is present however on the west side of Wasootch Creek, at present occupied by swampy ground on which the highway is built. A well developed terrace is present along the base of Mt. Lorette and upon it three alluvial cones have formed at the mouths of Lorette Creek, the small gully in the centre of the south face of the mountain, and the creek east of Mt. Lorette. The river swings toward the north side of the valley at the mouth of Porcupine Creek and has left only a narrow but well developed terrace at the base of the southern end of Heart Mountain, but a wide terrace south of the river between Porcupine Creek and the northern edge of the map.

The only muskeg in this area is in the Kananaskis Valley where beaver have dammed small streams. No muskeg is present anywhere in the mountainous part of the region.

Glaciation

At the present time there are no glaciers in this part of the Rocky Mountains but evidence of Pleistocene glaciation is abundant, though more strikingly developed in the Second Range west of the Mt. Allan syncline. There, numerous well developed amphlitheatre-like cirques are present at the heads of most valleys. Cirque-like basins are present but not well formed in the Wasootch Creek area and evidence for glacial action comes from other glacial features. In the Kananaskis Valley glacial scouring and rounding are much in evidence on the more exposed parts, in particular where it trends obliquily across the ranges. Mygdal (1956) explains that the mountains of the Bow drainage basin had acquired approximately their present shape before the last glacial period, and that the changes brought about by the glaciers were rather minor in comparison to the major dimensions of the mountains. In the Second Range where the Kananaskis River flows northward in a subsequent valley an excellent U-shaped valley has been formed and is best observed by looking south along the highway about 6 miles south from Boundary Cabin.

In the Wasootch Creek area Crockford (1949) examined well developed roches moutonees in the valleys of Lorette and Evans-Thomes Creeks. Glacial erratics were found by him as high as 7,500 feet. On either side of Wasootch Creek glacial erratics are present at elevations above 6,000 feet at points where the valley floor is 5,000 feet in elevation. Most of the creek valley appears to have been somewhat glacially scoured, and probably Porcupine Ridge was largely covered with ice.

It has been thought that the character of the great peaks of the ranges in the Rocky Mountains show that the Cordilleran ice-sheet did not pass directly over them, but was confined to the valleys. Valley glaciers near Banff may have been as much as 2,000 feet thick (Mygdal 1956), and in the Wasootch Creek area they may have been on the order of 1,000 feet.

In the Kananaskis Valley glacial deposits do not form a continuous layer but are present only locally. The only good deposit of glacial till found was exposed in a river terrace on the south side of the main valley, at the north end of Lac des Arcs Ridge (Figures 3, 4).

STRATIGRAPHY

Introductory Statement

The formations present in the Wasootch Creek area range in age from Middle Cambrian to Lower Triassic and all are of marine origin. The Cambrian and Upper Devonian formations are represented by limestones and dolomites. The Mississippian which is more varied in lithology contains fine clastics in the lower part, limestones in the middle part, and siliceous carbonates in the upper part. The Permian strata are mostly calcareous and dolomitic sandstones. The Triassic is represented by one small outlier of dolomitic siltstone. Most of the formations thicken to the north and west, and because of eastward truncations the Permian and Triassic formations are confined to the mountains proper.

Three major unconformities are present within the stratigraphic succession. The first, the sub-Devonian unconformity, separates the Upper Devonian from Upper Cambrian. The second forms the boundary between the Mississippian and Middle Permian, and the third divides the Mesozoic from the Paleozoic.

A table of the formations present in the Wasootch Creek area and the history of their development is given in Table I.

McConnell 1887	Dowling 1907	Shimer 1913	Allan 1914	Kindle 1924	Walcott 1924
Carboniferous passing downwards into Devonian: Upper Banff Shale	Pm.-Tr.: Upper Banff Shale	Perm.: Upper Banff Shale	Perm.: Upper Banff Shale	Tr.: Spray River	
Upper Banff Limestone	Carboniferous: Rocky Mountain Quartzite	Pennsylvanian: Rocky Mountain	Carboniferous: Rocky Mountain	Pennsylvanian: Rocky Mountain	
	Upper Banff Limestone	Upper Banff Limestone	Upper Banff Limestone	Rundle	
Lower Banff Shale	Lower Banff Shale	Miss.: Lower Banff Shale	Lower Banff Shale	Miss.: Banff Shale	
Lower Banff Limestone	Lower Banff Limestone	Devonian: Lower Banff Limestone	Lower Banff Limestone	Devonian: Banff Limestone & Dolomite	U. Dev.: Pipestone
					M. Devonian: Messines
Devonian: Intermediate Limestone	Devonian: Intermediate Series	Intermediate Limestone	Devonian: Intermediate Limestone		
				Lower half M. Dev?	
Camb.: Castle Mt. Group			Sawback Limestone	C.: Sawback	
Bow R. Gp.					

Shimer 1926	Warren 1927	McKay 1935	Warren 1937	Beach 1943	Clark 1949
Tr.: Spray River	Tr.: Spray River	Tr.: Spray River	Tr.: Spray River		Tr.: Spray River
Perm.: Rocky Mountain Quartzite	Penn.: Rocky Mountain Quartzite	Penn.: Rocky Mountain	Penn.: Rocky Mountain Quartzite		Pm.-Penn.: Rocky Mountain
L. Penn. & Miss.: Rundle	Penn? & Miss.: Rundle	Penn? & Miss.: Rundle	M. & U. Miss.: Rundle	Miss. & Penn?: Rundle	Mississippian: Rundle
Miss.: Banff	Miss.: Banff	Miss.: Banff	L. Miss.: Banff	Miss.: Banff	Banff
Devonian: Minnewanka	L? M. & U. Devonian: Minnewanka	Devonian: Minnewanka	U.D.: Exshaw	U? & M. Devonian: Exshaw	Upper Devonian: Exshaw
			U. & M? Devonian: Minnewanka	Palliser	Palliser
				Fairholme	Fairholme
	?: Ghost River	?: Ghost River			M? D.: Ghost River
?: Ghost River	C.: Sawback			M.C.: Fm. "D"	M. C.: Cathedral?
C.: Cathedral				M?C.: "C" "B" "A"	

DeWit & McLaren 1950	Douglas 1950	Douglas 1953	McLaren 1955	Warren 1956
	Tr.: Spray River			Tr.: Spray River
	Penn?: Rocky Mountain			Penn. Pm.: Rocky Mt.: Norquay Mountain / Tunnel Mountain
	Mississippian: Rundle D C B A	Miss.: Rundle: Mt. Head / Livingstone		
	Banff			
Upper Devonian: Exshaw			Upper Devonian: Exshaw	
Palliser: Costigan / Morro			Palliser: Costigan / Morro	
Alexo			Alexo	
Fairholme: Upper			Fairholme: Southesk	
Lower			Cairn	

Raasch 1956	Norris 1958	Douglas 1958	Wasootch Creek	thickness (feet)
Tr.: Spray River	Tr.: Spray River	Tr.: Spray River	Tr.: Spray River	600
M. Perm.: Rocky Mt.: Storm Creek / Norquay	Miss.Pn? Perm?: Rocky Mt.: Upper Unit / Todhunter	Penn.: Rocky Mountain	M. Perm.: Rocky Mt: Storm Creek / Norquay	625
	Mississippian: Rundle: Etherington / Mt. Head / Livingstone	Mississippian: Rundle: Etherington / Mt. Head / Livingstone	Mississippian: Rundle: Mt. Head / Livingstone	600 / 1300
	Banff	Banff	Banff	900
	Exshaw	U. Dev.: Exshaw	Exshaw	22
Belyea & McLaren 1957	U. Dev.: Palliser	Palliser	Upper Devonian: Palliser: Costigan / Morro	800 - 900
U. Devonian: Alexo			Alexo	141
Fairholme: Mt. Hawk			Fairholme: Southesk	1300
Perdrix / Flume			Cairn	
			U.C.: Ghost River (Arctomys)	0 - 49
			M. Camb.: Upper Eldon-Pika / Lower Eldon	1000

Table I. Comparative correlation chart of the formations in the Rocky Mountain Front Range of southern Alberta

PALEOZOIC

Cambrian

Pika and Eldon Formations

NAME AND HISTORY: The Eldon formation was originally defined by Walcott (1908) as "Massive, arenaceous, dolomitic limestones, with a few bands of purer bluish gray limestone," which he assigned to the Middle Cambrian and designated the type locality north of Eldon Switch on Castle Mountain. The formation was redefined in 1928 and the thickness altered. Deiss (1939) states that the formation is actually much thinner than Walcott reported and that it is nearly a pure dolomite. He amended the definition and thickness to include 1,015 feet of massive, thick bedded dolomites forming shear grey cliffs.

The Pika formation was proposed by Deiss (1939) for 550 feet of dolomite, limestone and minor shale which Walcott had originally included in the upper Eldon.

DeWit (1956) correlated the Cambrian rocks in the eastern part of the Fairholme Mountains at Loder Lime Plant with the Eldon formation, which he subdivided into Upper and Lower units, the Upper Eldon he believed might actually be the Pika.

THICKNESS: The Upper Eldon or Pika as measured by DeWit (1956) totalled 288 feet 8 inches, and a partial section of Lower Eldon was given as 76 feet. In the eastern part of the Wasootch Creek area a correlative section of the lower part of the Upper Eldon or Pika of DeWit is approximately 65 feet. The difference in the thickness between these sections is due to post-Cambrian erosion. The Lower Eldon correlative on the north side of Pass Creek probably approaches 800 to 900 feet, but is believed to be faulted at the base.

GENERAL CHARACTER AND DISTRIBUTION: From Kananaskis Gap northward Cambrian strata are exposed above the McConnell fault to beyond Ghost River and define the front of the mountains. South of Kananaskis River Devonian Palliser rocks form the frontal scarp of the mountains (Beach 1943).

In the Wasootch Creek area Cambrian strata are exposed above Porcupine and West McConnell faults, and in the easternmost part of the region. The exposure above the West McConnell fault is believed a direct correlative of the Cambrian at Loder Lime Plant examined by DeWit.

The strata here correlated with the Lower Eldon constitute the greater part of the range east of Porcupine Creek but cannot be considered as extending to the front of the mountains since Beach (1943) mapped Devonian Palliser above the McConnell fault outside the map area and in the Wasootch Creek area there was insufficient time to examine the formations to substantiate his findings. It is quite certain however that a fault does exist in the valley of the north fork of Pass Creek, where Cambrian beds may fault over Devonian.

The upper contact of these Cambrian strata, which may be examined at several localities, are perhaps the most interesting since the superjacent Ghost River formation is sometimes missing. The most accessible exposure of the Upper Eldon or Pika beds is on the north side of Pass Creek in the westernmost tributary. The Lower Eldon is also best studied on the north side of Pass Creek. Near the head of Wasootch Creek below the Ghost River section the entire Cambrian exposure can be easily examined. Relatively good exposure of the upper beds are present midway along the top of the ridge between the main branches of Porcupine Creek.

The Upper Eldon or Pika in this region consists typically of black, dense limestone in thin to thick beds, with extremely prominent and distinct ochre-brown or orange-brown mottling and banding. The Lower Eldon is a uniform, black, light grey weathering, cliff-forming limestone characterized by dolomitic mottling and banding. These two units were found to be both transitional over a narrow zone and in sharp contact. The uppermost beds may or may not be transitional into the overlying Ghost River.

LITHOLOGY: The lowermost beds of the Devonian Cairn formation in this region consist of black, fine-grained limestone which may not be readily distinguished from the Upper Eldon or Pika units. The presence of the Ghost River alleviates this trouble, but where this formation is absent through pre-Devonian erosion, the problem is enhanced since unconformities in the Rocky Mountains are commonly represented by bedding surfaces. DeWit and McLaren (1950) failed to find on Roche Miette an indication of a clear break anywhere in the succession from undoubted Cambrian strata to Devonian. Similarly on the ridge between the main forks of Porcupine Creek, a detailed section from lower Fairholme through to Lower Eldon, failed to reveal clear evidence of an hiatus of the magnitude known to be present.

At the top of the ridge the lower Cairn consists of a massive unit of black, vuggy dolomite containing stromatoporoids, below which is a thin zone of black dolomite containing black chert and stromatoporoids which overly a 7 foot zone containing many stromatoporoids. Underlying this is 19 feet of typical black, bedded Cairn dolomite and from this unit the following section continues downwards:

Unit	Fairholme	Thickness
1	Dolomite, black, fine to medium-grained, even textured, dark weathering, contains *Amphipora*	[illegible]
2.	Covered interval	4'
3.	Limestone, black, organic, very fine-grained, light grey weathering, dolomite gives a rough weathered surface, thin 6 inch beds . .	1½'
4.	Limestone, Black, fine-grained, even texture, brachiopods and stromatoporoids 3' from top, upper 3' contain dolomite that weathers to a porous irregular tracery that grades down to banding for 2'. Lower 2' is black, fine limestone with fine dolomitic laminations, somewhat silty and very thinly bedded, then becomes thicker bedded for 1' with fewer laminations	7'

Unit	Fairholme	Thickness
5.	Covered interval	3'
6.	Limestone, black, fine-grained, highly organic, dolomitic, some highly irregular stromatoporoids, silicified, very abundant . . .	1½'
7.	Limestone, black, dense, pellet limestone, dark weathering, weathered surface has a very rough, spongy-porous texture	1'
	Upper Eldon or Pika	
8.	Dolomite, light grey, light tan-grey weathering, very fine-grained. A fresh surface reveals many small, very fine-grained dolomite pellets and chips of dark color, interbedded in a lighter and coarser, clear dolomite matrix, flowage suggested in thin section, thick beds, gradational downwards	3'
9.	Limestone, black, very fine to dense, medium grey weathering, coarse, buff-brown, even bands weathering in relief, that change to 1' of dense, medium grey weathering limestone with buff mottling, grades down rapidly . . .	3'
10.	Dolomite, calcareous, light grey, light tan-grey weathering, very fine-grained, grades rapidly down	1'
11.	Limestone, black, dense, medium grey weathering, ochre-brown mottling and banding. Continues in thin (1") to thick beds, with orange-brown mottling and irregular banding interbedded with medium grey weathering, thin bedded, black limestones that are essentially unmottled or banded. Some intense mottling stands out in high and very conspicuous relief	60'

Unit	Upper Eldon or Pika	Thickness
12.	<u>Limestone</u>, black, dense, only partially mottled, a transitional zone	3'
13.	Lower Eldon	
	<u>Limestone</u>, black, very fine-grained to dense, medium grey to light grey weathering, much dark dolomitic mottling in very distinct bands, thick to medium bedded, forms a shear cliff	100^{+}'

As mentioned previously the Cambrian-Devonian contact was not observable in the field so that in order to detect the disconformity all samples were thin-sectioned and two important discoveries were made. First and perhaps most significant was the finding of a number of cross sections of small trilobites in the mottled limestones of unit 11, which prompted the close scrutiny of hand specimens which lead to the finding of a single agnostid trilobite of the genus <u>Pseudagnostus</u>? which proves the age of these beds as Middle-Upper Cambrian. Secondly unit 8 was found to be finely brecciated with strong indications of flowage, and unit 7 to be a rather fine, pellet and fragmental limestone. Although it is admitted that these criterea do not necessarily indicate an unconformity they are the only two units which differ markedly from the remainder of the units above and below. Since units 8 to 13 all appear to be gradational, and a dolomite such as that in unit 8 was nowhere observed at the base of the Fairholme, the Cambrian-Devonian contact was placed at the top of the unit.

The Lower Eldon was examined along the base of the mountain on the north side of Pass Creek, where the entire exposure is observable along the top of a talus slope. The greater part of the formation is thick to massively bedded and readily forms high cliffs. The lower parts are strikingly banded with thin layers of dark weathering dolomite which contrasts well with the light grey weathering of the limestone (Figures 9 - 12), which is almost entirely black, very fine grained to dense, and even textured. Many of the dolomitic layers are quite regular with only minor ramifying extensions, and some show primary flow structures. About 100 to 200 feet from the top of the formation the dolomitic layers change in character to much more irregular segregations referred to as mottling. The bedding also becomes much thinner nearer the top and the uppermost beds are very thinly bedded, in part argillaceous, and end abruptly at a distinct bedding surface. Above this plane are a few feet of variously bedded, black, dense, limestones with a very conspicuous linear dolomitic mottling. This in turn is overlain by the ochre-brown mottled, medium grey weathering, black limestones of the Upper Eldon or Pika.

The Lower Eldon exposed above the Porcupine fault is very much different from that just described, for it appears to have been almost completely dolomitized. At the northern end of Porcupine Ridge mottling is much in evidence but is not so strongly developed, and the beds as a whole are dolomitic. At the southern end of the ridge below the Ghost River section the formation is entirely medium to very dark grey, in part vuggy dolomite, greatly resembling parts of the Devonian Fairholme.

PALEONTOLOGY AND AGE: Walcott (1908b) stated that on Mount Bosworth the Eldon contained the trilobite genera Ogygopsis and Bathyuriscus and originally dated the formation on Castle Mountain as Middle Cambrian. Deiss (1939) reported only unrecognizable - algae (Girvanella?) from the Eldon on Castle Mountain.

Deiss (1939) defined the Pika formation on the basis of its differing lithologic character from the Eldon and also because it contained an undescribed Upper Cambrian fauna older than the Cedaria fauna of lower Dresbachian in the lower fifth. He tentatively placed the Upper-Middle Cambrian boundary at the Pika-Eldon contact.

H.W. Shimer (1926) assigned his Cathedral formation, which is probably DeWit's Lower Eldon, to the Middle Cambrian. Beach (1943) collected trilobites of the genus Ehmania of Middle Cambrian age from the middle part of his Formation D, which he suggested might be correlative with the Ghost River formation. The lower 51½ feet of this section however appears to be correlative with the Lower Eldon or Porcupine Creek, and it was from the upper beds of this unit that the trilobites were collected. The 78 foot unit above may represent the Upper Eldon or Pika.

Clark (1949) who correlated the Cambrian in the front of the range with the Middle Cambrian Cathedral formation, collected trilobites 35 to 40 feet below the base of the Ghost River formation that probably represents the same zone from which Beach collected fossils.

The generally accepted practice is however to place the Middle-Upper Cambrian contact at the top of the Pika, and for the purpose of this paper that usage will be followed.

No fossils were found in the Cambrian in the Wasootch Creek area except for the cephalon of an agnostid trilobite, probably Pseudagnostus which ranges from Middle to Upper Cambrian.

PALEOZOIC

Cambrian

Ghost River (Arctomys) Formation

NAME AND HISTORY: The Ghost River formation was referred to by McConnell (1887) as a light-yellowish, siliceous band, varying in thickness from 100 to 400 feet, near the base of the Fairholme. Little consideration was given it until Walcott (1921) proposed the name Ghost River for 285 feet of largely buff-yellow weathering variagated shales, silts and dolomites. Walcott immediately recognized the possibility of either a Devonian or Cambrian age of the beds since they were conformable with the overlying and underlying formations. In the years that followed both a Cambrian and Devonian age have been assigned the Ghost River. Recently DeWit (1956) stated "The lithology of the Arctomys formation is identical with part of the Ghost River," and that "It now seems apparent that the lower unit of the Ghost River does fit quite well into the Cambrian sequence, and that it can logically be correlated with the well known Arctomys formation..."

DISTRIBUTION AND THICKNESS: In the Front Ranges of the Rocky Mountains Upper Devonian strata regionally truncate southwestward dipping Cambrian and Ordovician formations by what is called the sub-Devonian unconformity. Little or no angular discordance is visible and the magnitude of the hiatus is evaluated from faunal and stratigraphic evidence. In the easternmost part of the Front Range, Devonian rests directly on Middle Cambrian units while farther west Ordovician formations underly the Devonian. This regional truncation coupled with an eastward thinning of the formations which are broken into a great many northwestward trending fault slices makes a study of the sub-Devonian very complicated.

The thickness of the Ghost River is highly variable, in part due to pre-Devonian erosion, in part because different writers assign beds to the formation which in reality belong to other units. In the Wasootch Creek area the Ghost River is not everywhere present. At the north end of Porcupine Ridge it is poorly exposed but may approach 100 feet in thickness. At the southern end of the ridge an excellent exposure of the formation is present in a small tributary to the east fork of Wasootch Creek $4\frac{1}{4}$ miles upstream from the highway (Figure 13). At this locality it is $53\frac{1}{2}$' thick but soon thins to zero along strike. In the easternmost part of the area above and below the West McConnell fault the Ghost River is entirely absent.

LITHOLOGY: In the Wasootch Creek area the Ghost River consists of pale green to yellowish-buff, thin to very thinly bedded, fine-grained, non-silty dolomite. Thin layers of maroon-red and green dolomite give the measured section a variagated appearance but these colors are local and can disappear within a few feet. Of particular interest is the absence of silt in the section on Wasootch Creek. Elsewhere the formation is characterized by its silt and sand content which often form sandstone layers. Although silt is entirely lacking the dolomite is probably somewhat argillaceous. The dolomite is fine-grained to dense and usually evenly textured. Thin sections reveal that it consists of many dolomite rhombohedra set in a cryptocrystalline matrix.

At the head of Wasootch Creek the upper part of the Pika-Eldon formation is a fine-grained, even textured, medium grey dolomite in thin beds with highly undulatory surfaces. Upwards this apparently grades into a buff weathering, fine-grained, buff-yellow dolomite in thin to very thin beds, 3 to

4 feet thick, that contain many angular to sub-rounded fragments of the lower grey dolomite. The pebbles of this conglomerate range from ¼ to 4 inches which become finer upwards and gradually disappear. Laterally the conglomerate may be replaced by a few inches of fine-grained, light tan dolomite containing a few small fragments of dolomite, together with a small amount of silt. The contact with the underlying formation is concordant although a peculiar fracture system below the latter lithology looks very much like an angular unconformity. It is believed that shallow water conditions are indicated by this conglomeratic zone and a small amount of erosion may have occurred during its formation. The uppermost unit consists of a breccia which was probably formed under shallow water conditions by the fragmentation of the underlying very thinly bedded, platy limestone (Figure 14).

Because of its thin bedded and in part argillaceous character, the formation is relatively easily eroded and good exposure is not common. Where it is exposed however, it forms an excellent marker horizon for mapping purposes because of the contrast in color with the adjacent formations.

The following section was measured near the head of Wasootch Creek:

Unit	Thickness		Total from base
1	0-11'	Limestone, breccia, yellowish-buff weathering, composed of fragments and chips of the underlying unit, separated by an 8" transition zone, lower surface slightly undulatory	42½-53½

Unit	Thickness		Total from base
2	4'	Limestone, greenish-yellow, tan-yellow weathering, thin bedded, platy, argillaceous recessive	42½
3	2½'	Dolomite, pale green, pale yellow-green weathering, dense, even textured, fine to sugary, middle ½' yellow-tan dolomite, greatly fractured into long splinters, lower 4" green dolomite that crumbless into small chips.	38½
4	6'	Dolomite, dense to very fine, even textured, variagated, dark red to maroon, tan-yellow, in thin alternating layers, thin green shale parting . .	36
5	1½'	Dolomite, dense, pale green at very top, rest is fine-grained, sugary, greenish-yellow . .	30
6	2'	Dolomite, dense, even textured, alterating red and green to pale green	28½
7	2'	Dolomite, very fine-grained, dark red to dark maroon, with dark grey-green, fine patches . .	26½
8	7'	Dolomite, dense even textured, alternating red with tan-yellow weathering pale green in ½ - 1' zones	24½
9	3'	Dolomite, fine-grained to dense, thin alternating layers of pale green and dark red-maroon with fine green mottling, ½' of light grey-white, fine dolomite	17½
10	2'	Dolomite, fine, even textured, dark red-maroon, with ½' green at top	14½

Unit	Thickness		Total from base
11	1'	<u>Dolomite</u>, fine, even textured, splintery fracture, upper green, lower red . . .	12½'
12	2'	<u>Dolomite</u>, fine dark red-maroon, rusty-brown weathering	11½'
13	1'	<u>Dolomite</u>, very thinly bedded, three alternations of green and red	9½'
14	1'	Covered interval	8½'
15	1'	<u>Dolomite</u>, fine grained, even textured lower half pale green, upper half dark red-maroon with small irregular green mottlings which weather to tan-yellow	7½'
16	4'	Covered interval	6½'
17	½'	<u>Limestone</u>, fine-grained, grey breccia, unrelated to rest of lithology	2½'
18	1'	<u>Dolomite</u>, fine-grained, even textured very thinly bedded, tan, tan-yellow weathering . . .	2'
19	½'	<u>Dolomite</u>, dense, bluish-green, even textured, hard, tan weathering	1'
20	½'	<u>Dolomite</u>, fine-grained, light tan, containing a few small fragments of the underlying grey dolomite, very slightly silty	½'

Underlying formation - Pika-Eldon

<u>Dolomite</u>, medium to fine-grained, medium grey, medium grey weathering, medium to thick bedded with thin partings.

PALEONTOLOGY AND AGE: The Ghost River formation is typically barren of fossils so that its age and correlation must be based entirely upon lithologic and stratigraphic evidence. It was partly on this basis that deWit (1956) subdivided the Ghost River in the Bow Valley region into an upper basal Devonian unit and a lower unit correlated with and designated as the Arctomys formation of lowermost Upper Cambrian age. Because the strata underlying the Ghost River in the Wasootch Creek area are believed correlative with the Pika-Eldon of deWit in the Fairholme Mountains, the Ghost River is also believed correlative with the Arctomys formation in that area.

PALEOZOIC

Devonian

Fairholme Group

NAME AND HISTORY: To the dark brownish-black and light grey dolomites below the prominent limestone cliffs of the Palliser, McConnell (1887) gave the name Intermediate Limestone which apparently included the Alexo and Ghost River, and to which he assigned a Devonian age (Table I). This name persisted until 1924 when Kindle combined the present day Fairholme, Alexo and Palliser into the Banff Limestone and Dolomite. Walcott (1924) proposed the name Messines for equivalent beds of the Intermediate Limestone on Mount

Messines at the head of Glacier Lake Canyon, and to which he assigned a Middle Devonian age. Nowhere in the literature has a statement been found to invalidate this term, and it should technically therefore have priority as a valid formational name.

Shimer (1926) proposed the Minnewanka formation for the Fairholme, Alexo and Palliser, a name used until Beach (1943) proposed the term Fairholme, from the Fariholme Mountains, for the original Intermediate Limestone of McConnell, exclusive of the Ghost River. DeWit and McLaren (1950) excluded the Alexo from the Fairholme, and McLaren (1955) raised the formation to group status by the subdivision of the Fairholme into two distinct formations, the Southesk and Cairn. Belyea (1955) extended the Fairholme Group to include the carbonate sequence in the subsurface of the southern Alberta Plains.

Two major facies are present in the Fairholme Group in Alberta, a carbonate reef or bank facies, and a dominantly clastic, shale or basinal facies. The clastic facies is typically developed north of the Bow Valley region and has undergone a similar nomenclatural development to the carbonate facies. Raymond (1930) proposed among other formations a basal Flume of Middle Devonian age and Perdrix of Upper Devonian. DeWit and McLaren (1950) adopted Raymond's earlier formations and erected one new formation for the uppermost part of the sequence, the Mount Hawk. McLaren (1950) correlated the Mount Hawk and uppermost part of the Perdrix formations with the Southesk formation, and the major part of the Perdrix and the Flume with the Cairn. Belyea and McLaren (1956, 1957) however correlate the Perdrix and Flume with the Cairn and the Mount Hawk with the Southesk. Fox (1951) proposed the Cheviot formation to include the Alexo and Mount Hawk as members.

In the Wasootch Creek area the carbonate facies is excellently developed and the Fairholme Group is readily divisible into the Southesk and Cairn formations.

THICKNESS: In the Bow Valley area there seems to be a general eastward thinning of the carbonate facies. On Sulphur Mountain it reaches a maximum for this region of 1,672 feet, whereas on the southeastern end of Mt. Rundle at Whitemans Pass, McLaren (1955) reports 1,244 feet, and Fox (1954) measured 1,203 feet. At Lac des Arcs in the Bow Valley the Fairholme is 1,050 feet, and at Loder's Lime Kiln it is reported to be 1,090 (Taylor 1957) and also 1,188 feet. DeWit (1953) however reports 1,314 feet at Loder's Lime Kiln. In the easternmost part of the Front Range Clark (1949) measured 1,300 feet. Eastward at Moose Dome the Fairholme has thinned to between 1,100 and 1,200 feet.

Good sections of Fairholme are not present in the Wasootch Creek area so that estimations of thickness must be extrapolated from the Bow Valley area. Although the thicknesses of correlative sections in the Bow Valley are little more than 1,000 feet, the 1,300 feet measured by Clark (1949) is probably nearer the thickness of the Fairholme south of Kananaskis River. The formations probably thin eastwardly somewhat because exposures occur on four fault-blocks which palispastically may represent a distance several times the present distance between sections at the western and eastern parts of the area.

DISTRIBUTION AND GENERAL CHARACTER: The Fairholme is known throughout the Front Range from the Crowsnest area to the Peace River area, and throughout the Plains regions of Alberta. The carbonate facies is typically developed in the mountains from the Wasootch Creek area to the North Ram River, northwestward in the Mt. Coleman area, and in the easternmost ranges from Wapiabi Creek to Mt. MacKenzie. In the Front Range area of the North Saskatchewan River a clastic facies is present, and northwest and west of the Mountain Park area to the Athabasca River region the Fairholme is represented by the clastic facies. South of the Bow Valley region the Fairholme has been little studied but in the Crowsnest Pass area a clastic facies begins to appear (DeWit 1953).

The carbonate Fairholme is considered to have been deposited in shallow water and to have consisted predominantly of material formed from the growth and destruction of form-building organisms, as well as other carbonates influenced by the proximity of organic growth. Definite reefs as well as 'reefal-buildups' were present in both definite linear trends and as irregularly scattered growths on very extensive, shallow platforms. No evidence of a shore-line has been found in the Eastern Rockies and the nature of the sediments was entirely controlled by the depth of water, and the rate of subsidence, among the most important factors in reef development, and in some areas by the amount of clastic material brought into the area. The clastic facies represent basinal areas between the carbonate banks which received varying amounts of mud and silt although limestone and dolomite are the dominant lithologic types. Between the bank areas and clastic basins a certain amount of relief existed, although it cannot have been great, so that deposition of clastics was mostly prevented over the reef areas, and the carbonate facies usually are relatively pure. According to Belyea (1956) subsidence seems to have been to the north and northwest away from the southeastern Alberta shelf.

In a reef complex a distinction must be made between individual structural elements normally organic and the complex as a whole which may contain a high proportion of carbonate clastics. Several distinctive lithologic types have been recognized in the reef Fairholme which are: (1) black, bedded dolomite, fetid and bituminous, consisting largely of stromatoporoids, Amphipora, and corals, that is commonest in the Lower Cairn and Flume. (2) black, massive dolomite, bituminous, vuggy, largely or entirely of stromatoporoids with subordinate Amphipora and corals, broadly lenticular, most common in the Lower Fairholme, and often designated as 'black reef'. (3) dark green and brown, bedded and massive dolomite, largely consisting of colonial corals, typically developed in the upper Fairholme. (4) black and grey, bedded dolomite, without obvious organic constituents, and presumably of detrital origin. (5) light grey, massive dolomite, porous, vuggy, and frequently with a bituminous odor, without obvious structure, broadly lenticular, an important unit of the upper Fairholme, and often designated as 'white reef'.

The Cairn formation is in general somewhat more extensive than the Southesk and at the margins of Southesk developments the Perdrix black shales and dark limestones overly the Cairn. The Cairn has been called a shoal reef, or a formation in which reef growths develop in irregular patches amidst submerged shoals of calcareous debris. In the Cairn, these patch reefs were largely formed of stromatoporoids and Amphipora. The sediment was probably deposited in fairly shallow water into which small amounts of mud and silt were introduced. The very dark matrix of the Cairn usually leaves a bituminous residue after solution in hydrochloric acid. The Cairn is presently almost entirely dolomite which is believed to have secondarily replaced original limestones. The main diagnostic features of the formation are its dark brown to black color, medium to thick and massive bedding, the very abundant traces of organic remains, particularly stromatoporoids, Amphipora and corals, and the common presence of a fetid odor when broken. McLaren (1955) states that there is evidence of numerous breaks in the succession, such as minor erosion surfaces, channelling, and sudden facies changes.

The Southesk on the other hand has been termed a bank reef, or a formation in which large reef growths develop over submerged highs more or less completely surrounded by deeper water. These highs may be tectonically or structurally controlled, so that the reefs are given a linear trend. The Southesk is believed to have been deposited, for the most part, in very shallow water, and occassionally it may have been exposed. Upper Fairholme sedimentation was initiated by small differences in relief on the sea floor allowing reefs to develop on the positive areas away from interference from clastic material. Evidence suggests that the white reefs in the Southesk were formed by lime secreting and lime-trapping algae, probably in very shallow water, for the reefs seem to be largely algae when not dolomitized although they and the entire Southesk are almost always entirely dolomitized. All reef growth ceased at the end of Mount Hawk and Southesk time when relief between reef and basin areas had almost vanished and partial regression of the sea caused erosion in some areas prior to Alexo deposition. In contrast to the Cairn, the Southesk is dominantly a light grey, coarse to medium grained, thick bedded to massive, often structureless dolomite, sometimes with minor limestone. McLaren (1955) reported a middle coral bed member of a lithology similar to the Cairn, which may extend beyond the limits of the formation below and interfinger with the Mount Hawk, as may the grey dolomites above.

The Fairholme is exposed on each of the four main fault blocks in the Wasootch Creek area but nowhere is it well exposed. It typically outcrops on the eastern faces of the fault block ridges and produces moderate to rather steep slopes that are always largely vegetated. The lowermost and uppermost parts are the most resistant to erosion and on the west side of the ridge between the main branches of Porcupine Creek the lower Cairn is prominently exposed, the upper Southesk to a lesser degree (Figure 4). The most readily accessible and probably the best exposure of the entire formation is on Porcupine Ridge, immediately east of Wasootch Creek, one mile southeast of the highway. There the Fairholme is exposed as many relatively narrow, alternating exposed and covered intervals from which the general lithologic character of the formation may be determined. The recessive and covered intervals may represent slightly argillaceous horizons.

The Fairholme in this region is relatively easy to map because the dark brownish-black of the Cairn and light grey of the Southesk are very conspicuous from a distance and outcrops are usually rounded and subdued. In addition the formation is low in the stratigraphic sequence and commonly is exposed below timberline so that it is almost always vegetated in varying degrees, whereas most of the other Paleozoic formations are rarely vegetated. Also in a normal sequence the Fairholme underlies a prominent Palliser cliff and overlies the very conspicuous Ghost River or highly resistant Lower Eldon.

The upper contact of the Southest is abrupt and non-gradational with the Alexo while the lower as previously discussed is locally disconformable but regionally unconformable.

LITHOLOGY: At the type locality the Southesk formation is divisible into three members (McLaren 1955). The upper and lower members are light grey, medium to coarse-grained, thick to massively bedded, structureless dolomite, 202 and 281 feet respectively. A middle coral bed member, 45 feet thick, is dark brownish grey, slightly argillaceous, medium-grained, thick to massively bedded dolomite with abundant Amphipora, massive stromatoporoids, and corals.

In the section sampled on Porcupine Ridge the lower contact of the Southesk was taken at the base of the lowest thick bedded, very vuggy, light grey, medium-grained dolomite, about 15 feet thick, which has a 2 foot bed of black, fine-grained dolomite at the top containing Amphipora. The contact is however gradational, in most areas over some 20 to 50 feet. Near the middle of the formation is a zone 20 to 30 feet thick that consists of dark brownish-black weathering, medium to fine-grained, even textured, vuggy, medium to thickly bedded, black dolomite that may correlate with the middle coral bed member of McLaren (1955). Immediately above and below are medium grey, fine-grained, light grey weathering, very even textured, structureless dolomites. Downward from this middle unit to the base the lower unit consists of structureless, light grey, medium to coarse-grained, even textured, well bedded, medium to thick dolomite, in part with fine vugs. The upper unit similarly is light grey, with some medium grey, medium and fine-grained, even textured, thick to medium bedded dolomite. The uppermost bed usually consists of a very coarse, very porous, light grey dolomite which because of its coarseness is a fairly reliable marker. The bedding of the Southesk is mostly medium to thick, though some is quite thin, but it is all very distinct which suggests a relatively flat, inter-reef depositional area. Thin sections reveal that the dolomite consists of a mossaic of dolomite rhombohedra, often with scattered intergranular porosity. The dolomite is completely structureless and gives no hint of its original texture. On a weathered surface the dolomite has a saccharoidal or sandy appearance due to differential weathering of the dolomite rhombs. Within the formation there are several 2 to 3 foot zones of dolomites which consist almost entirely of *Amphipora* and may be black or light grey.

Two very well developed reefs are present in the Wasootch Creek area, both of which are located at the eastern margin of the mapped area, east of the West McConnell Fault. One is located on the west side of the mountain immediately north of Pass Creek and easily examined just east of the highway in the northernmost creek tributary to Kananaskis River. The second is located near the headwaters of the east fork of Porcupine Creek above and below the thin slice of anticlinally folded Ghost River. Both reefs are extremely massive, vuggy and the northern one is very thick.

The Cairn formation at the type locality is divisible into two members which are widely recognizable. The lower is designated the cherty dolomite member (McLaren 1955) and consists of 101 feet of dark grey, fine to medium-grained dolomite, with nodules, bands and stringers of chert, abundant in the upper 70 feet. Some stromatoporoids occur in the top 65 feet and Amphipora is abundant in the beds below. The upper or organic dolomite member is 457 feet thick and consists of grey to dark brownish grey to brown and black, medium grained dolomite, medium and thick bedded to massive and slightly argillaceous, with very abundant traces of organic remains. The thicker and more massive units are largely composed of spheroidal stromatoporoids with scattered Amphipora and corals. Scattered calcite filled vugs occur and most beds emit a fetid odor when broken. Amphipora occur typically in definite thin units interbedded with thicker dolomites. Rapid alternations of these various types occur and the thick to massive stromatoporoidal developments appear to be broadly lenticular.

The two members of McLaren may be said to be present in the Wasootch Creek area although the lower one is not well developed and does not merit the designation of a member. Approximately 20 feet above the base is a zone from 20 to 30 feet thick that consists of a brownish-black, fine-grained, even textured dolomite containing numerous stromatoporoids and many small, black chert nodules. The stromatoporoids vary in size from 1 foot to 1 inch and weather white and light grey (Figure 15.) The zone as a whole is medium to thick bedded but many irregular partings give it a thin bedded appearance. In the easternmost part of the area this zone is only a few feet thick, and at the head of Wasootch Creek it is replaced by a sequence of dolomitic limestones approximately 15 feet thick. They are black, fine-grained and on a weathered surface typically strongly laminated to banded from very thin layers of dolomite. The beds vary from ½ to 3 feet and six distinct beds were sampled. The lowest bed is not completely exposed but is a dolomitic mottled limestone. Immediately above is a 3 foot bed of strongly banded limestone which in thin section is found to be graded bedded. Below the chert and stromatoporoidal unit is a black dolomite which may contain numerous small, white specks 2 - 4 mm. long which give to a weathered surface a light grey color. Some medium to coarse dolomite contains coarse to fine sized white masses that may represent reworked fragments of Amphipora.

Immediately above the chert unit is a bed of black, even textured dolomite containing crinoid columnals and some scattered silicified corals. At the top of a 20 foot covered interval are more though fewer crinoid columnals. Near the base of the Cairn or Pass Creek are two thin zones of highly crinoidal, black dolomite which may be a single faulted bed.

Most of the remainder of the Cairn consists of finely crystalline, dark to very dark weathering, very even textured black dolomite, in which are occassional thin units of *Amphipora*. Some zones are slightly lighter in weathering colors than the majority of the beds, and some units are very vuggy. Much of the bedding is fairly even but some is poor and massive. In the southeastern corner of the area below the Southesk reef, the Cairn is extremely well bedded, most beds being thin to medium.

In the upper part of the formation, perhaps 100 feet from the Southesk is a 'black reef' unit about 50 feet thick, consisting of black, fine-grained, even textured, dark weathering dolomite with extremely rough, irregular, vuggy weathered surfaces (Figure 16). Some *Amphipora* is present and most stromatoporoids that were present have been leached out. Above this unit, 3 to 5 foot layers of grey weathering, grey dolomite, medium to fine-grained, alternate with black dolomite. One such layer is 1 foot thick and consists of grey, very fine, even textured, dolomite, distinctly lighter weathering than the thin *Amphipora* zones on either side.

Several feet below the top of the formation is a bed of breccia about 5 feet thick, that is medium to light grey weathering and consists of an upper 1 foot of fine breccia with fragments ¼ to ½" and a lower 4 feet of coarse breccia with fragments 1 to 1¼ inch. It is generally massive and non-bedded. The breccia fragments are dark, brown-grey dolomite, fine-grained, well crystallized to a mossaic of rhombs, and surrounded by a granular matrix of clear, white calcite.

The whole mass is very porous and crumbles relatively easily.

Above a 20 to 30 foot covered interval is a 15 foot unit of medium bedded, black, Amphipora dolomite that becomes lighter near the top. Above this is the lower light grey, thickly bedded dolomite of the Southesk formation.

PALEONTOLOGY AND AGE: The Fairholme group is generally highly fossiliferous but only in the clastic facies. Any fossils that may be present in the dolomitized carbonate sequence are usually too poorly preserved for identification. In the Wasootch Creek area the Cairn formation is much more organic than the Southesk. Near the base of the Cairn a zone containing corals and crinoid columnals is common. Where the lower units consist of limestone, such as near the head of Wasootch Creek, a highly fossiliferous zone containing Schizophoria may be present. Stromatoporoids and Amphipora in thin zones are common throughout the Cairn and a few Amphipora zones are distributed through the Southesk.

The paleontology of the Fairholme has been described by many writers. Brachiopods and corals are the dominant types present and they indicate an Upper Devonian age. Some writers suggest that the basal parts may be Middle Devonian in age but the general practice is to consider the entire group as Upper Devonian.

PALEOZOIC

Devonian

Alexo Formation

NAME AND HISTORY: The Alexo formation has only recently been given formal status although McConnell (1887) referred briefly to "... passage beds partaking of the lithological character of both groups ... at the junction of the formations." The Alexo was included in the Fairholme and considered not to be worthy of formational rank by Beach (1943). DeWit and McLaren (1950) proposed the name for silty, sandy, brecciated, shaly limestones and dolomites that are present in all Devonian sections. Fox (1951) however included the formation as a member in the Cheviot formation.

THICKNESS: In the Rocky Mountains the formation varies from about 100 to 665 feet although the average thickness is less than half the latter. At the type section in the Brazeau Range at The Gap the Alexo is 240 feet thick. At Devils Gap, Lake Minnewanka the Alexo is 166½ feet and on Sulphur Mountain it totals 196½ feet. In the Wasootch Creek area it is 141½ feet. Comparison of thicknesses of Alexo with facies of the underlying Fairholme has shown that the formation thickens away from the carbonate developments and increases in thickness toward the basinal areas. As would be expected the greatest thicknesses are reported from the Athabasca Valley area, but further south the thickness of Alexo appears to be less related to the underlying facies.

GENERAL CHARACTER AND DISTRIBUTION: The Alexo is present in all Devonian sections from the Crowsnest region to the Athabasca River area and from as far west as Sulphur Mountain and the Banff-Jasper Highway to correlative units in the Plains. Characteristically it is composed of silty and laminated limestone and dolomite, siltstone, breccia and irregularly distributed argillaceous material. Often the lower parts are argillaceous, silty and sandy though in places they may be almost entirely carbonate. The upper units are usually dolomite and limestone that is typically silty, often partly laminated, and commonly brecciated.

Topographically the formation is expressed as saddles, benches or stream gullies, for the Alexo is quite non-resistant relative to the overlying Palliser, the boldness of which it accentuates by its recessive nature. Despite its recessiveness, relatively good exposures are quite numerous particularly in stream gullies above timberline. An almost perfect exposure was measured near the headwaters of Wasootch Creek, on the east side of Lac des Arcs Ridge. A second much more accessible exposure was examined on the southeast corner of Mt. Lorette where the formation weathers in part to a conspicuous light yellow that is readily seen from the highway.

The Alexo is always concordant with the underlying Fairholme but according to McLaren (1955) in many areas there is evidence of erosion before the Alexo was deposited, and in others there appears to have been a period of non-deposition. A disconformity may very well separate the two for although the contact was not observable in the two sections examined, the lowermost beds of silty, ochrous weathering dolomite and dark green shale presumably rest directly on the coarsely crystalline, pure, light grey dolomite of the uppermost Southesk. This abrupt break in lithology accompanied by the first appearance of silt strongly suggests a disconformable break.

The upper contact is transitional in many areas and at the measured section no contact could be obviously drawn. On Mt. Lorette however a distinct surface separates the basal Palliser from Alexo.

LITHOLOGY: At the type locality in the Brazeau Range the Alexo is divisible into a lower one-third that is typically argillaceous and silty dolomite, siltstone and shale which is mostly buff and ochre weathering, and an upper two-thirds that is essentially siltstone, and limestone and dolomite breccia which dominates. At this locality the formation rests with sharp break on the thick bedded, dark brownish grey dolomites of the Mount Hawk formation. The upper contact is gradational into the Palliser. This lithology in general characterizes the Alexo in the mountains although relative amounts of clastic and carbonate rock vary.

The Alexo in the area under consideration is similar in general lithology in all sections examined but minor differences are conspicuous and probably result from the shallow water origin of the rock. Following is a detailed section from Lac des Arcs Ridge near the headwaters of Wasootch Creek:

Overlying beds - Palliser black limestone, medium grey weathering

Unit	Thickness		Total feet from base
1	-	<u>Limestone</u>, dark grey to black, medium to dark grey weathering, thick bedded, dense, containing many dolomite rhombs which give the weathered surface a sandy appearance, transitional between Palliser and Alexo	
2	3½	<u>Limestone</u>, black, dense, medium grey weathering, medium bedded, highly organic, slightly pyritiferous, etching reveals many dolomite rhombohedra which give a sparkle to fresh surfaces, microstylolitic seams contain black bituminous residue, also present is similar limestone containing patches less than 1" long that contain only a few dolo. rhombohedra and weather out in relief giving the appearance of smooth surfaced breccia fragments; grades down quickly into unit 3	141½
3.	4	<u>Limestone</u>, dolomitic, light grey, light grey weathering, weathered surfaces 'sandy' from dolomite rhombs, strongly laminated with tan-yellow argillaceous, recessive layers, and darker layers of dolomite rhombs which weather in relief; both types very thin, parallel and widespread, thick bedded; a <u>brecciated</u> zone at the top varies from 0 to 6 inches thick, and consists of fragments of fraction of an inch to 2 inches long, it is porous and varies in thickness laterally;	138

Unit	Thickness		Total Feet from base
4	10	Breccia, limestone, thickly bedded; one type contains more fragments than matrix and consists of small fragments generally less than ½ inch, commonly 1/8 to 1/4 inch, are a yellow-ochre color on fresh and weathered surfaces and are well laminated, the matrix is a medium grey dolomitic limestone with many dolomite rhombs giving weathered surfaces a 'silty' appearance; in the other type most of the fragments are medium grey like the matrix which about equals the fragments in volume, very porous and vuggy; interbedded irregularly throughout is a very thinly bedded, laminated dolomitic limestone	134
5	1½	Limestone, black, dark grey weathering, dense, with a few scattered dolomite rhombs, very numerous stylolitic seams which weather as recessive fine, subparallel and continuous lines	124
6	4	Dolomite, dark brown, dark brown weathering, soft, saccharoidal, extremely porous, vuggy, fetid odor, many fine calcite veins, the lower two feet are harder, light grey weathering but also porous and highly calcareous and bears white markings of unknown origin that are rounded to elongate rods, maximum length 2/5 inches, most 1/5 inch long; . . .	122½
7	8	Limestone, light grey, light grey weathering, hard, non-lamin, containing numerous white specks about 1/5 inch in dia., part consists of dolomite limestone, laminated, light grey weathering, fetid, very porous, many laminations of orange-yellow color which may be bituminous material	118½

Unit	Thickness		Total Feet from base
8	2½	Limestone, dark grey, medium grey weathering but slightly brownish, dense, generally even textured but with some laminated and slightly brecciated	110½
9	7½	Dolomite, calcareous, very dark grey, dark brown weathering, fetid odor, coarse and fine laminations, microscopically consists of a tight mossaic of rhombs; resembles non-vuggy Cairn dolomite	108
10	2½	Limestone, slightly dolomitic, light grey, light grey to grey white weathering, strongly laminated; laminations consist of darker more resistant bands which are rel. large rhombs, while the lighter more recessive bands are much finer crystalline and possibly somewhat argill., several bands are about 1/10 inch wide, are yellowish brown and seem to be iron stained from the weathering of limonite or hematite particles scattered through the layer, these bands are more finely crystalline than the darker bands and possibly contains some clay material; silt particles are angular to subangular and widely scattered throughout, they are not concentrated in any particular layers	100½
11	7	Breccia, almost identical to that of unit 4; generally fine breccia but some large fragments are 2½ inches long, vuggy in part, a dolomitic limestone, the matrix weathers a light grey and the fragments are yellowish-grey; quite silty, rather massive; unbrecciated layers particularly in the lower part	98
12	5	Limestone, medium brownish grey, medium grey weathering, strongly laminated bands consist of highly silty zones of angular to subangular silt grains of quartz and feldspar; partially brecciated but obscurely so . . .	91

Unit	Thickness		Total Feet from base
13	6	Limestone, dolomitic, medium to dark grey, medium grey weathering, weathered surface 'silty' looking from dolomite rhombs; microscopically consists of a tight mossaic of rhombs, even textured, pure, massive	86
14	3½	Limestone, slightly dolomitic, light grey near the top, darker grey at the bottom, light grey weathering, massive, dense to very fine grained containing bands of fine angular to subangular silt	80
15	3	Limestone, medium to light grey, light grey weathering, finely crystalline, even textured, massive bedded	76½
16	10	Dolomite, slightly calcareous, medium to dark grey, medium to light grey weathering, very even textured, massive to thickly bedded; laminations consisting of recessive bands due to relatively larger rhombs, the smaller rhombs constituting the majority of the rock between the laminations . .	73½
17	½	Sandstone, orthoquartzitic, light tan to dirty white, very hard, even textured, very fine grained	63½
18	2	Limestone, very light tan grey, light grey weathering, very highly silty, fine to dense, silt is concentrated in irregular layers and lenses which stand out strongly on weathered surfaces	63
19	1½	Dolomite, medium grained, rhombs form a tight mossaic, light grey, medium to light grey weathering, even textured, slightly calcareous; a few scattered subangular silt grains . .	61

Unit	Thickness		Total Feet from base
20	1½	<u>Limestone</u>, medium grey, very light grey, weathering, fine to dense, very even textured, strongly laminated due to layers of finer grained calcite (possibly slightly argillaceous) which stand out in high relief	59½
21	3	<u>Dolomite</u>, slightly calcareous, medium grey, medium grey weathering, to light grey weathering, very even texture, pure, medium crystalline consisting of a tight mossaic of dolomite rhombohedra	58
22	2	<u>Limestone</u>, dolomitic, medium to light grey, light grey weathering, very even textured, pure, medium crystalline, tight mossaic of rhombs	55
23	2½	<u>Limestone</u>, light grey, light grey weathering, very dense, even textured, scattered angular to subangular silt grains	53
24	6	<u>Dolomite</u>, slightly calcareous, light grey, light grey weathering, porous, very even textured, a few scattered silt grains, interlocking mossaic of large and small dolomite rhombs . .	50½
25	1	<u>Limestone</u>, light grey weathering, very fine crystalline, medium grey <u>breccia</u> fragments less than 1 inch	44½
26	5	<u>Limestone</u>, light tan grey, light grey weathering with brownish cast, weathers 'sandy' from rhombs, fine to medium crystalline, porous, bituminous; becomes somewhat lighter near the bottom	43½
27	3	<u>Limestone</u>, light grey weathering, medium grey, dense, contains scattered dolomite rhombs, slightly silty; upper 1 foot light, darker in lower 2 feet which consists of black limestone with scattered rhombs, very finely brecciated in thin section .	38½

Unit	Thickness		Total Feet from base
28	6½	Limestone, breccia, not obviously a breccia on weathered surface, medium to light grey weathering, fragments and matrix about equal and average about 1/4 to 1/2 inch and consist of dark grey, crystalline, even texture limestone non silty, a mossaic of interlocking rhombs; the matrix is cryptocrystalline, light grey, with scattered rhombs and silt particles; lower 2 feet much finer breccia	35½
29	4	Covered	29
30	6	Limestone, medium grey to light grey, medium grey weathering, very porous and finely vuggy; appears rotten and crumbles easily, soft, fine to medium crystalline, slightly silty .	25
31	6	Covered	19
32	13	Dolomite, dense, blue-green, weathers a very characteristic buff-brown color, hard, silty, thick to thinly bedded .	13

The breccia which characterizes the Alexo, while not abundant in the Lac des Arcs section, is distributed throughout and totals approximately 32 feet. On Mt. Lorette however, breccia constitutes almost half the formation. The occurrence of breccia in the Alexo, and also in the Costigan member of the Palliser has been attributed by DeWit and McLaren (1950) and others to solution of evaporites with consequent slumping and brecciation of the enclosing beds. DeWit and McLaren consider the fact that many layers between the breccias are undisturbed would seem to indicate the solution origin, and that the breccias are not tectonic in origin. In some localities however pencontemporaneous slumping shortly after deposition may have produced the breccia. Those in the measured section may be due to leaching and slumping since they alternate with unaffected and uniformly bedded layers.

Silt is a rather minor constituent of the Alexo in this area and is confined to the lower 100 feet. It was discovered that the majority of the silt present in any sample is irregularly scattered throughout and not concentrated in thin layers which weather in relief to produce laminated surfaces. Although some laminations are actually silty, many are the result of the thin layers of crystalline dolomite which because of its resistance to weathering stands out in relief on a weathered surface and unless tested for hardness cannot be distinguished from true silty laminae. These laminae must therefore be called dolomitic laminations (Figure 17). A similar situation was found to exist in the Costigan member of the Palliser which contains many laminations previously described as silty laminae, however in the Wasootch Creek area the Costigan was found to be entirely lacking in silt. Dilute hydrochloric etching combined with stain tests for calcite and thin section examination have proven the presence of dolomite and absence of silt in these rocks.

The origin of thin laminae of dolomite is commonly ascribed to either primary deposition or diagenetic replacement, but since negative evidence argues against the former, the latter is generally favored. Reaction and replacement of a calcareous sediment at the sediment-water interface by magnesian carbonates in solution might take place during continuous deposition, then cease when the magnesian carbonates or salts are depleated or fall below a critical concentration. Continued deposition of limestone would form a thicker layer of limestone the surface of which might be again replaced by magnesian carbonates or salts which had become concentrated in the meantime to the level necessary for replacement. It has been suggested that highly saline waters favor deposition and concentration of magnesian salts and because the dolomitic laminations in the Alexo and Costigan member are closely associated with brecciated limestones attributed to solution of evaporites, super-saline waters may have contributed to the formation of these dolomitic laminae. The oscillatory nature of the layers may reflect fluctuations in the salinity of the sea water which in turn may have been due to alternating periods of evaporation and influxes of normal sea water.

Within the area an excellent marker bed defines the base of the formation on Lac des Arcs Ridge, Mt. Lorette and on the ridge between the main forks of Porcupine Creek. It consists of a dense, blue-green, hard, silty, thick to thinly bedded dolomite that weathers a very characteristic buff-ochre to brown color. Associated with this may be a dark greenish, crumbly, very thinly bedded shale, which is very thin on Mt. Lorette and Porcupine Creek.

PALEONTOLOGY AND AGE: The Alexo is unfossiliferous over much of the Rocky Mountain region, and occurrences of fossils are highly sporadic. Rare tabulate and rugose corals are present in limestone beds of the lower part but brachiopods constitute the greater part of the fauna. The brachiopod fauna includes _Cyrtospirifer_, _Camaroteochia_, _Hypothyridina_, _Paurorhyncha_, _Pugnoides_, _Leiorhynchus_, _Athyris_, and _Nudirostra_. This association indicates that the Alexo is definitely of Upper Devonian age. No fossils were discovered in any of the exposures of the formation in the Wasootch Creek area.

PALEOZOIC

Devonian

Palliser Formation

NAME AND HISTORY: McConnell (1887) designated the highly resistant cliff-forming limestone below the brown weathering, recessive Banff, the Lower Banff Limestone. The name persisted until 1924 when Walcott proposed the name Pipestone from a type section on the northeast side of Pipestone Pass in Clearwater Canyon. All previous terminology was abandoned by Shimer (1926) who included the formation in the Minnewanka formation. Beach (1943) proposed the formational name Palliser for the heretofore designated upper part of the Minnewanka formation, a name derived from the Palliser Range, which is a continuation of the Fairholme Range northward from Lake Minnewanka (Figure 1). More recently DeWit and McLaren (1950) divided the Palliser into an upper Costigan member and a lower Morro member.

THICKNESS: The Palliser formation varies in thickness from about 800 feet to a little more than 1,000 feet, though thicknesses of 600 feet are reported, generally from outlier ranges in the Foothills.

On Sulphur Mountain Warren (1927) recorded 1,050 feet and DeWit and McLaren (1950) give 990 feet. At Lake Minnewanka Shimer (1926) measured 1,000 to 1,050 feet but DeWit and McLaren (1950) report only 838 feet. In the Moose Dome area Beach(1943) found the Palliser to vary from 800 to 950 feet. In the Fairholme Mountains he measured 930 feet, and at Mount Lorette 860 feet. Clark (1949) reports a thickness of 800 to 900 feet in the Bow-Kananaskis Valley area.

The average thickness of the formation thus appears to be around 900 feet in the Front Range and with some exceptions thickens westward.

GENERAL CHARACTER AND DISTRIBUTION: The Palliser formation is a wide-spread unit in the mountainous areas of southwestern Alberta, occurring from the Crowsnest Valley to beyond the Athabasca Valley, and in such uplift areas in the Foothills as Moose Mountain, Limestone Mountain, Brazeau and Bighorn Mountains and Nickanassin Range. It outcrops typically as a single, bold vertical cliff several hundred feet high, commonly on the steep, eastern faces of fault-block mountains, and is perhaps used more than any other formation as a marker in the determination of structural details.

In the Wasootch Creek area it is second only to the Rundle in the formation of the higher peaks where differential erosion is allowed to operate on fault-blocks containing both Rundle and Palliser (Figures 5 and 6). If generalizations are valid it may be said that the Palliser occurs more typically near timberline whereas the Lower Rundle is never vegetated. These relationships are excellently displayed on Mt. Lorette.

Exposure is usually excellent but because of the cliff-forming nature of the Palliser, it is often impossible to measure sections easily. On the steeply dipping fault-blocks where the outcrops extend down into a transverse valley, such as on the southern face of Mt. Lorette, almost perfect sections are readily accessible. Almost the entire formation is exposed at the north end of Lac des Arcs Ridge, just south of the highway, and a complete but composite section was sampled on Mt. Lorette and on the southern face of Heart Mountain (Figure 6).

The Palliser is almost always readily distinguishable from other units in the Paleozoic succession where they occur as a single group. Where the structure is complicated by faulting and poor exposure the Palliser may be confused with the massive Lower Rundle, and extreme difficulty was met in differentiating between the Cambrian Lower Eldon and Morro member of the Palliser, regardless of whether the rock was examined from a distance or in hand specimen. The prominence of the Palliser cliff is, in uncomplicated sections, emphasized by the dominantly recessive nature of the underlying, typically vegetated Alexo and Fairholme, and the easily eroded Banff and Exshaw shale formations above, which weather to gentle talus covered slopes. Weathering colors aid greatly in the recognition of the formation. The Fairholme below weathers both very dark and light grey whereas the Banff above weathers to a conspicuous buff. The Palliser between the two weathers almost entirely to a light grey, which upon closer examination is found to be in large part, medium grey weathering.

The formation has been divided into two members, the lower of which is much the more massive and resistant and it is to this part that the formation owes most of its cliff-forming ability. The upper member contains more thinly bedded units that are less resistant than the massive limestones in the lower member.

The upper contact of the Palliser with the Exshaw black shale is very abrupt and in some areas distinctly disconformable while in others no obvious disconformity is present. The uppermost beds and upper surface of the formation are well exposed below the Exshaw section in the gully on the south side of Heart Mountain. One to two feet below the base of Exshaw the bedding surfaces of the Palliser are strongly undulatory and pitted, and contained nodules of black chert and pyrite, the weathering of which has stained much of the surfaces with iron oxide. Above these highly irregular surfaces are beds of dense, evenly bedded limestone, the upper few inches of which are argillaceous and crinoidal, and the uppermost surface is very regular and even. Unfortunately a very thin shear zone is present between the uppermost surface and a pyritic zone at the base of the Exshaw so that evidence of any gradation was destroyed, although such appeared to be the case dispite the shearing.

At this locality evidence for a disconformity is poor. The extreme abruptness of the change in lithology from almost pure carbonate to virtually pure shale however, presents evidence too strong to be denied. The entire depositional environment was changed completely and the mode of sedimentation was initiated for much of the Mississippian during an interval of time represented by such a very narrow zone that a considerable lapse of time must by necessity be postulated. It seems inconceivable that environmental and depositional conditions could change so completely in an instant of geologic time. On a regional scale however, evidence for a period of erosion is not altogether conclusive either.

The presence of a considerable amount of breccia in the Costigan, member, which has been attributed to the solution and consequent collapse of evaporitic material, presumably anhydrite, suggests that relatively shallow water conditions prevailed and a small amount of uplift would undoubtedly exposed a vast area of uppermost Palliser from which varying thicknesses of strata could have been stripped off. It is suggested by many that the variations in Palliser thickness is the result of this uneven erosion. An erosion hypothesis however, breaks down when it is considered that black, pyritic, non-calcareous shales, which are typically formed in stagnant waters under reducing conditions, immediately overly normal shelf limestones. It is difficult indeed to imagine how the waters of an inundating sea could immediately form a 'black shale environment,' unless of course deposition was delayed until the sea floor subsided below the base level of erosion.

An alternate suggestion is that no erosional disconformity is present but rather that a diastem or chemical unconformity separates the limestone and shale. Subsequent to the formation of the last deposit of evaporitic material, which is some distance below the upper surface, the waters may have gradually deepened to such a depth that near the close of Devonian time little or no limestone was being deposited. During a period of non-deposition it is conceivable that organic and inorganic processes could produce irregularities on the sea floor similar to that observed at the top of the Palliser. Reducing conditions may very well have existed at this time as suggested by the presence of pyrite nodules in the uppermost parts. A last flourish of Devonian life is often preserved at the top of the Palliser that doubtlessly has some environmental significance.

During this hiatus, uplift of adjacent land areas provided fine clastic sediment which suddenly blanketed the upper Palliser surface. That the uppermost surface of the Palliser was not yet lithified at the introduction of the mud is suggested by crinoidal limestone containing many thin stringers of black, non-calcareous shale immediately below highly pyritiferous Exshaw shale. The variations in the thickness of the Palliser could easily be accounted for by deposition on locally higher bank areas.

For these reasons a disconformity will be considered to form the upper boundary of the Palliser formation.

The lower contact of the formation is definitely gradational into the Alexo at one locality whereas on Mt. Lorette a distinct bedding plane clearly separates the two but there is no evidence of a disconformable relationship.

LITHOLOGY: The Palliser formation varies little in lithology throughout its known distribution in the mountains from the Crowsnest region to the Athabasca Valley. The only variation of importance is the commonly intense dolomitization in widespread localities.

The formation is usually divisible into two unequal units each of variable thickness. The upper, thinner unit is designated the Costigan member which is much more variable in lithology than the lower, thicker and more uniform Morro member.

Lithologically the Costigan is dominantly a limestone, and dolomite is relatively minor in amount. The dolomite is virtually confined to a breccia zone about 15 feet thick in the lower part of the member, and is typically tan to tan-grey, laminated, and tan-grey to medium grey weathering. The limestone units are generally medium to thickly bedded but most are only a few feet thick so that the member consists of a large number of relatively thin, rapidly changing limestone units. Most of the limestones are light grey to medium grey weathering, and the majority of them are black, dense and even textured, and thinly bedded nearer the top. Some of the limestones however are shades of tan and brown with corresponding weathering colors. A few are highly organic and in fact may be termed pellet limestones or pseudo-olitic limestones. Near the middle of the member is a grey weathering, dark grey, even textured, finely crystalline limestone that contains a 6 inch layer of light grey weathering limestone. A thin section reveals that this layer is almost entirely composed of organic fragmental debris (Figure 18) among which are radiolarians, and crinoid columnals.

A characteristic structure of the Costigan member wherever it occurs is what has been referred to as silty laminations. The laminations are present in both the limestone and dolomites and are very conspicuous on a weathered surface for the laminae stand out in varying degrees of relief and may be exceedingly even over long distances. From the examination of thin sections it was found that in this area silt is entirely lacking in the Costigan so that the laminations are not the result of the differential weathering of silty layers. As mentioned previously in connection with the Alexo formation, these laminae are due to very thin layers of dolomite, and should be called dolomitic laminations.

At the north end of Lac des Arcs Ridge approximately 70 feet from the top of the formation a small angular unconformity was observed but the structure is probably only a local development. Black, dense, even textured, medium grey weathering limestone clearly truncates at an angle of 10 to 15 degrees a fine grained, medium to light grey, sugary, thin bedded dolomite. Although no breccia was noted, the structure may be connected with slumping consequent on solution of what is considered to have been primary evaporites.

A typical structure on the light grey weathered surfaces of the black limestones of the Palliser are small projections or welts which are formed by differential erosion. These welts are typical of the Costigan whereas dolomitic mottling is typical of the Morro. Differential erosion of small, irregular bodies, possibly of organic origin, produce very rough surfaces much like coarse sandpaper. The masses increase in size up to 1/4 to 1/8 inches long and project up to 1/4 inches above the weathered surface. Close examination reveals nothing that might be ascribed to fossils though such structures could have been destroyed by dolomitization, silicification or recrystallization. The welts are relatively sharp and hard and may be present on any surface. A second type of differential weathering structure that forms on any relatively smooth surface are elongate, sharp crested, narrow ridges, almost identical to oscilation ripple marks, which occur in groups up to several feet in area. The groups of ridges vary from being almost parallel to perpendicular to the dip of the beds and on large surfaces two groups may trend in entirely different directions. The ridges which may be several feet long, are not necessarily straight, and vary in relief from less than 1/2 inch to more than 1 inch. Some may be attributed to the channeling effect of running water but others because of their orientation cannot be so explained.

The major part of the Morro is a black, very fine-grained to dense, even textured, thick to massively bedded, medium and light grey weathering limestone that is generally barren of fossils and is characteristically mottled from the irregular distribution of dolomite. In the Wasootch Creek area such lithology is repeated in monotonous sequences in all but the lower parts which have been completely dolomitized.

The overall weathering color of the member is light grey when viewed from a distance but medium grey is as common as light grey. These shades of grey are not confined to alternating beds of slightly different lithology for the colors vary from one to the other along strike with no apparent control by lithology. Zones of intense dolomitic mottling give a darker color to the member also.

The mottling of the Morro is perhaps the only character worthy of special note for it characterizes the Morro over hundreds of square miles. Beales (1953) (1956) has described in detail the mottling and depositional environment of the Palliser and the writer has found his descriptions to be adequate and only substantiating evidence for diagenetic origin of the mottling is here presented.

The dolomitic mottling is caused by the presence of irregular, reticulating masses of crystalline dolomite distributed through dense limestone and is observable on a weathered surface because of the resistance of the dolomite to weathering agents. The mottling varies from thin, almost incipient masses through all gradations to the degree where the rock has been almost entirely replaced by dolomite so that mottling is almost indistinguishable. On a weathered surface normal to the bedding the mottling often defines and parallels the bedding because it occurs typically as relatively thin, widespread layers from which irregular protuberances extend in all directions (Figures 19, 20, 21). Characteristically the mottling is present not evenly throughout a great thickness of strata, but in zones of intense replacement which may vary from less than 1 foot up to 10 or 15 feet in thickness (Figures 9, 10), which are separated by zones of limestone containing much less dolomite or, completely barren of dolomitic mottling. At some horizons however, the distribution of the mottling is relatively even vertically and the pronounced layered type is wanting (Figures 20, 21). Bedding planes containing dolomitic mottling (Figure 22) generally present a uniform surface covered with highly irregular reticulating masses of dolomite with no constant definable shape. On weathered surfaces the dolomite may be lighter than the unreplaced limestone but usually it is much darker than the light to medium grey weathering limestone.

In thin section the dolomitic areas are easily distinguished from the limestone by means of their differences in crystallinity. The limestone is microcrystalline to cryptocrystalline whereas the dolomite consists of a mossaic of brown colored, euhedral rhombs of fine to medium grain. The limestone-dolomite contact varies from extremely sharp to gradational and diffuse though the latter type is most common. In some horizons the boundaries are commonly formed by stylolitic seams (Figure 24), but usually only on one side of an area of dolomite, the other side being diffuse. These seams may develop because of a difference in hardness between the limestone and dolomite when under pressure, or may be due to the growth pressure of the dolomite crystals. Where microfossils and shell fragments are present the dolomite may be conspicuously selective, and small fractures sometimes appear to have controlled some replacement. The dolomite often truncates such primary structures as the recrystallized shells of fossils, or very thin layers of fine pellet limestone for which the dolomite often seems to have a great affinity.

The origin of the dolomitic mottling is generally ascribed to a diagenetic replacement process, and although the details are far from understood a considerable amount of evidence favors this origin. Perhaps one of the strongest arguments in favor of a diagenetic or syngenetic replacement is the vast scale of replacement in thin layers virtually continuous for hundreds of feet. Rather definite evidence for an early origin of the mottling was found in limestones of Cambrian age in the northeastern corner of the map area. Figures 10 and 11 picture what are interpreted as flowage structures in intensely mottled layers of dolomite which, significantly enough, are absent on either sides of the dolomitic horizon so that small scale faulting cannot be postulated for their origin. These structures must have formed while the sediment was unlithified but already partially replaced by dolomite, and still on the sea floor. The dolomite layers may represent primary layers of dolomite, or more likely are the result of reaction and replacement of the calcareous sediment with magnesian carbonates in solution in the sea water. The concentration of these salts may have fluctuated periodically above and below a critical amount necessary for reaction, so that layers of dolomitized and unreplaced limestone alternate in sequences of varying thickness.

Dolomitic mottling in the Morro member may be readily examined in a large exposure beside the highway at the north end of Lac des Arcs Ridge.

The lower part of the Morro member in this region is variously dolomitized and at some localities the rock cannot be distinguished from the black dolomites of the Cairn formation. On Mt. Lorette the lower approximately 100 feet is almost completely dolomitized. The dolomite is largely very dark to medium grey weathering, very dark grey to black, generally even textured and medium to very fine grained. Parts of the dolomite are laminated, and in some areas dolomitic mottling appears to have progressed to the point where only small vugs represent the unreplaced limestone areas. The lowermost 6 inch bed of the Palliser on Mt. Lorette is a thinly bedded, black, finely banded, dense, non-silty limestone which is separated from the Alexo by a bedding plane surface.

PALEONTOLOGY AND AGE: At some localities the Palliser is richly fossiliferous but the fauna is usually confined more to the Costigan member where it occurs in zones. Thin but widespread zones of brachiopods may be present in the Morro and they are rarely found in the mottled limestones. The uppermost beds of the Costigan member are characteristically richly fossiliferous, brachiopods being the most abundant, but the specimens are difficult to recover. In the Wasootch Creek area fossils are conspicuously absent except on the uppermost surfaces which are often covered with many brachiopods, gastropods, bryozoa, and crinoid columnals.

McConnell (1887) collected a fauna from the Palliser which he believed to contain both Devonian and Carboniferous elements and consequently did not state precisely the age of the formation. Shimer (1913) was the first to present evidence suggesting the Upper Devonian age for the Palliser although he apparently assigned the formation only to the Devonian. Kindle (1924) appears to have been the first to state definitely that the Palliser is Upper Devonian in age. Walcott (1924) also dated his Pipestone formation as Upper Devonian on the basis of a number of corals. Since this time the identification of a great many fossils has definitely established its Upper Devonian age, although Fox (1954) has suggested that some doubt has been cast upon this designation, and that the Mississippian-Devonian boundary may actually lie somewhere near the base of the Costigan.

The faunal lists from the Palliser are dominated by brachiopods such as Athyris, Camarotoechia, Cyrtia, Leiorhynchus, Productella, Schizophoria, Cyrtosipirifer, Crytiopsis, and Spirifer most of which are decidedly Devonian.

PALEOZOIC

Mississippian

Exshaw Formation

NAME AND HISTORY: McConnell (1887) was perhaps the first to make note of the black fissile shales above the massive cliffs of Palliser limestone and below the buff weathering shales and siltstones of the Banff formation. He included them in the overlying Lower Banff shale and described them from "... a point about two miles up a small creek, which joins the Bow from the north a short distance above the Bow River gap" (p.18D) which sounds very much like the locality on Jura Creek, the type locality proposed by Warren 51 years later. (Warren 1937).

THICKNESS: The Exshaw formation is remarkable for its widespread distribution and persistence regardless of thickness, which varies from extremes of 6 inches to about 60 feet. It is usually less than 50 feet thick in outcrop and in the subsurface of the Plains has come to be regarded as one of the principal stratigraphic markers, even though its thickness is commonly ½ to 1 foot.

Warren (1937) gives a thickness of less than 30 feet for the type section, while others give 34 and 33 feet. Beach (1943) measured 34 feet about ½ mile west of the Exshaw cement plant. Beales (1950) measured 35 feet, presumably on the north face of Mt. Rundle. DeWit and McLaren (1950) report a thickness of 43 feet on Sulphur Mountain while on Mt. Norquay, Beales (1950) gives 55 feet.

In the Kananaskis-Bow Valleys area Clark (1949) included an overlying 30 foot bed of limestone in the Exshaw formation, on the argument that it was from the base of the limestone that both he and Warren (1937) collected the cehpalopod fauna, and since they both assigned a late Devonian age to the Exshaw, he proposed to subdivide the Exshaw into an Upper

Limestone member and a Lower Shale member. The black shale member is 30 to 40 feet in this area and with the included limestone totals 60 to 70 feet.

In the Wasootch Creek area an excellently exposed section was measured on the north side of the Kananaskis River in a gully on the south side of Heart Mountain and was there found to total 22 feet.

Eastward on Moose Dome the Exshaw is 30 feet thick (Mountjoy 1956), and at Mt. Head it has thinned to 12 feet. Southwestward at Beehive Pass it is 21 feet thick (Norris 1958). The formation has been traced northward to Wapiti Lake where it varies from 0 to 32 feet.

GENERAL CHARACTER AND DISTRIBUTION: The widespread distribution of such a thin, incompetent unit as the Exshaw shale is rather remarkable, for it has been found over most of the area of the Eastern Rocky Mountains from Wapiti Lake to Crowsnest Pass, and eastward through the Foothills into the Plains where it is present throughout most of Alberta and into southeastern Saskatchewan. It has been correlated by several writers with thin black shales between the Devonian and Mississippian of Montana, and with the Bakken of the Williston Basin. At one time it may have been even more extensive than we know it today, since post-Paleozoic erosion has removed the Mississippian and part of the Devonian rocks in northern and eastern parts of Alberta and Saskatchewan.

The formation erodes so easily that in the maturely disected Rocky Mountains complete and readily accessible exposures are rare, and even partial exposure is uncommon. Outcrops are almost always situated in depressions periodically occupied by streams and mostly covered with talus and stream gravels. The formation weathers as a unit with the Banff but the Exshaw usually erodes more readily and tends to accentuate the cliff-forming nature of the Palliser. In the Kananaskis Valley the topography correlates perfectly with rock resistance on Mount Lorette, the north end of Lac des Arcs Ridge and on Heart Mountain (Figures 5,6,7).

On the Exshaw Fault Block (southern end of Heart Mountain) where the formation was measured, the massive buff weathering limestone of the lowermost Banff which Clark (1949) included in the Exshaw, is very well developed and because of the color contrast between the light grey Palliser, black Exshaw, and buff limestone forms a useful marker horizon when the Exshaw is covered. The formation is excellently exposed at the type locality for the area where over a distance of perhaps 10 to 20 feet both upper and lower contacts are well defined. Throughout most of the gully however, the shale is covered with talus and gravel.

LITHOLOGY: The Exshaw shale is persistent not only in its distribution but in its general lithologic composition. Typically it consists of black, fissile to thin bedded, characteristically rusty-brown weathering shale which is usually very pyritic at the base and is distinguished from the Banff by the absence of calcareous material. Silt is often distributed throughout but a highly silty zone is common at the base.

In the Wasootch Creek area the upper 6 feet is fissile, soft black shale that weathers to small, thin flakes and chips. The top few feet are calcareous and grade up into a 1 foot bed of thinly bedded, black, fairly hard, calcareous shale of the Banff, which in turn grades into the hard, black, resistant, buff-brown weathering, argillaceous limestone of the lowermost Banff. All but the remaining 6 inches at the base is a black, even textured, thin to very thinly bedded shale, with shale laminations between thicker layers. A rusty stain throughout and many sharp, well defined, smooth plane fractures typify the formation. It is well bedded and no sedimentary structures were observed. This 16 feet of the formation is well indurated and fairly hard.

The lowermost beds totalling 6" are perhaps the most interesting part of the formation for it is these beds which initiated the entire Banff cycle of clastic deposition. It was discovered, however, that some shearing has taken place at the lower contact so that exact interpretation of the depositional history of the lowest beds is not possible.

Immediately below the 16 foot unit of shale is a 2 inch zone of shale which contains a large amount of pyrite in the form of laminae up to $\frac{1}{4}$ to $\frac{1}{2}$ inch thick. One layer $\frac{1}{2}$ inch thick contained ripple-like ridges which in cross-section indicated flowage, and on a bedding surface were long, straight, narrow truncated ridges. This pyrite layer may be arbitrarily taken as the base of the Exshaw since directly below it the shale becomes calcareous and crinoidal and appears to grade down into the Palliser.

Below the pyrite layer two lithologic types are present in a zone only a few inches thick. The first type consists of medium to coarsely crystalline, recrystallized crinoidal limestone, which contains many thin stringers of black, non-calcareous shale with small, scattered crinoidal fragments. The relative amounts of limestone and shale vary so that either an argillaceous limestone or highly calcareous shale is present. Thin sections reveal that the shale stringers contain appreciable amounts of fine, angular silt, probably mostly quartz and feldspar, and some calcite grains. Some of these calcite grains were partially and irregularly silicified and pyritized prior to their final deposition as indicated by the fact that chert and pyrite end sharply and smoothly at grain boundaries and the adjacent matrix is unaffected by secondary replacement. The calcite grains contain large and irregular masses of pyrite while small rounded to angular silt-size grains of pyrite occur quite abundantly with the quartz and feldspar grains in the shaly matrix. A few grains consists entirely of pyrite and chert and it was not determined which had replaced the other.

Below this shale-calcarenite unit the second lithologic type is a fine sandstone to siltstone consisting of fine angular grains of quartz and feldspar, with a small amount of argillaceous and calcareous cement. This fine sandstone is highly pyritized in irregular patches and considerable amounts of pyrite are scattered throughout. In such patches the pyrite equals the grains in amount and it is not possible to determine definitely whether the pyrite has replaced susceptible areas of some material other than sand or whether it has replaced the sand or silt grains at susceptible points. Of the grains present, many of the boundaries have been slightly replaced by the pyrite giving the grains very angular and sometimes irregular outlines.

Definite evidence of shearing was found in parts of the shaly crinoidal limestone directly below the pyrite layers. Many of the calcite grains have been obviously rotated and the shale matrix has sheared and 'flowed' around most of the grains. The majority of the grains have been drawn out into augen, some are bent, and all are subparallel. Good evidence of the shearing of this rock is afforded by the growth of fibrous quartz on the edges of some of the contained pyrite grains, as seen in thin section. Knopf (1929) referred to such halos as feather quartz, and Pabst (1931) illustrates similar fringes called pressure shadows. Pabst describes feather quartz that was best developed in smooth slates on the facese of pyrite cubes. The growths are always widest in the direction of elongation in the plane of schistosity in metamorphosed rocks. The pressure shadows appear on one or both ends of the pyrite crystals and not infrequently narrow fringes occur entirely surrounding the pyrite. Quartz was found to be the dominant mineral in forming the shadows, and the axes of elongation of the grains is invariably oriented normal to the pyrite faces. Pabst believed that the shadows are the result of extension in the slate in the plane of schistosity which tended to pull the matrix from the sides of the pyrite porphyroblasts, the potential opening being filled continuously with quartz. The feather quartz in the shale-calcarentie rock is associated only with the larger pyrite masses which are not cubic crystals but irregular clastic grains. The pressure shadows are only a minor development on a few of the grains but are typically confined to the sides of the grains directed toward the direction of elongation of the calcite grains. Except for one grain the growths are almost entirely absent from surfaces normal to the direction of movement. The orientation of the long axes of the quartz seems to be controlled more by the direction of extension and shearing, than to the direction and orientation of smooth faces of the pyrite grains. One grain shows feather quartz and granular quartz growths parallel to the side of the elongated grain but parallel to the direction of shearing. On the sides of the large pyrite grains the quartz axes are not normal to grain faces but are orientated parallel to the direction of shearing.

Although the evidence for shearing and movement is conclusive in this very thin zone, the remainder of the formation has in no obvious manner been sheared or contorted.

PALEONTOLOGY AND AGE: The Exshaw shale was considered a basal unit of the Banff formation and given a Mississippian age until Warren (1937) collected fossils, discovered by J.A. Allan on Jura Creek, that were subsequently identified by Dr. A.K. Miller as ammonites and nautiloids among which was the genus Tornoceras cf. T. (T) uniangulare (Conrad) of Devonian age. The other cephalopods were considered to have a Devonian aspect. From this evidence, apparently quite conclusive, Warren placed the Exshaw without hesitation in the uppermost Devonian and erected it as a new formation. Just above the Exshaw Warren collected a typical Kinderhook fauna from the Banff and on the basis of this evidence placed the Mississippian-Devonian contact at the top of the Exshaw. Clark (1949) collected Tornoceras cf. uniangulare from the basal 2 feet of a 30 foot basal Banff limestone unit and also assigned the Exshaw shale plus the limestone unit to the Upper Devonian.

Crickmay (1952) explains that because the goniatite identified as Tornoceras cf. uniangulare occurs stratigraphically higher than the Cyrtiopsis zone of the upper Palliser it cannot belong to the genus Tornoceras which had become extinct by early Upper Devonian time. Crickmay would identify the specimens as Aganides cf. A. discoidalis Smith and dates the formation as earliest Mississippian. Fox (1951) was prompted by Crickmay's unpublished evidence to revise his earlier opinions, and concluded that the top of the Devonian might lie within the Palliser, thus necessarily making the Exshaw Mississippian in age.

More recently C.B.Pamenter (1956) collected a varied fauna from a pyritic siltstone lens in the basal Exshaw which contained the goniatite Imitoceras, a form not previously reported from rocks older than the Mississippian in North America. This evidence suggests a Mississippian age for the Exshaw. Baadsgaard and Folinsbee (1959) give as an absolute age for the Exshaw, at least 267 m.y.

At this point the problem of the age of the formation stands, with conflicting evidence for and against a Mississippian age. The general practice in such a case is to rely on lithologic evidence, and in the case of the Exshaw, because it is so closely associated with the Kinderhook by reason of its shale lithology, it is placed in the Mississippian Kinderhook. This practice is followed in the Wasootch Creek area.

Only two fossils were taken from the Exshaw by the writer, and they were taken from the sheared zone at the base of the formation. One of the fossils is a Tentaculites sp. but a specific determination was not made. The other is tentatively identified as a fish tooth (Figure 25)

PALEOZOIC

Mississippian

Banff Formation

NAME AND HISTORY: The Lower Banff shale of McConnell (1887) was first amended by Kindly (1924), and the name in use today was adopted by Shimer (1926). To Shimer goes the credit for establishment of the Banff formation, for until 1926 no section had really been designated a type section. Although Shimer did not name a type locality it is presumed to be on Mount Inglismalidie. Beales (1950) however, contends that while Shimer's sections at Lake Minnewanka have priority, the Banff sections referred to by Kindle (1924) are considered preferable as type sections because Kindle did designate the north end of Mount Rundle as the type locality for both Banff and Rundle formations. It is also argued that Shimer, by adopting Kindle's terms, automatically related his sections back to the Banff area.

THICKNESS: The Banff formation is distributed throughout the Front Ranges, Foothills and in the Plains regions, and from the Banff area thins northward, eastward and southward.

The Mount Rundle section contains the greatest thickness of Banff recorded, 1,458 according to Beales (1950), and 1,408 feet according to Warren (1927). On the next fault block to the west Fox (1955) reports 1,325 feet and Fox (1953) 1,388 feet for the Sulphur Mountain section. The Minnewanka section measured by Shimer (1926) is about 1,200 feet thick. In the vicinity of the Three Sisters Mt. on the west side of the Cascade Coal Basin Clark (1949) measured 1,350 feet and eastward on the easternmost range he measured 950 to 1,050 feet. The Mt. Lorette section measured by Beach (1943) totalled 819 feet, while in the Moose Mountain region Beach gives 575 to 600 feet for the thickness.

In the Wasootch Creek area a hurriedly measured section on Lac des Arcs Ridge was found to be approximately 900 feet.

DISTRIBUTION AND GENERAL CHARACTER: The Banff formation as is the entire Mississippian, a typical Front Range unit, occurring most commonly in the Front Range sub-province from at least as far north as Wapiti Lake (Laudon et al 1949) to as far south as Montana and Wyoming, and in general from the Front Range-Main Range boundary eastward under the Plains. Throughout this large area it retains its general lithologic character of shale, limestone, and chert.

In the Wasootch Creek area the formation is readily divisible into three members (Figure 5), the upper and lower of which are non-resistant and weather readily into gentle slopes of dark grey and buff talus. The middle member is much more resistant and forms a well-marked prominence in the centre of the shaly talus covered slopes above and below. The upper member is a dark grey weathering, black, argillaceous limestone that is slightly more resistant than the lower member but nevertheless outcrops poorly through talus covered slopes. The middle member contains thick limestone and dolomite beds which contain most of the chert in the formation. Hard, resistant zones alternate with weaker, which upon weathering produce many small ledges. The entire unit weathers to a light or medium grey color. The lower member is the most easily eroded unit for it consists of very thinly bedded (Figure 26), buff weathering, generally calcareous shale and siltstone, and is the more clastic part of the formation.

The Banff formation represents a constantly changing depositional environment. The lower member is highly clastic and slightly calcareous; the middle member is predominantly hard, cherty limestone and dolomite with almost no clastic material; the upper member consists of highly fossiliferous, argillaceous, limestone which becomes highly calcareous near the top and grades quickly into the Rundle

The Banff formation is an incompetent, poorly resistant unit that is characteristically expressed topographically as a recessive, bench-like zone between the massive, cliff-forming Rundle and Palliser. It is on ledges such as these, particularly where the headwaters of two adjacent streams form a low, rounded saddle that almost perfect sections are located. This recessive nature coupled with the recessiveness of the Upper Rundle adds to the prominence of the Lower Rundle.

LITHOLOGY: The following section was measured on Lac des Arcs Ridge. The lower member of the Banff formation is about 310 feet thick and weathers to a very conspicuous buff color. The lower 120 feet consist of buff weathering, black, mostly silty shale, with one 25 foot zone of argillaceous limestone, that varies from thin to very thinly bedded with some laminated and occasionally fissile zones. The bedding surfaces of the lower 30 feet bear small, irregular current irregularities, and is generally more thickly bedded than that above. At the northernmost end of Lac des Arcs Ridge the lower 15 feet consist of thick bedded, dark, hard, brown weathering limestone. The major part of the upper 190 feet is mostly a medium grey weathering with some buff, very thinly bedded to platy laminated, evenly bedded, black, even textured, calcareous shale, that is mostly block jointed. The lower 20 feet contain numerous white, straight, calcite veins. The upper 30 feet contains thin and medium beds of black, dense limestone, slightly argillaceous, varying to highly argillaceous limestone in thin bedded zones. Also present are limestone beds up to 1½ feet thick bearing numerous ripple marks or irregular bedding surfaces, interbedded with calcareous and silty shale in beds 4 to 6 inches thick.

At the head of Porcupine Creek the Lower Banff member consists almost entirely of calcareous siltstone and silty limestone very similar to the Triassic Sulphur Mountain. On the saddle where it is well exposed it forms low cliffs of buff-brown weathering, thin to very thinly and evenly bedded, highly calcareous, dark grey to tan-brown siltstone. The grey siltstone is commonly finely and evenly laminated, due to compositional and textural differences. The lighter colored beds have a higher proportion of limestone and less silt. Interbedded rather regularly throughout are thin beds of black to very dark grey and slightly brownish, very fine grained, silty, hard limestone. The silt of the member is angular, and argillaceous material is fairly abundant.

The middle member of the Banff is approximately 250 to 300 feet thick and is rather variable in lithology. The lower 80 feet is black, dense, even textured limestone, medium to very thinly bedded, and light to dark grey weathering. From this horizon upwards silica becomes common and accounts for some of the resistance of the member. The dolomite present in the member is light grey weathering, thinly and evenly bedded, dense to fine grained and even textured, black to medium and dark grey. Much contains chert or dolomitic chert in the form of nodules, bands and irregular shaped lenses. Approximately 40 to 50 feet from the top of the member is a bio-stromal layer 2½ feet thick that consists almost entirely of crinoid fragments. It is very coarse, light grey and light grey weathering, and thins rapidly laterally to be replaced by a finer, light grey limestone, Above this unit are thin to medium bedded, fine grained to dense, even textured limestones, some of which are crinoidal.

The uppermost beds of the middle member are thin bedded, grey-brown weathering, calcareous shale, above which a similar lithology becomes very thin to medium bedded for 5 feet. From this unit upwards the remainder of the formation is thin bedded, black, calcareous shale or argillaceous limestone containing abundant crinoid columnals and brachiopods. This constitutes the upper member which is approximately 300 feet thick. In the lower 50 feet very thin beds are common. The uppermost beds become resistant and dark weathering and clearly grade into the lower Rundle. The highest unit is a very fine grained to dense, hard, thickly bedded, brownish black, brown weathering dolomite, with dark grey, medium crystalline, medium to dark grey weathering limestone. This lithology grades over a distance of about 1½ feet into dark grey to black, medium crystalline, grey weathering, crinoidal limestone of the lowermost Livingstone.

PALEONTOLOGY AND AGE: The Banff formation is usually highly fossiliferous but not uniformly throughout, the fauna being typically confined to the central and upper parts.

In the Banff area the Middle member contains mostly brachiopods which date the unit as distinctly Kinderhookian, although some of the forms seem to indicate a higher horizon (Warren 1927). In the Eastern Ranges of Jasper Park the upper Banff is richly fossiliferous and contains a Kinderhook fauna (Allen et al 1932). Douglas (1958) and Douglas and Harder (1956) state that the Banff fauna from the Mount Head area is of Kinderhook age. In the Minnewanka section Shimer (1926) collected a large number of species identical with those of the Kinderhook of the Mississippi Valley. In the Athabasca Valley Brown (1952) found the Banff to be entirely Kinderhook in age.

In Bow Valley, Sunwapta Pass and at Mount Coleman, Osage faunas have been collected from the upper beds of the Banff formation (Harker 1954). In the Banff area Warren (1927) collected a fauna from the uppermost beds of the Banff which had a Kinderhook aspect though not so well marked as the fauna of the lower middle horizon. Beach (1943) collected forms from the upper horizon of the Banff in the Moose Mountain area which were also indicative of a somewhat higher horizon than the fauna found in the middle of the formation. Nelson (1958) believes that the Banff is Kinderhook and in part Osage in age.

Brachiopods constitute the bulk of the fauna and the following genera are typical: Camarotoechia, Cliothyridina, Composita, Dictyoclostus, Spirifer, Productus, Reticularia, Linoproductus.

In summary it may be said that the lower member or lower parts of the Banff formation are characteristically barren of fossils and that the first recognizable fauna occurs in the middle parts where a definite Kinderhook age is shown. The fauna of the upper parts indicate a higher horizon and often many elements suggest and in fact prove an Osage age. (Nelson unpublished manuscript).

PALEOZOIC

Mississippian

Rundle Group

NAME AND HISTORY: The Rundle Group was originally called the Upper Banff limestone (McConnell 1887) and was undifferentiated from the Rocky Mountain formation. E.M. Kindle (1924) proposed the name Rundle, and established the type section at the northern end of Mount Rundle at Banff (Figure 1). The Rundle has been divided into many units or members mainly for use in the subsurface, but the twofold division by Douglas (1953) into an upper Mt. Head and lower Livingstone formations has been the only terminology adopted for the Wasootch Creek area because the two formations are so well developed. With better exposure however, finer divisions could easily be made, and the Mt. Head subdivided into Mt. Head and Etherington (Nelson 1958, Douglas 1958).

THICKNESS: The thickness of the Rundle Group is, like most of the Paleozoic formations of the Front Ranges, much greater in the western regions than in the easternmost ranges, Foothills, and Plains. At the type locality Warren (1927) reports a thickness of 2,431 for the group and Beales (1950) measured a total of 2,368 feet. The Rundle section at Lake Minnewanka measured by Shimer (1926) totalled 2,100 feet. In the area between the Bow and Kananaskis Rivers Clark (1949) reports a westward thickening from 1,700 feet in the easternmost part of the range to 1,900 feet in the west. No section of Rundle was measured by the writer, but a thickness of 1,900 is considered to be very close to the thickness of the Rundle on Lac des Arcs Ridge. On Moose Dome Beach (1943) recorded a thickness of 1,350 to 1,400 feet, and Douglas (1953) reported 1,215 feet. Twenty miles northeast of Moose Dome in the subsurface of the Jumpingpound Region, Douglas (1953) gives 1,070 feet for the Rundle.

DISTRIBUTION AND GENERAL CHARACTER: The Rundle Group is a readily recognizable unit in the Eastern Rocky Mountains and Foothills from the Crowsnest Region to and beyond the

Athabasca River, for it retains its general lithologic character throughout. In the southern Rockies it is present throughout the Front Range, and in the outlier ranges in the Foothills it is often the dominant unit. Farther eastward in the Plains it is extensively developed but considerably thinner due to pre-Jurassic and pre-Cretaceous erosion.

The Rundle Group in the Kananaskis-Bow Valley regions is readily divisible into two distinct formations, the upper, thinner Mt. Head, and lower, thicker Livingstone. The Mt. Head formation is itself divisible into two subequal divisions, the lower of which is very dark, argillaceous and bituminous, non-resistant limestone, whereas the upper part is typically siliceous, silty and cherty, dense, even textured, hard, generally dark grey, buff weathering limestone, more resistant to weathering than the lower part. In contrast the Livingstone formation is highly resistant, light grey weathering, thick to massively bedded, light grey to dark grey, fine to coarse grained, somewhat cherty, crinoidal limestone.

The Rundle is well exposed on Lac des Arcs Ridge and is an excellent example of perfect correlation of rock hardness to topographic expression. In fact Mounts Lorette and McDougall and all of Lac des Arcs Ridge owe their prominence to the Rundle Group (Figures 4, 5). The Livingstone dips steeply westward and constitutes the backbone and highest parts of the ridge. The dip shallows quickly towards the axis of the Mt. Allan Syncline, but more by reason of the anticlinal flexure on the syncline limb which is reflected at the surface by the Mt. Head in its generally shallow dips. For purposes of measurement the Livingstone is fairly well exposed in the second creek valley immediately north of Boundary Cabin and it was here that the Rundle was examined. In this valley however the weaker beds in the lower member of the Mt. Head were not exposed nor was the upper part of the member exposed because of the depth of erosion. A good section of Rundle is exposed however on the southern end of Mt. Lorette.

The Livingstone-Mt. Head contact was not examined in detail but from a distance the contact is very sharp and easily recognized. The Livingstone-Banff contact also lends itself readily to mapping purposes for although the contact is gradational, it is over a narrow zone, and the differences in rock resistance above and below the contact are highly contrasting.

The upper contact of the Rundle with the overlying Rocky Mountain formation is much more difficult to see. In the Wasootch Creek area the upper Mt. Head is similar in its lithology and weathering characteristics to the lower Rocky Mountain and from a distance it is almost impossible to pick the contact with accuracy. At the base of the Rocky Mountain sampled section, vegetation concealed the contact and relationships were underterminable. G.O. Reasch (1956) has given rather convincing evidence of pre-Rocky Mountain erosion. P.S.Warren (1956), Warren (1927), Beales (1950) and Norris (1958) describe conformable and continuous sequences.

It seems then that until the age of the lower part of the Rocky Mountain can be definitely proven, determination of the conformable relationships on the basis of lithology only will not be successful.

LITHOLOGY: The Mt. Head formation which comprising the upper one third of the Rundle Group, is readily divisible into two distinct members on the basis of their contrasting lithology. The two units are correlative with others of various names in other areas but are here simply designated as the upper and lower members. Exposure of the Mt. Head was not sufficient to allow measurement or detailed sampling and although the upper part of the upper member was absent representative samples were collected from most of the member. The lower member consists of alternating resistant and non-resistant units and reference can only be made to the resistant, outcropping units.

The upper member is typically a hard, dense, silty laminated, cherty, very even textured, generally dark grey, limestone that is greenish in some units. Thin zones of pale green calcareous shale are widespread but not abundant, and most of the limestone seemed to be slightly argillaceous.

A high percentage of silica characterized this member and it is present in three forms: as silt evenly distributed through a bed, or concentrated in laminated bands, as micro-crystalline silica distributed evenly through the limestone, or in the form of chert nodules and bands. The chert is present in a great variety of shapes and colors and both secondary or replacement and primary or syngenetic types seem to be present (Figures 27 - 30). Although the uppermost parts were not seen, except as scattered outcrops, the percentage of chert appeared to increase greatly. The silt in the form of laminations was abundant only in one thick zone near the middle of the member.

Most of this member is thickly bedded and weathers to a buff or dark grey color, the buff probably due to the argillaceous content. Relative to the lower member it is quite resistant and in the small valley where it was examined formed canyon-like cliffs up to 30 feet high.

Fossils are only sparingly present and those seen were poorly preserved. Crinoidal fragments were conspicuously absent.

The lower member of the Mt. Head differs markedly from the upper resistant, siliceous member. It is entirely bituminous and argillaceous limestone and consists of many alternating resistant and non-resistant units. The resistant exposed units consists almost entirely of black, very fine grained, even textured, argillaceous, bituminous, limestone which on a fresh fracture is dull black with small to medium sized, clear crinoid ossicles and fragments randomly distributed throughout which give a sparkle to a fresh fracture. There are occasional beds of medium crystalline, crinoidal, grey limestone.

The lowest bed exposed consists of a black, very fine grained, brown-grey weathering, highly organic limestone composed of medium to coarse crinoidal fragments, organic pellets, and many recrystallized foraminifera and a few radiolaria. The uppermost unit of the member is a medium to coarsely crystalline crinoidal limestone, dark grey, grey to buff weathering, that seems to mark the upper part of the lower member and lower part of the upper member. Throughout this member both chert and silt are conspicuously absent. It may be said in summary that the lower member is related, by reason of the presence of crinoidal material, to the Livingstone, whereas the upper member is more closely related, because of the common occurrence of silt and chert, and lack of crinoidal debris to the Rocky Mountain cycle of deposition.

The Livingstone formation is the highly resistant unit in the Rundle which is typified by the presence of much crinoidal material, some chert and light grey weathered surfaces. Its thickness in this area is approximately 1,300 feet and similar to the Mt. Head it is divisible on a lithologic basis into an upper member occupying the upper one third of the formation, and a lower member representing the lower two-thirds.

The lower member, as previously mentioned, grades quickly up from the Banff formation and throughout most of its thickness is relatively uniform in composition. It consists mostly of medium grained crinoidal limestone, but fine and coarse crinoidal limestone is not uncommon, in fact some

some thin beds are almost wholly crinoidal with fragments up to .3 inches long. Within this lower member the crinoidal limestone gives way upwards to either fine grained crinoidal limestone or essentially non-crinoidal limestone which is light grey, even textured, light grey weathering separated by a few very wide zones of crinoidal limestone measurable in tens of feet. In the lower one quarter of the member the limestone is dark grey to very dark grey whereas in the upper three quarters it is lighter grey. The color of weathered surfaces are not always representative of the color of the rock, and it varies from dark to light grey.

Within the Livingstone formation the chert is mostly confined to the lower parts where it is common but not too abundant. It was noted that in the beds where chert lenses and nodules were present, crinoidal fragments were almost always absent and the rock instead consisted of very fine to almost dense even textured limestone. This may suggest that the chert is primary in origin and that certain concentrations of silica were intolerable for crinoids because crinoidal limestone is present above and below the fine, chert-bearing limestone. This relationship was also reported by Warren (1927) from the Banff area.

The upper one third of the Livingstone, is also entirely limestone which is medium to fine to very fine grained dark to very dark grey, medium to light grey weathering, with fine to medium grains of clear, crinoid fragments scattered throughout but not forming the bulk of the rock. The irregularly distributed clear crinoid fragments resemble those found in the lower member of the Mt. Head formation. Chert is occasionally present in this member but not nearly so much as in the lower member.

The bedding of the Livingstone as viewed from a distance appears distinct and even. Closer inspection, however, reveals bedding that is not particularly distinct, but somewhat massive and sometimes rather difficult to trace in weathered outcrops. Thick to medium bedding is the most common though parts may be very massive.

PALEONTOLOGY AND AGE: The exact age of the upper parts of the Rundle Group has been a disputed question since Dowling (1907) subdivided the Upper Banff limestone and assigned to it a Carboniferous age. The uppermost beds have been considered both Pennsylvanian and Mississippian in age, and even today considerable disagreement exists as to which is correct. The general practice is however, to include all Mississippian strata in the Rundle and all post-Mississippian beds in the Rocky Mountain formation. The problem is thus resolved to whether the uppermost beds are Chesteran or Meramecian in age. Those who have worked with this problem believe that good evidence exists to indicate that the four subdivisions of the mid-continent Chester, Meramec, Osage and Kinderhook are represented in the Mississippian formations of the Alberta Rocky Mountains. Laudon (1948) however, insists that the Osage series is absent and that a very substantial unconformity exists within the Rundle.

A recognizable assemblage of Osage fossils occurs above the Kinderhook and there seems little doubt that all of the Livingstone is Osage in age. G. O. Raasch (in A.S.P.G. 1954) states that the upper part of the Livingstone at Tunnel Mountain yielded late Osage Keokuk faunas and earlier Osage faunas from the lower part (Warren 1927). Raasch (1956) correlates the Livingstone with the Osage in the Highwood Pass region.

Above the Osage fauna is a relatively unfossiliferous interval and the next recognizable fauna is probably fairly late Meramecian. Raasch (1956) correlates strata of Meramecian age in the Highwood Pass area with the Mt. Head formation, and Douglas and Harker (1956) also place the Mt. Head formation in the Meramecian. H.W. Shimer (1926) assigned the upper two thirds of the Rundle to the Pennsylvanian and the lower one third to the Mississippian, but Crickmay (1955) remeasured Shimer's Minnewanka section and concluded that he had misidentified certain species and he believes that no doubt exists of the late Mississippian age of the uppermost Rundle. Harker (1954) believes that on the basis of the contained Spirifers it seems likely that all or part of the Chester is represented at the top. P.S.Warren (1927) found the Rundle to be generally sparsely fossiliferous except for the upper 400 feet which carried a fauna that was shown to be predominantly Mississippian with certain Chesteran affinities. Douglas and Harker (1956) have proposed that the Rundle occupies only strata of

Osage and Meramec age and that rocks of Chester age are Rocky Mountain. Raasch on the other hand would include all of the Rundle in the Osage, Meramec and Chester, but to the strata of Chester age he would give the name Tunnel Mountain.

R.J.W.Douglas (1950) subdivided the Rundle into members A, B, C and D, the latter of which he has correlated with the Tunnel Mountain member of the Rocky Mountain (Warren 1927), and the Etherington member of Douglas (1953). Members C and B are correlative with the Mt. Head formation, and member A with the Livingstone. D.K.Norris (1958) on the other hand had subdivided the Rundle at Beehive Pass into a Livingstone, Mt. Head and Etherington formations, the latter of which seems to be correlative with the upper member of the Mt. Head formation at Wasootch Creek.

The Rundle has yielded a large number of fossils but they are distributed in zones throughout and the inter-fossiliferous zones may be completely barren of identifiable fossils. In the lower parts Productus burlingtonensis, Spirifer centronatus, S. logani, S. rundlensis, and Reticularia pseudolineata are brachiopods characteristic of Burlington-Keokuk ages of the Osage (Warren 1927). D.K. Norris (1958) collected many corals of Meramecian age from the upper half of his Mt. Head formation. These include species of Faberophyllum, Koninckophyllum, Lithostrotion, and Syringopora. About 400 feet from the top of the Rundle at Banff (Warren

1927) collected Lithostrotion whitneyi, L. pennsylvanicum and L. banffense and correlated the horizon with the middle Meramecian St. Louis Limestone. Above the Lithostrotion reef, fossils were plentiful and Warren's list includes Pentremites, Fenestrella Productus, Rhynchopora, Spirifer, Composita, Igoceras which because of the association of forms he correlated with the Chester.

D.K.Norris (1958) placed the upper contact of the Rundle at the highest beds containing the Chesteran brachiopods Spirifer leidyi, and S. increbescens. C.H.Crickmay (1955) considers Spirifer bifurcatus and S. leidyi as uppermost Mississippian index species.

S.J. Nelson (1958) on the basis of brachiopods has zoned the Mount Head and Etherington formations into eight zones which indicate that the Mount Head formation is mainly Meramecian and the Etherington formation mainly Chesterian in age. Nelson (unpublished manuscript) has also zoned the entire Mississippian into 12 divisions on the basis of Lithostrotonid corals.

From the evidence gathered in the past few years there seems little doubt that strata of Osage, Meramec and Chester age are present in the Rundle Group and whether beds of Chester age are included in the Rundle or Rocky Mountain will depend more on the lithology than on the included fauna. The formation here designated as Mt. Head correlates with the Mt. head and Etherington formations of Nelson (1958) and Douglas (1958).

PALEOZOIC

Permian

Rocky Mountain Formation

NAME AND HISTORY: The name 'Rocky Mountain Quartzite' was introduced by D.B. Dowling (1907) for siliceous beds at the top of the Paleozoic sequence in the Bow Valley area of the Front Ranges. He did not describe a section or designate a type locality, other than to mention that the formation frequently formed the lower slopes of the west side of many of the fault blocks because it occurs high in the Paleozoic section. Dowling grouped the Rocky Mountain quartzite, the Upper Banff limestone (Rundle), the Lower Banff shale (Banff) and the Lower Banff limestone (Palliser) together and assigned to them a Carboniferous age. The term 'quartzite' is currently abandoned because true quartzite is very minor in the formation. It was not until 1956 that the Rocky Mountain was subdivided into two divisions by both G.O. Raasch and P.S. Warren (Table I). Norris (1957) designated the lowermost part of the formation in the Beehive Pass area south of Highwood Pass, the Todhunter member.

THICKNESS: Until agreement is reached as to what strata should be designated Rocky Mountain and what should be designated Upper Rundle, thickness variations, except for local areas, will have little use for correlation purposes.

Considered regionally however, there seems to be a progressive eastward truncation, similar to that of the Triassic beds above, as a result of pre-Spray River erosion.

A section of Rocky Mountain on Tunnel Mountain at Banff as measured by Warren (1927) is 698 feet, and by Beales (1950) as 615 feet. The same section has been recorded by Fox (1954) as 671, and by Warren (1956) as 657. This section is commonly considered the type locality. At the western end of Lake Minnewanka the Rocky Mountain is only 7 feet thick, a distance of just over 5 miles, but because these two sections are on different fault blocks the palinspastic distance may be several times their present distance apart. The Lake Minnewanka section is however, on strike with the Highwood Pass, and Pigeon Mountain sections. The Pigeon Mountain section measures 625 feet (Crockford 1949) and lies 18 miles southeast of the Minnewanka section which represents a thinning of 34 feet per mile. Dowling (1907) considered 1,600 feet to be a good average for the formation in this area, but this seems much too high when compared with the other sections.

MacNeil (1942) recorded a thickness of 250 feet on Moose Dome to the east of the Front Range, but Beach (1943) states that if Rocky Mountain was ever present in the Moose Mountain region it must have been very thin and at present it is completely absent as is the Triassic above.

Southward at Beehive Pass Norris (1957) measured 1202 feet of Rocky Mountain. Eastward in the Gap Map area Douglas (1950) recorded only 66 feet of Rocky Mountain.

From this regional examination there appears to be a northward and eastward thinning of the formation and in the Bow Valley region it is entirely confined to the mountains and absent in the foothills.

DISTRIBUTION AND GENERAL CHARACTER: Though no type locality was given by Dowling (1907) the exposure on Tunnel Mountain has come to be regarded as the type section. Raasch (1956) however, located what he describes as a much more complete section in Highwood Pass at the head of Storm Creek and he advances the suggestion that this section be regarded as an alternative or supplemental type section.

In the Wasootch Creek map area excellent exposures of Rocky Mountain were found on the small ridges leading to the southwest off the first two peaks immediately north of Mt. McDougall, but unfortunately these sections are difficult to measure. Samples of the formation were taken in a westward trending valley on the west slope of the anticlinal hill on the west side of Lac des Arcs Ridge. Exposure was relatively poor although an overall picture of the lithology was obtained from thirty samples.

In spite of the superior hardness of the strata, the formation weathers easily and does not form a conspicuous member in the stratigraphic sequence. Topographically it would be more readily grouped with the Mesozoic strata. In general it occurs on the western slopes of the fault block mountain ranges and is commonly obscured by glacial drift, vegetation and talus so that good exposures of the formation are rare.

The Rocky Mountain is composed mostly of fine-grained, dolomite, sandy dolomite, sandstone, bedded chert and quartzitic sandstone, with chert nodules occurring frequently in the calcareous beds. Most of the beds are noticeably lens-like and lateral changes in their lithology are quite rapid so that most sections are conspicuously different. The chert beds appear to be more stable and constant in their stratigraphic position than the more clastic beds, while the shale beds are the most variable.

The upper surface of the Rocky Mountain formation is always disconformable and in local outcrop no truncation can be detected. In Highwood Pass the lowermost bed of Triassic is a dirty grey brown, silty, thin-bedded, platy sandstone. Immediately below this is a regolithic, limonite cemented chert, rusty weathering, 1.7 feet thick with a roughened upper surface. Immediately beneath this is a dolomitic sandstone which in places is weathered to a virtual soil, but dispite these features the contact is essentially level. The uppermost bed in the Tunnel Mountain section is also a massive, dark grey weathering chert with white siliceous seams throughout. In the Ribbon Creek area Crockford describes the uppermost beds as a breccia composed of angular chert and rounded quartz pebbles and having a deeply pitted upper surface. These pits measured as much as 18 inches in diameter and 12 inches deep.

Contrasting views are held regarding the conformability of the lower contact of the Rocky Mountain on the Upper Rundle. Warren (1956) on the one hand has found little good evidence of a time break between the two formations though the contact is quite sharp on Tunnel Mountain. Warren (1927) states that in most areas an unconformity does exist between Mississippian and Rocky Mountain strata but that in the Banff section sedimentation was continuous throughout Mississippian into Pennsylvanian (Rocky Mountain) time but there was a change in lithology. Beales (1950) places the base of the Rocky Mountain at the base of a silicified, granular dolomite (possibly quartzite) which is 4 feet thick and well laminated in the lower part. Below, the Rundle is a relatively massive, coarse-grained, fossil-fragmental limestone but upwards dolomitic, crinoidal limestones give place to fine to medium-grained, chalky weathering dolomite, with no apparent break in the stratigraphic sequence.

Raasch (1956) on the other hand believes that the Rocky Mountain is Permian in age and that a substantial unconformity exists between it and the Mississippian strata. In the Storm Creek section the basal bed is 20 feet thick and is described by Raasch (1956) as a dolomitic, grey, pale weathering porcellanite. Twelve feet below the top is a zone of fossiliferous, buff dolomite with a band of black chert nodules near the base. A few inches higher is a band with poorly sorted, rounded aand grains, dark chert granules and pebbles, and debris of silicified fossils. There is no discrepancy in the dips of the basal Rocky Mountain and underlying Rundle in local outcrop, though taken on a regional basis a considerable amount of truncation seems to exist.

In the Beehive Pass area the upper unit is truncated by an erosional unconformity and consists in its upper part of hard cherty dolomite with interbedded dolomitic sandstone. The lower contact is possibly an unconformity Norris (1957).

LITHOLOGY: At the section sampled in the Wasootch Creek area the lower contact was covered but samples from what was considered the lowest Rocky Mountain consist of medium grey, brown and grey weathering, hard, dense, dolomite in thick to medium beds, calcareous, with highly arenaceous laminations and scattered silt grains throughout. Some slightly calcareous sandstone is also present that is light grey, medium grey weathering, medium grained, with some chert grains, well sorted and relatively pure. Also some beds of medium grey, dense, hard dolomite are present and in this material a thin zone of silicified brachiopods were found. The remainder of the exposures except for the upper 50 feet consisted of sandstone. They are all very hard, clean and nearly all somewhat dolomitic, and weather most commonly to some shade of red due to the presence of grains of magnetite, though some are brown and grey. The sand grains are dominantly quartz but feldspar is probably abundant and a few chert grains were well represented in all the samples examined. The upper 40 to 50 feet consists of highly silty dolomites, dark grey, dense, very even textured, brown weathering and with black lenses and nodules throughout. A representative sample contained a small concentration of magnetite and a small chert nodule containing silt grains and many dolomite rhombohedra. The uppermost bed exposed consists of 10 to 15 feet of dark grey weathering, relatively fine breccia that is composed of even textured, dark grey, calcareous dolomite.

The Rocky Mountain formation in the Wasootch Creek area, though largely covered, seems to correlate well with the clastic section in Highwood Pass and appears itself to consist mostly of calcareous and dolomitic sandstone. It is notably more clastic than the Tunnel Mountain section.

PALEONTOLOGY AND AGE: Fossils are relatively scarce in the Rocky Mountain formation and those present are often in a poorly preserved state, so that precise determination is inhibited. Since 1907 when Dowling first established the formation it has been given both an Upper Carboniferous and Permian age (Table I) and even at the present time argument exists as to whether it is Permian, Pennsylvanian or partly both. The current practice, according to Raasch (1956) is to consider the Rocky Mountain as that part of the Paleozoic section considered to be post-Mississippian, that is excluding the Chesteran beds that were originally included in it.

Shimer (1926) was the first to consider a Permian age for the formation while Warren (1927) believed the fauna to be undoubtedly representative of Pennsylvanian and perhaps of Permian age in the uppermost beds. In 1947 Warren divided the formation into an upper member probably of Permian age and a lower probably of Pennsylvanian age thus placing an unconformity of considerable magnitude within the formation (Warren 1956).

P.S.Warren (1956) listed the total fauna of the Tunnel Mountain member as follows:

Caninia torquia (owen)?
Orbiculoidea arenaria Shimer
Schuchertella? sp. indet.
Dictyoclostus semireticulatus (Martin)
D. coloradoensis (Girty)?
Juresania nebrascensis (Owen)
Paraphorhynchus obscurum Shimer
Dielasma arkensanum Weller
Spirifer rockymontana
Phricodothyris perplexa (McChesney)
Bakewellia parva M. & H.
Myalina wyomingensis (Lea)
Deltopecten occendentalis var. latisformis Shimer
Euconospira turbiniformis M & W
Euphemus carbonarius arenarius

According to Warren (1956) this fauna is undoubtedly representative of Pennsylvanian age. The fauna from the Norquay Mountain member was collected mostly from the lower beds and include:

Linoproductus multistriatus (Meek)
Dictyoclostus ivesi (Martin)?
Schizodus cf. ferrieri Girty
Straparollus umbilicatus M & W.?
Euphemites arenarius Shimer
Plagioglypta canna White
Helicoprion Karpinsky

This fauna, states Warren, has definite Permian affinities and he would correlate the Norquay Mountain member with the Middle Permian Phosphoria and the Tunnel Mountain member with the Quadrant quartzite of Montana.

Raasch (1956) lists the following fauna taken from his Norquay Member:

Stenopara aff. S. gracilis (Dana) S.nigris Crockford
Stenopara aff. S. tasmaniensis Lonsdale
Euphemites carbonarius arenarius Shimer
Dentalium (Plagioglypta) canna White
Schizodus taxanus Clifton
S. oklahomensis Beede
Allorisma cf. rothi (Newell)
Pleurophorus cf. albequus Beede
Dozierella gouldi (Beede)
Ditomopyge cf. decurtata

G.O. Raasch (1956), on the basis of richly fossiliferous chert from the Fernie-Flathead area, and the above fauna which includes Permian bryozoa, concludes that evidence is sufficient to consider the Norquay member as Permian in age and thus that the entire formation is Permian and correlative with Middle Permian units in the western United States.

In the Wasootch Creek section the only fossils found were a few silicified brachiopods in the lower part of the formation but their fragmented condition prevented indentification. For the purpose of this thesis the terminology and age of the formation as established by Raasch (1956) has been adopted.

D.K.Norris (1957) collected Dictyoclostus cf. porthlockianus Norwood and Pratten from the lower part of his upper member, and from the Todhunted member Composita sp. Spirifer sp. Orbiculoidea arenaria Shimer, and Archimedes sp. which he considered to be Permian in age and correlative with the Storm Creek section.

MESOZOIC

Triassic

Spray River Formation

NAME AND HISTORY: The Spray River formation was originally designated the Upper Banff Shales by McConnell (Table I) who assigned to it a Carboniferous age. It was not until 1915 when G.H. Girty and L.M. Lambe (1916) examined fish remains and invertebrate fossils from outcrops west of Banff, that the age was definitely established as Lower Triassic. In 1924 E.M.Kindle proposed a number of changes in the formational nomenclature of the Front Range units among which was the designation of the heretofore termed Upper Banff Shale as the Spray River formation with the type locality established 7 miles south of the town of Banff, in the Spray River gorge, at the southern end of Sulphur Mountain.

THICKNESS: In the vicinity of the Bow Valley the Triassic beds vary greatly in thickness due to a rapid eastward thinning of approximately 50 feet per mile (Crockford and Clow 1953). A thickness of 3,400 feet was recorded by Warren (1927) at the type locality but folding and faulting make this figure invalid. A second section measured by Warren gives a thickness of 1,243 feet for a group of lower dark grey laminated beds, and 610 feet for upper grey limestones intermixed with darker shales. A complete section is not present in the area under consideration but Crockford (1949) established a type section for the Ribbon Creek area on Evans-Thomas Creek which is complete except for the basal 20 feet. The section measures 583 feet and consequently 600 feet is suggested for the total formation. As this section is 2 miles long strike from the only Triassic encountered in the Wasootch Creek area it will be taken as the type locality and thickness.

H.W. Shimer (1926) measured 1,498 feet of Spray River at the west end of Lake Minnewanka. If this section is unfaulted it represents an increase in thickness of 2½ times that of its strike equivalent on Evans-Thomas Creek.

In the southern part of the Alberta Rockies the Triassic beds are entirely confined to the mountain region for no Spray River has been found in outcrop in the foothills nor in any wells drilled in the foothills. Beach (1943) in his study of the Moose Mountain area failed to find beds ascribable to the Spray River but in place found a thin bed of black, chert pebble conglomerate resting on the channeled, upper surface of the Rundle of Mississippian age. Beach believes that on the basis of thinning eastward from the Banff area, Triassic sediments were probably present in the Moose Mountain area but were reduced to rubble, as was the Rocky Mountain formation, before the advance of the Jurassic seas.

Northward Triassic sediments occur in the foothills and spread onto the Peace River plains. In the vicinity of the Alberta-British Columbia boundary in that area, the Triassic system attains a thickness of 2,000 feet with Lower, Middle and Upper Triassic being present.

DISTRIBUTION AND GENERAL CHARACTER: In Southern Alberta the Lower Triassic consists of a single unit, the Spray River formation, which in the Wasootch Creek area is essentially an argillaceous, highly calcareous siltstone to silty limestone, thinly bedded, reddish-brown, and platy weathering. Farther north on the McLeod River in the vicinity of Cadomin and Mountain Park, the Spray River is thinner and is divisible into two distinct members, the lower Sulphur Mountain and upper Whitehorse which is a light grey, almost white, lithographic dolomite.

The Triassic Spray River in the Wasootch Creek area is confined to the east limb of the Mt. Allan Syncline, thereby placing it on the west side of Lac des Arcs Ridge. Erosion has all but removed the non-resistant Spray River from the ridge but a small remnant outlier remains on the crestal area of the anticlinal flexure northwest of Mt. McDougall. Exposure is generally poor to lacking on this hill and the only good exposure is on the northeastern side of the outcrop area at the head of the unnamed creek whose mouth lies near Boundary Cabin. Here a vertical cliff exposes over 50 feet of thin bedded, platy siltstone. The easternmost occurrence is in a small, narrow saddle at which point the beds are almost vertical and conformable on the steeply westward dipping Rocky Mountain, whereas only a few feet west of this contact they are horizontal and from a distance give the appearance of a thrust fault, though actually it is only a very sharp flexure. Over the rest of this small anticlinal hill the formation dips gently southwestward at angles of 10 to 15 degrees.

The Spray River weathers to a distinctive dark reddish-brown and because of its weakness to weathering and erosion is typically poorly exposed and most often outcrops in river valleys. On the anticlinal hill in question the Spray River outcrops entirely above timberline and outcrops are covered with a thick growth of grass. The greater part of the formation is thinly bedded, mostly not more than a few inches thick. Upon exposure the rock breaks into angular plates $\frac{1}{4}$ to 1 inch thick which litter slopes and add to the striking color. On a fresh surface the rock is generally grey to dark grey and black, and a fine banding or lamination is not uncommon, particularly in the lower part.

Erosional disconformities form both upper and lower contacts and in local exposures no truncation has ever been seen. In the Evans-Thomas Creek section the lowest beds are concealed but probably consist of fissile, poorly indurated, dark grey shale immediately subjacent to which is a conglomerate composed of pebbles and cobbles of grey quartzite and chert firmly cemented in a siliceous matrix and ascribed to the Rocky Mountain. In the Highwood-Elbow area immediately to the south the lower contact is definitely erosional for the underlying Paleozoic beds are pitted by smooth depressions and the basal Triassic beds consists of a basal sandstone to chert pebble conglomerate.

The upper contact is also definitely erosional since Lower Jurassic beds directly overly Lower or at most Middle Triassic beds. In the Ribbon Creek area in every instance hard dolomitic siltstones give way abruptly to soft, black, fissile shale with no appreciable change in the dip of the two (Crockford 1949). The erosional interval is of greatest magnitude in the south where Jurassic overlies Lower Triassic, and gradually becomes less northward until in the Peace River district Upper Triassic is present beneath the Jurassic Fernie. The erosional interval is also greater in the eastern part of the mountains than in the western part since the formation is truncated in an eastward direction.

LITHOLOGY: Spray River section measured on Evans-Thomas Creek in the Ribbon Creek area is predominantly a siltstone, essentially argillaceous though dolomitic, calcareous and arenaceous types are well represented. Near the top dolomitic siltstones become characteristic and are prominent by virtue of their superior resistance to erosion than the underlying rocks. A summary of this section follows:

Siltstone, hard, cliff-forming, dolomitic or with argillaceous or arenaceous streaks, dark grey, thick bedded	72'
Siltstone, sandy to dolomitic, thin bedded, includes two fossil horizons	187'
Dolomite, blue-grey, dense, massive, argillaceous, Lingulae abundant	5'
Siltstone, dark grey, hard, dense, argillaceous with numerous sandstone lenses, some algal impressions	183'
Siltstone, dark grey, hard, brittle, upper part argillaceous and distinctly stratified, lower part evenly bedded, laminae of fine sand, numerous, fossiliferous . . .	106'
Shale, dark grey, fissile, beds $\frac{1}{4}$ - $\frac{1}{2}$ inch, poorly indurated	30'
Concealed, but probably as above	17'
Total thickness of S.R.	600'

The samples collected by the writer for microscopic examination were taken from scattered outcrops from the lower Spray River which consist of highly dolomitic siltstone that probably accounts for its exposure. Thus the findings regarding the lithology of these samples are not indicative of the lithology of the entire formation.

These resistant beds in the lower Spray River consist essentially of silt, dolomite and argillaceous material. The silt size grains consist mostly of quartz and feldspar, both orthoclase and sodic plagioclase though the plagioclase is not abundant. The grains are so small however, that except for an occasional positive identification, determination of the grain compositions is very difficult in thin section. The maximum sizes of grains fall in the very fine sand grade while the average grade is that of coarse silt, in the range .062 to .031 mm. Grades below .031 mm. in the medium and fine silt grades are also present but minor. On the whole the sediment is moderately well sorted. Muscovite in one sample amounted to 7% to 8% and was a maximum. Many sizes of flakes are present but the greater abundance seemed to occur in the lower sand sizes and the majority of them are alligned parallel to nearly parallel to the lamination. The quartz and feldspar grains are typically subangular, some being subrounded, while the muscovite flakes are always well rounded. Accessory minerals are few but those present are also well rounded. Where quartz and feldspar grains are in mutual contact pressure welding is common and where they are in contact with calcite or dolomite sutured, replacement boundaries are typical. No secondary enlargements were found on any of the grains. Inclusions were common in most clastic grains and the feldspar was noticeably but not greatly weathered and altered.

In most cases the sediment contains a high proportion of carbonate material in the form of dolomite and some calcite which sometimes amounts to 75% of the rock. Often the percentages of silt and dolomite are almost equal and difficulty is met in classifying them as dolomites or siltstones. This dolomite probably is a secondary replacement of primary calcite and is mostly in the form of rhombohedra.

Typical of siltstones deposited in an aqueous environment is a very conspicuous lamination, which characterizes much of the Spray River. At first glance the lamination seems to be very regular and parallel and to continue for considerable distance without variation. Upon closer examination however, it is seen that fine dark bands wedge-out quite rapidly and re-appear again quickly on the same level or perhaps at a higher or lower level. On a small scale, the laminae are undulatory and wavy. The lamination is due to alternating layers of light grey dolomitic material and very dark grey clay rich material, or very dark grey clay and tan-brown argillaceous and dolomitic material. Some samples are notably lighter in color, almost a tan-brown while others are very dark grey color. This color variation is due to the presence of either an ochreous, argillaceous clay associated with tan colored quartz and feldspar, or to dark grey-brown clay associated with light grey silt. In thin section the clay is not observable but the lamination may be seen to be the result of alternating layers containing slightly higher concentrations of silt, with others containing higher concentrations of dolomite.

During times when the influx of fine clastic material was dominant during the deposition of this lower Spray River, the sea floor must have consisted of a very soft mud which because of its high water content would tend to be quick, and deposition on a surface of even low relief would eventually produce some flowage of the sediment. In the Spray River formation,while it is admitted that very little of it was actually seen in detail, flowage phenomena seemed to be absent. This observation together with the fact that the lamination is often so well developed over such large areas that the sea bottom must have been very flat indeed. The presence of this fine lamination also indicates that a rich benthonic fauna was absent, as does the paucity of fossils, since any amount of burrowing or movement by them would destroy the lamination.

PALEONTOLOGY AND AGE: The Spray River formation is sparsely fossiliferous probably because during its deposition the sea bottom consisted of soft, dark mud prohibitive to most kinds of benthonic invertebrates. It is therefore not surprising to find that most of the fossils are free swimming ammonites such as Flemingites, Ophiceras (?), and Meekoceras (?) the pelecypod Claraia stachei, and a great abundance of Lingula (Crockford 1949). In the Highwood-Elbow area a simimar fauna was collected including Meekoceras mushbackanum var. corrugata Smith.

This fauna corroborates the conclusions of Lambe and Girty (Lambe 1916) that the formation is definitely of Lower Triassic age.

STRUCTURAL GEOLOGY

The Wasootch Creek area is located in the Front Range sub-province of the Rocky Mountains which is defined on the west in the Bow Valley region by the Castle Mountain Thrust, and on the east by the McConnell Fault which is the sole thrust of the Front Ranges. Within this sub-province are four ranges defined from west to east by the Bourgeau Fault, the Sulphur Mountain Fault, the Mount Rundle Fault, and the McConnell Fault. The map area under consideration lies entirely within the First Range or easternmost range, that is between the Mount Rundle Fault and the McConnell Fault, which defines the mountain front (Figure 1).

The First Range is dominantly a thrust fault area where folds are subordinate in importance. One large fold however is present at the western margin of the First Range and is known as the Cascade Coal Basin. Throughout much of its length it is an overturned syncline, and the Mount Rundle Fault has thrusted over the overturned, west limb. Between the Mount Rundle Fault and the McConnell Fault are several major faults which from west to east are the Lac des Arcs Fault, Exshaw Fault, Porcupine Fault, West McConnell Fault and McConnell Fault (Figure 3). Four other minor faults present within the area may develop into major faults to the south.

Detailed mapping has revealed the two-fold nature of the previously considered single McConnell Fault. The Mc-

Connell thrust first becomes well defined at Mt. Head, about 45 miles to the southeast in the Highwood Range, where Rundle is thrust over various Paleozoic and Mesozoic formations. North of Mt. Head in the Dyson Creek area Rundle gives way to Palliser above the thrust, and farther northward in the Moose Mountain area the thickness of Palliser exposed increases until at Kananaskis Gap the entire front of the Range consists of Palliser (Beach 1943). North of Red Deer River Cambrian formations are exposed above the sole thrust. Regionally therefore the McConnell Fault cuts deeper into the Paleozoic sequence in a northward direction, exposing older formations in that direction.

Northward from the Kananaskis River at Barrier Dam, Cambrian beds alone are exposed above the McConnell fault to at least as far as Ghost River (Beach 1943, Clark 1949, Henderson and North 1954) and continues to do so for most of the distance to the Athabasca River. The Kananaskis Gap therefore is a critical area, a point south of which Devonian and Mississippian beds only appear above the master thrust, and north of which Cambrian beds are essentially the only strata in the basal part of the overriding Paleozoic block.

These relationships are shown in Figure 4 where attention is drawn to the northeast trend of the Kananaskis River transverse to the regional strike, which abruptly changes to a north-south direction to parallel the mountain front, and which is in direct line with the McConnell fault immediately north of Barrier Dam. Detailed mapping in the vicinity of Porcupine Creek revealed the presence of a fault in which Cambrian beds have been thrust over Devonian Palliser. The fault is concealed in the alluvium of Kananaskis Valley so a fault was looked for north of the river with which this fault could be connected. It is considered that by correlating this thrust within the mountains, with the McConnell fault at the mountain front north of the river, two important problems could be solved. First and most important it explains why Cambrian and Devonian formations are exposed on either side of the valley above what appears to be the same fault. Secondly it accounts for the almost north-south trend of the structures in the lower part of the Kananaskis River, and for the direction of the river itself.

Examination of Henderson and North's Tectonic Compilation Map (1954) reveals the presence of a lobe projecting beyond the general even front of the mountains in the vicinity of the Red Deer River near James Pass. This lobe begins to emerge from the mountains at 51° 30' north latitude and the bounding thrust, which is called the McConnell, bends sharply northeastward, swings in a wide arc to the northwest and continues in that direction as the sole thrust of the mountains. Close examination of the area where the lobe emerges suggests an alternate possibility. The fault bounding the lobe may not be the same fault which bounds the mountain front south of 51° 30'. It seems rather that this southern

McConnell fault continues northwestward and that the lobe actually does emerge from under the McConnell, and is bounded by an entirely separate fault. Since Devonian beds are exposed immediately above this fault for a short distance, it is suggested that this fault correlates with the sole thrust south of Kananaskis River at Barrier Dam, which also exposes Devonian beds above the fault. This means therefore that between Kananaskis Gap and 51° 30' north latitude a second lobe, which probably exposes Cambrian above the fault between these two points, has overridden a fault which north and south of these two points exposes Devonian beds above the fault. Although the thrust between Kananaskis Gap and 51° 30' is of greater stratigraphic throw, bringing Cambrian over Cretaceous, than the sole thrust on either side of these two points which bring Devonian over Cretaceous, it is considerably less within the mountains behind the other thrust.

Since two separate thrusts are believed to be present in this region two separate names should be used in reference to them. The name McConnell fault, however, was originally proposed by Clark (1949) specifically for the sole fault of the Front Range in the Bow Valley area which thrusts Cambrian over Cretaceous strata but since this time the term has been applied by Douglas (1950, 1958) and Norris (1958) to faults south of this area which do not expose the Cambrian. The thrust which exposes Cambrian between Kananskis Gap and 51° 30' north latitude therefore should be called the McConnell fault and the sole thrust north and south of these critical points referred to by a different name. Since this fault however is well established as the McConnell fault and because it soon exposes Cambrian above the fault plane north of its emergence it would be illogical to advocate this change. It is suggested however, that the thrust between Kananaskis Gap and 51° 30' north latitude should be given a separate name, for although it was for this fault that the name McConnell was originally and specifically proposed, it is not, in the opinion of the writer, the master thrust of the Rocky Mountains south of the Kananaskis River nor is it for some unknown distance northward.

The proposals made above are based in part upon interpretations made from a generalized map and before the presence of the two-fold nature of the sole fault can be proven, the northern end of the lobeate region must be mapped in detail. For this reason a new name will not be proposed for this second fault, and in the Wasootch Creek map area the thrust forming the sole fault of the Front Range will be designated the McConnell Fault and the sole fault north of the Kananaskis River will be designated, within the mountains, the West McConnell Fault.

As mentioned previously thrust faulting is the dominant type of deformation in this area. The faults which all dip in the same direction at similar angles, are commonly thought of as originating as off-shoots from the underlying low angle sole thrust, probably beginning as low angle or bedding plane thrusts that soon steepen and merge at the surface as high-angle, reverse faults of much smaller stratigraphic displacement than the master thrust from which they originate. These faults which slice the thrust sheet into a series of overlapping plates or blocks produce an imbricate structure, that is controlled largely by the rock competency.

There are many contrasting lithologies in the stratigraphic succession but the majority of the strata are competent, massive limestones and dolomites, generally with sufficient strength to transmit tectonic stresses for appreciable distances without themselves becoming greatly or noticeably deformed. Within this dominantly competent sequence are three important zones of weakness, corresponding to the Ghost River formation, the Alexo formation, and the Exshaw-Lower Banff formations. These zones, because of their relative incompetence and stratigraphic position, exercise a controlling influence in the formation of faults, for they tend to localize the faults and by reason of their lubricating effect, decrease the frictional resistance to movement along the fault planes.

The elongate mountain ridges in this area are the topographic expression of these thrust-fault blocks and while the valleys do not always represent fault zones, they may result from the superposition of resistant over weaker strata or vice versa. Because this is a maturely eroded area and because the more competent and resistant formations have been raised to higher elevations by faulting, the mountain peaks and ridges are composed of the more massive, competent limestones and dolomites of the Livingstone, Palliser, Southesk, Cairn and Eldon formations.

Lac des Arcs Fault Block

The Lac des Arcs fault block is that ridge underlain by the Lac des Arcs fault Clark (1949) (Figure 3) which is traceable from north of the Bow River to south of Evans-Thomas Creek. The highest parts of the ridge are carved from the Livingstone limestone, the two most conspicuous peaks being Mt. Lorette and Mt. McDougall. On the west side of the ridge, which is the east flank of the Cascade Coal Basin, is a small northward plunging, anticlinal fold which extends beyond the southern border of the area where it soon disappears. This flexure has contributed to the strong westward deflection of the Banff and Rundle outcrop patterns in the Kananaskis Valley.

The trace of the underlying Lac des Arcs fault lies in the valley of Wasootch Creek and it is this structure that has controlled the direction of the stream. Throughout the length of the fault, except in the southern part of the area, Fairholme is overridden Palliser to Rundle. Within the Fairholme is a subsidiary fault which exposes Palliser that has been both folded and faulted. The Palliser is first exposed south of the highway in the lower reaches of Wasootch Creek (Figure 32) and extends southeastward on the east side of Lac des Arcs Ridge for a distance of 2¼ miles (Figure 4, 33). Four obsequent streams flow down the eastern side of the ridge, cutting through this thrust slice, thus affording excellent opportunities to observe the development of the folds and faults throughout the entire exposure. By so doing it was found that southward the deformational stresses increased in magnetude to such a degree that the Palliser beds failed by rupture in part, and were folded anticlinally above the fault (Figure 34).

The thrust along which Fairholme overrides Palliser south of the Kananaskis River must be present within the Fairholme on the north side of the river because the section is abnormally thick. South of the highway Southesk has been thrust over several hundred feet of Palliser, which because of its superior resistance is exposed in the form of an almost vertical cliff, which ends abruptly just south of the highway (Figure 32). A deep stream valley separates this cliff from the next exposure which from the north appears to be a spire, but is actually a short ridge. At this point the deformational forces have increased and the fault slice is folded into a tight syncline (Figure 35). In the valley of the second stream the syncline has been faulted in the axial region so that in the next exposure southward there is virtually no syncline left, but rather a sequence of easterly dipping beds, faulted over a group of westerly dipping beds which represent the east flank of the original syncline. The tectonic forces have apparently increased somewhat to the south for the original syncline has soon become 'inverted' to an anticline which is faulted at the base of its eastern limb over west dipping Palliser that represents the east limb of the original syncline. At the southern end of the structure (Figure 31) the lower Palliser has been folded into a symmetrical anticline, faulted over by the Fairholme, and itself faulted over lower Palliser. This latter fault may not be of great displacement, in fact it may be only a zone of intense shearing and bending with no real displacement along a single, definite fault. With depth the rupture zone may or may not merge into the axial zone of a tight syncline where no rupture has occurred. South of this last exposure of Palliser the presence of dense vegetation and little outcrop makes interpretation of the structure difficult but it does appear that one or two faults are present within the Fairholme for the section is abnormally thick and the beds do not always dip uniformly to the west. This faulting probably continues southward beyond the headwaters of Wasootch Creek.

Exshaw Fault Block

The Exshaw fault from the Kananaskis River to north of the Bow River exposes Palliser above the fault plane and midway between the two rivers on Heart Mountain a subsidiary fault has brought Rundle over Spray River. (Clark 1949). At the southern end of Heart Mountain on the north side of Kananaskis River, Mississippian and Devonian formations wrap around the end of the ridge and are truncated by the Exshaw fault. Correlation of the structure with the south side of the valley is difficult because of the thick alluvial cover, and absence of outcrop in the valley.

The Palliser exposures on either side of the river are believed to be correlative, as are the two Fairholme exposures. It seems evident that the Banff is gradually truncated across the width of the valley. Correlation of the Exshaw fault across the valley poses a more difficult problem. Of three possibilities, there is little likelihood that it connects with the Porcupine fault. The only other fault with which it might be connected is the Lac des Arcs fault, but this fault is at the top of the Palliser, whereas the Exshaw fault is at the base of the Palliser. This requires the faults to cut through almost the entire thickness of the Palliser which is questionable, though not altogether impossible. The third possibility is that the Exshaw fault connects with neither fault, but diminishes in displacement across the valley to be lost either within the Fairholme or as a bedding plane thrust between the Palliser and Fairholme, that is within the Alexo. This latter possibility is perhaps the simplest and most likely for two reasons. First, the Exshaw fault quickly diminishes in stratigraphic throw from the top of Heart Mountain to the north side of the Kananaskis valley where Palliser overrides Fairholme, that is younger over older, a rare situation, so that fault appears to be dying out. Secondly it is entirely possible that a thrust could originate between the Palliser and Fairholme, that is within the Alexo which is a relatively incompetent unit capable of controlling the position of a fault within the sequence. This thrust at the base of the Palliser may originate as far south as the point on Porcupine Ridge where the Fairholme was sampled. The conspicuous elongation of the northern end of this ridge which consists of Palliser, may in part be a topographic reflection of this fault.

Porcupine Fault Block

The fault herein named the Procupine fault occupies a near crestal position on the ridge between Wasootch and Porcupine Creeks, and gives to this ridge its name (Figure 3). Throughout most of its length it has thrust Cambrian over Palliser or Banff, but in the southeastern part of the area a thin slice of Fairholme intervenes between Cambrian and Banff. The Porcupine fault was observable only on the crest of the ridge at the head of Wasootch Creek, as was the fault below. It was learned that in the Moose Mountain area (Beach 1943) the fault which thrusts Fairholme over Palliser west of Compression Ridge and Mt. Bryant "... has caused strata of the

Fairholme formation to overlie vertical Banff shales along the backs of Compression Ridge and Mount Bryant." Extrapolation of this fault and the use of aerial photographs enabled its correlation with the fault below Porcupine fault and below the slice of Fairholme.

A second correlation was made between the Rundle outlier and a similar outcrop of Rundle on the peak of Mt. Bryant which is immediately east of the small lake in the southeast corner of the Wasootch Creek area. These Rundle outcrops occupy the axial part of a flat syncline which on both peaks has an overturned west limb, and which represents the northern termination of the here designated Nihahi syncline in the Moose Mountain area.

The northern end of the Porcupine fault was mapped by Clark (1949) at the western end of Barrier Dam. The Cambrian which occupies the position above the fault south of Kananaskis River apparently wedges out in the valley so that on the north side of the river Lower Fairholme overlies a thin slice of Palliser, both of which die out within the Fairholme in the valley northwest of Barrier Dam (Figure 4).

West McConnell Fault Block

It has been previously discussed the manner in which the McConnell fault is deflected westward from the mountain front in behind the mountain scarp south of Kananaskis River and the reason for this designation. The fault everywhere brings Cambrian over Devonian Palliser and the near identical lithology of the Morro member and Eldon formation make structural interpretations very difficult. The only locality where the fault could definitely be observed is on the south side of the ridge at the northern end of the east fork of Porcupine Creek, about 2/3 miles east of its junction with the west fork. Near the headwaters of the east branch of the west fork of Porcupine Creek, at the edge of the mapped area, definite faulting is present but although Middle Cambrian is stratigraphically above Devonian, detailed relations were not determinable.

Attempted correlation of this fault with Beach's Moose Mountain map is impossible for the only fault he has designated in the mountains in the northwest corner of his map, is a small thrust bringing Fairholme over Palliser, but which because of its position does not warrant correlation. For this and other reasons some discrepancy is believed to exist in Beach's map north of Mount Bryant. According to his map almost the entire area behind the McConnell fault consists of Palliser which is deformed into a number of folds. From the northwest the West McConnell fault, and probably a thrust east of it, together with Cambrian, Fairholme, and Palliser formations pass into this area and it is not considered likely that these formations wedge out before doing so. Also, such a sizeable area of Palliser outcrop is not common and may indicate some error. It is suggested that there may be Middle

Cambrian Eldon in fold and fault relationships with Palliser in which case structural interpretation may be almost impossible.

On the east side of the ridge between the two branches of Porcupine Creek a thin slice of Ghost River is exposed above a thrust which has brought Ghost River over reefy Southesk, thus accounting for the abnormal thickness of Fairholme. This fault continues northward within the Fairholme for an unknown distance but probably does not cross Porcupine Creek.

One traversewas made up Pass Creek to the saddle at its head, but difficulty was met in the separation of Cambrian and Palliser formations. In the valley of the largest creek on the north side of Pass Creek a fault is believed to exist with Eldon above and possibly Palliser below. Beach (1943) who mapped the front of the range on either side of the map area recorded Palliser above the McConnell fault but in the Wasootch Creek area closer examination is required before these relationships are proven.

Age of the Deformation

It was long considered that the period of deformation of the Canadian Cordillera terminated the Mesozoic Era but more recently evidence indicates that orogenic movement periodically occurred throughout much of the Mesozoic and into the early Tertiary, and that the real Rocky Mountain deformation took place in the Tertiary.

L.S. Russell (1951, 1954) has dated the Front Range deformation from New Mexico to Canada and has found that the period of orogeny occurred most commonly in Late Paleocene and Eocene. In the southern Canadian Rockies two periods of deformation have occurred (Russell 1954) which centred around the Eocene-Oligocene time boundary.

Beveridge and Folinsbee (1956) made potassium/argon and lead/Uranium age dates of several volcanic and plutonic rocks in the Cordilleran region and suggest that the principal Mesozoic intrusives are of late Cretaceous age.

J.A. Dorr (1958) gives conclusive evidence for Tertiary orogenies in Middle Paleocene, late Early Eocene and Middle Eocene time, in eastern Idaho and western Wyoming.

In southwestern and southern Alberta non-marine sediments of latest Cretaceous age are the Edmonton formation, and those of Paleocene age are referred to as the Paskapoo formation, both of which have similar lithologies. In the valleys of the Red Deer River and Bow River in the plains, the Paskapoo formation rests unconformably upon the Edmonton formation, but in the foothills, Tozer (1953) believes that no substantial unconformity separates the two formations. Rutherford (1927) found that fossil evidence indicated that the lower beds of the Edmonton-Paskapoo group between Cochrane and Kananaskis to be late Cretaceous in age and the uppermost beds to be early Tertiary, so that the main orogeny occurred in early Tertiary time, and since the Paskapoo is Paleocene, the revolution probably culminated in Eocene time.

In the Cypress hills residuals of erosion are composed of Cretaceous sediments overlain by Paleocene strata and capped by a heavy conglomerate of Oligocene age. The paucity of Eocene sediments in Alberta and the Oligocene conglomerate suggest that the Rockies were elevated prior to Oligocene time, and P.S. Warren places the time in the Eocene.

There seems to be little doubt therefore that the date of the Rocky Mountain orogeny was during or near Eocene time, and although there may have been two or three phases of deformation, the Early Tertiary and not the Cretaceous was the time of the revolution.

ECONOMIC GEOLOGY

Oil and Gas

Petroleum has long been produced from relatively strongly faulted strata in the Foothills of southern Alberta. Recently exploration has been extended into the mountains which heretofore have been considered too intensely deformed to contain productive fields.

In the Wasootch Creek area the Rundle and Fairholme groups, which contain tremendous quantities of petroleum in the Plains, are exposed at the surface in several fault blocks. Any oil and gas that they may have contained has long since escaped. It is considered that this small area holds no prospect for the discovery of petroleum.

Cement and Lime

The non-metallic mineral resources of this part of the Rocky Mountain Front Range have long contributed substantially to the industry of Alberta. Limestone has been quarried in the Bow Gap since the late 1800's for a variety of uses but primarily for the manufacture of cement and lime. Loder's Lime Company Limited is quarrying high-calcium Cambrian limestone at the front of the mountains. The Canada Cement Company Limited quarries Devonian limestone for the manufacture of Portland cement at the town of Exshaw.

The Cambrian and Devonian formations in the Bow Valley from which this rock is being quarried are also present in the Kananaskis Valley, and are of a sufficiently high calcium content to be potentially sources of cement and lime. Two other requirements however, accessibility and proximity to a railroad, are needed to make a deposit economic and both of these to some extent are lacking in this region.

In the Kananaskis Valley there are three areas where limestone suitable for lime production outcrop beside the highway. At the north end of Lac des Arcs Ridge the Palliser formation is well exposed but could not be too easily quarried. The second is at the junction of Wasootch Creek with the highway (Figure 4). At the north end of Porcupine Ridge on the east side of the valley, the Palliser is exposed on a small spur. This locality is much more accesible than the first mentioned and the limestone is probably less magnesian. The adjacent area consists of a gravel floored flood plain and would make an excellent foundation for quarrying operations. The third area lies outside the mapped area and is located beside the highway in Kananaskis Gap. The formation here is also believed to be Palliser and some quarrying has already been done.

Gravel

The Bow Valley and adjacent flood plains contain unlimited amounts of sand and gravel so that deposits in the Kananaskis Valley will not likely become economic. There are however probably good deposits of gravel of both fluvial and glacial origin in the valley in the vicinity of Wasootch Creek. The even flood plain and nearness to the highway would make quarrying operations fairly simple.

SUMMARY AND CONCLUSIONS

1. The Wasootch Creek area and the adjacent Bow Valley are excellent areas for examination of typical Rocky Mountain Front Range structure, stratigraphy and physiography, and should be used extensively for such purposes.

2. Between the Cascade Coal Basin and the McConnell fault are several elongate fault blocks which owe their shape to high angle reverse faults and mature dissection of resistant carbonate rocks.

3. Although the area has been glaciated, glacial features are not abundantly developed.

4. Middle and Upper Cambrian, Upper Devonian, Mississippian, Permian and Lower Triassic formations constitute the stratigraphic succession.

5. The Cambrian formations in this area are correlated with the Eldon, Pika, and Arctomys of the Bow Valley region.

6. The Ghost River or Arctomys formation is absent above the West McConnell fault and is one of the few places where it is not present below the sub-Devonian unconformity.

7. The Upper Devonian of this area is a well developed carbonate facies containing two massive reefs in the upper part.

8. The four major reverse faults in this area have been controlled in their position within the stratigraphic succession

by three weak zones corresponding to the Ghost River, Alexo and Exshaw-Lower Banff formations.

9. The McConnell fault consists of two separate faults north and south of the Kananaskis River at which point the northern fault overrides the southern fault and is thereby deflected westward within the mountains.

10. It is suggested that detailed mapping of the formations above the McConnell between the Ghost and Red Deer Rivers be undertaken to prove the presence of an overthrusting lobe between Kananaskis River and 51° 30' north latitude.

11. The Exshaw fault is believed to die out as a bedding-plane thrust in the northern part of the area.

12. The northernmost end of the 'Nihahi syncline' in the Moose Mountain area is faulted over by the Porcupine fault in the southeast corner of the area.

13. There is little prospect of a petroleum discovery in this area. High calcium limestone and gravel is abundant along the main highway and could prove economic with increased demand.

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Plate I

Figure 4. Aerial photograph of the Wasootch Creek and adjacent areas, showing relationship of McConnell and West McConnell faults

Plate II

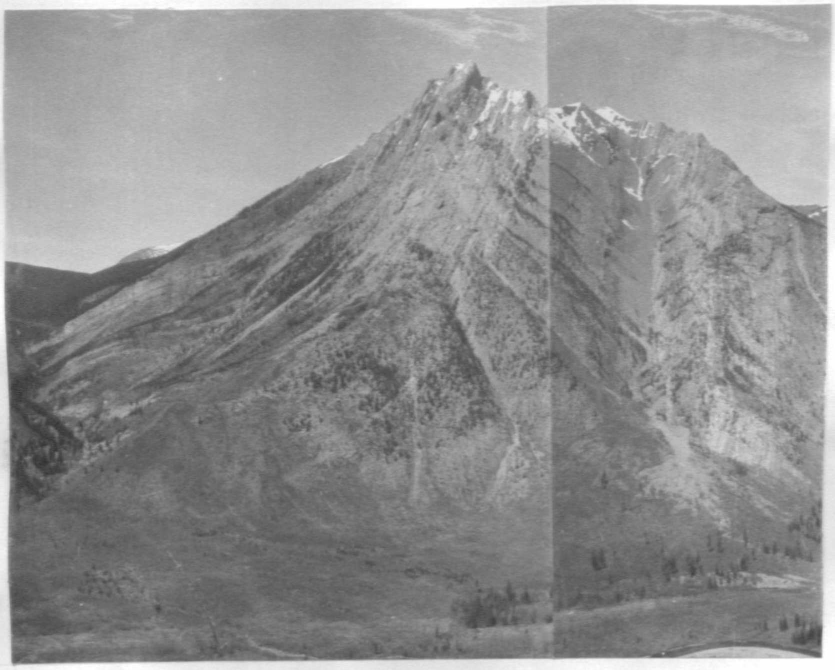

Figure 5. View of Mt. Lorette from highway. From left to right are Mt. Head, Livingstone, Banff, Exshaw and Palliser formations, representing the east limb of the Cascade Coal Basin or Mt. Allan Syncline.

Plate III

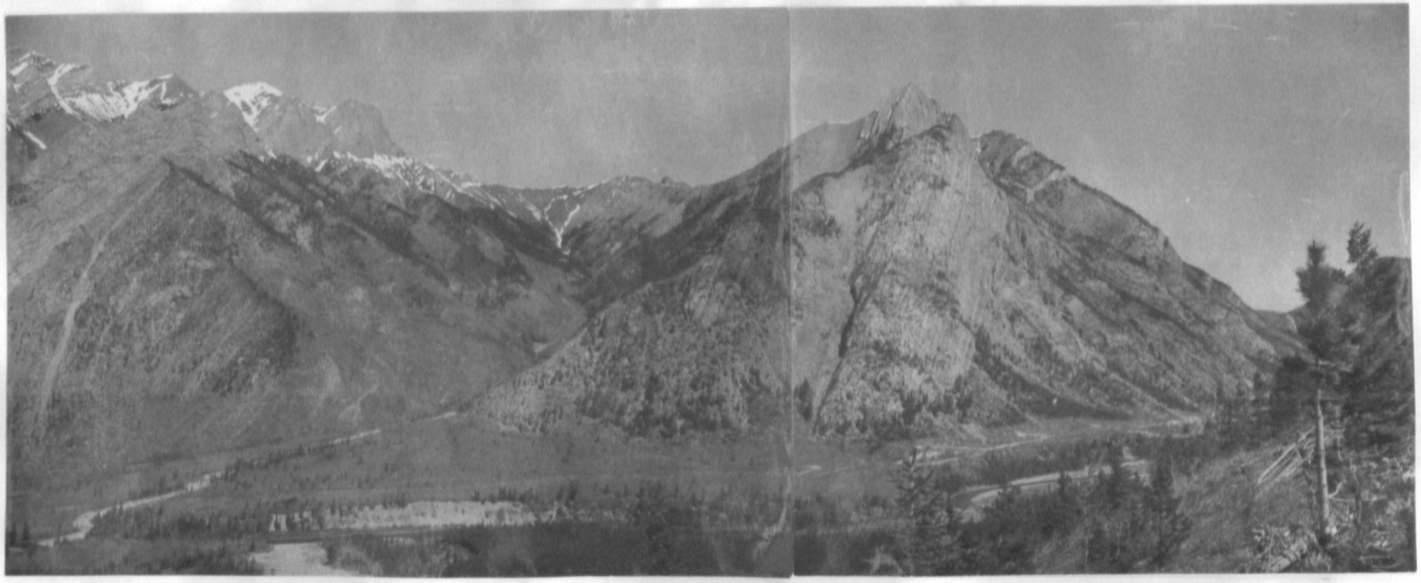

Figure 6. Panoramic view looking north to north side of Kananaskis Valley showing Mt. Lorette on left, and southern end of Heart Mt. on right. Lac des Arcs fault occupies the valley between the two mountains, Exshaw fault is below Palliser cliff on Heart Mt.

Figure 7. Exshaw valley at north end of Lac des Arcs Ridge. Uppermost Palliser on left, Exshaw in valley occupied by snow slide, snow-covered Banff in center at top, Livinstone form-peak at right.

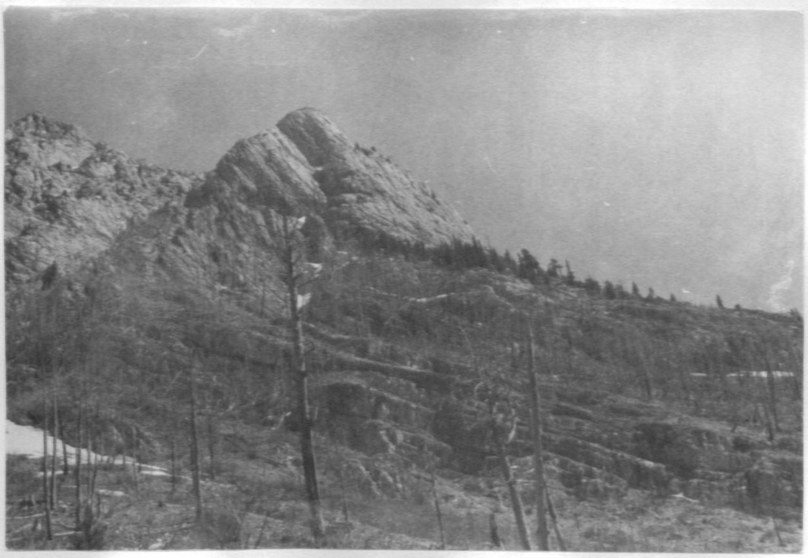

Figure 8. View looking south from highway at northwest corner of Lac des Arcs Ridge, showing resistant Livingstone and non-resistant Mt. Head formations. Dips change rapidly due to anti-clinal flexure at right.

Plate V

Figure 9. Dolomitic mottling in Middle Cambrian Lower Eldon formation in Bow Valley at Loder Lime Plant

Figure 10. Dolomitic mottling in Middle Cambrian Lower Eldon on Pass Creek. Highly dolomitized zone contains syngenetic flowage folds

Plate VI

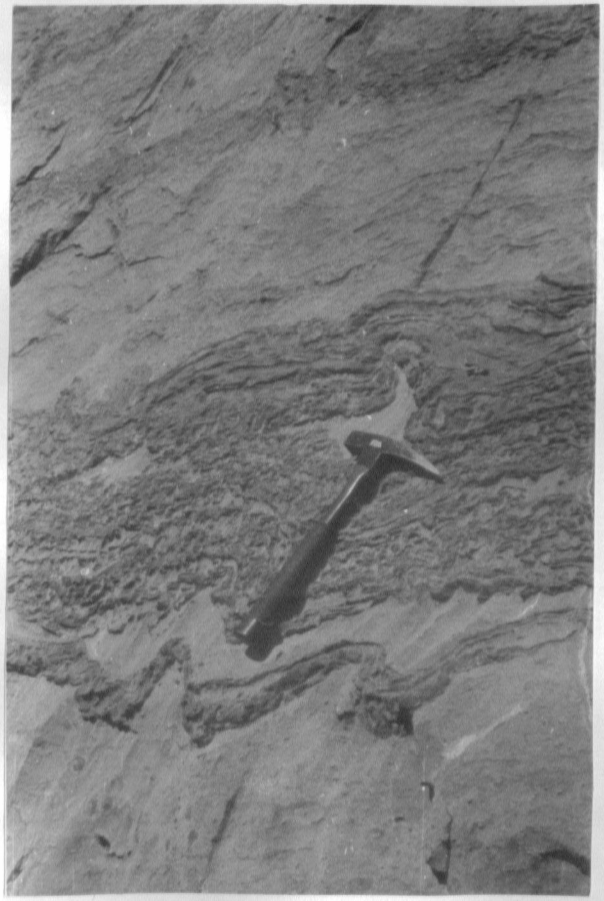

Figure 11. Syngenetic folds in highly dolomitized zone of Lower Eldon limestone

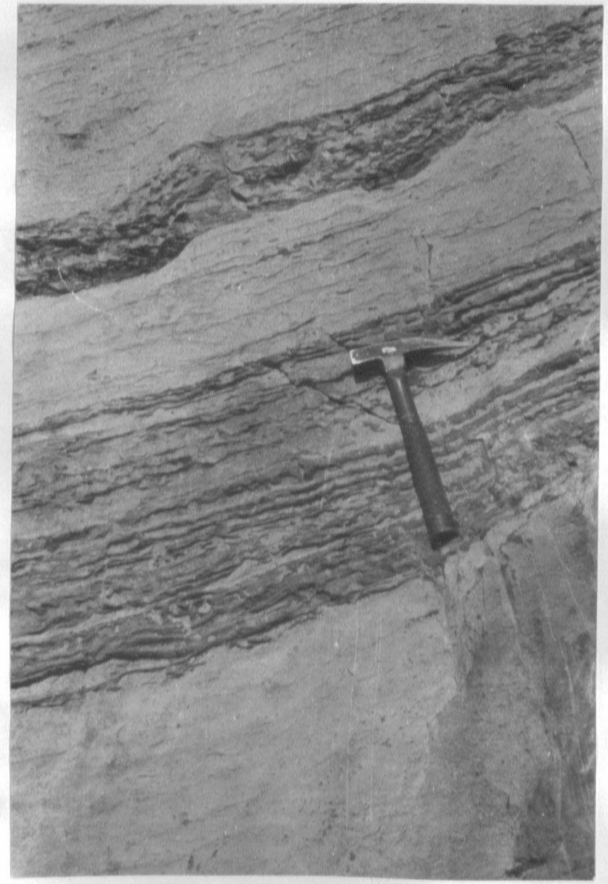

Figure 12. Dolomite in Lower Eldon in the form of thin layers, rather than as mottlings

Plate VII

Figure 13. View looking north at yellow-buff weathering Ghost River, exposed on left side of gully. Dark, thin beds of Cairn above, dark weathering Lower Eldon below

Figure 14. Limestone breccia at top of Ghost River Formation. Magnification 2x

Plate VIII

Figure 15. Bedding surface of light grey weathering stromatoporoids in lower Cairn black dolomite

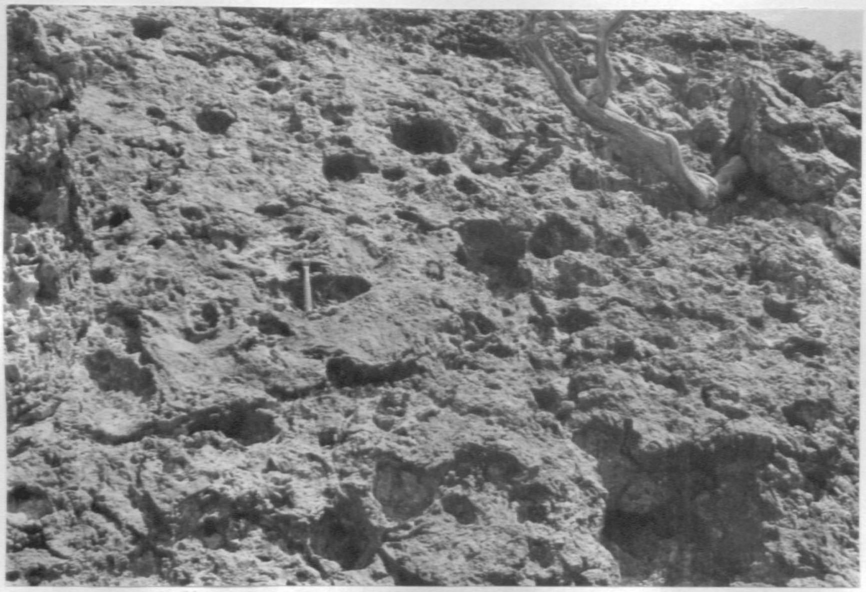

Figure 16. Extremely vuggy, black, massive dolomite in upper part of the Cairn formation

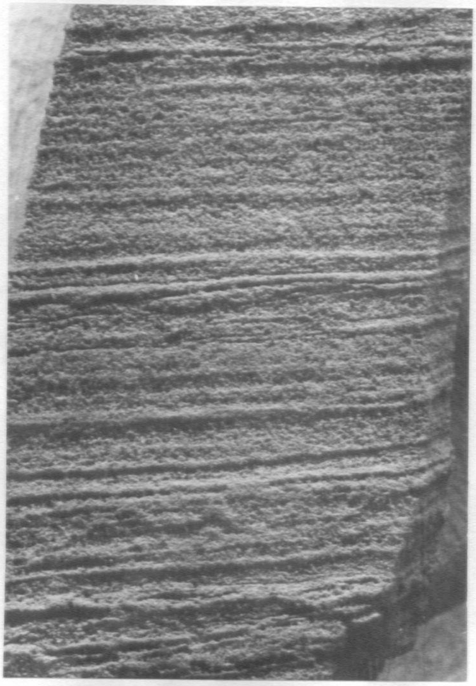

Figure 17. Acid etched surface of dolomite laminations from the Alexo formation

Figure 18. Photomicrograph of highly organic layer in the Costigan member of the Palliser formation. Magnification. X20

Plate X

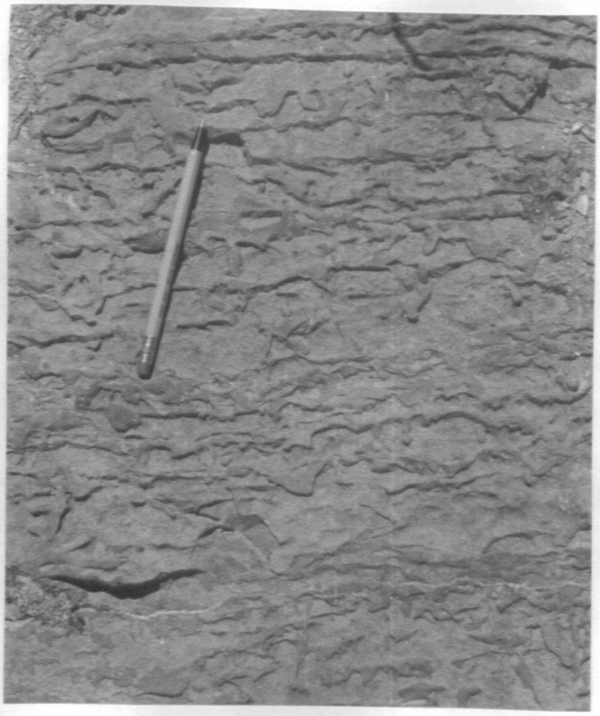

Figure 19, Dolomitic mottling normal to bedding in Morro member, Palliser formation

Figure 20. Dolomitic mottling normal to the bedding in Morro member, Palliser formation

Plate XI

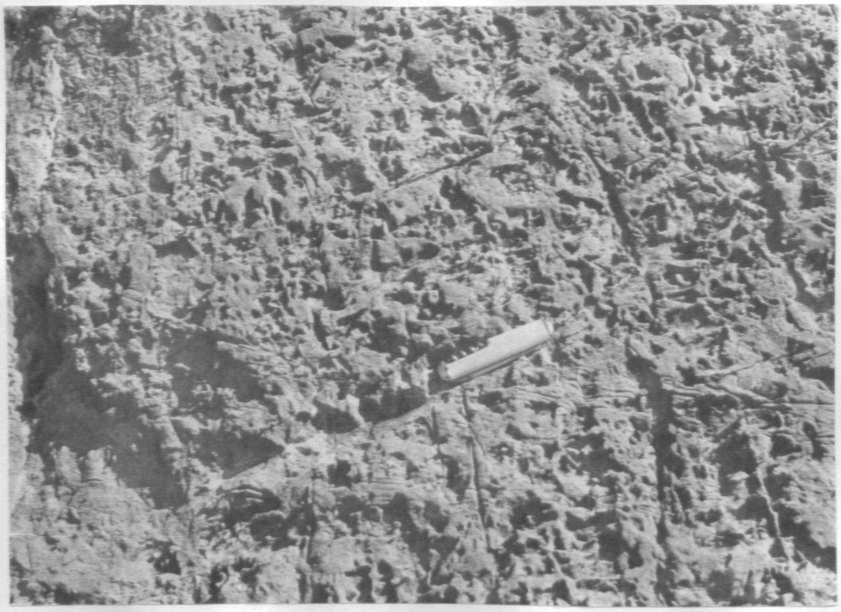

Figure 21. Dolomitic mottling in Morrow member of the Palliser formation, which has almost completely replaced the original limestone

Figure 22. Dolomitic mottling in Morro member of the Palliser formation, showing a bedding surface

Plate XII

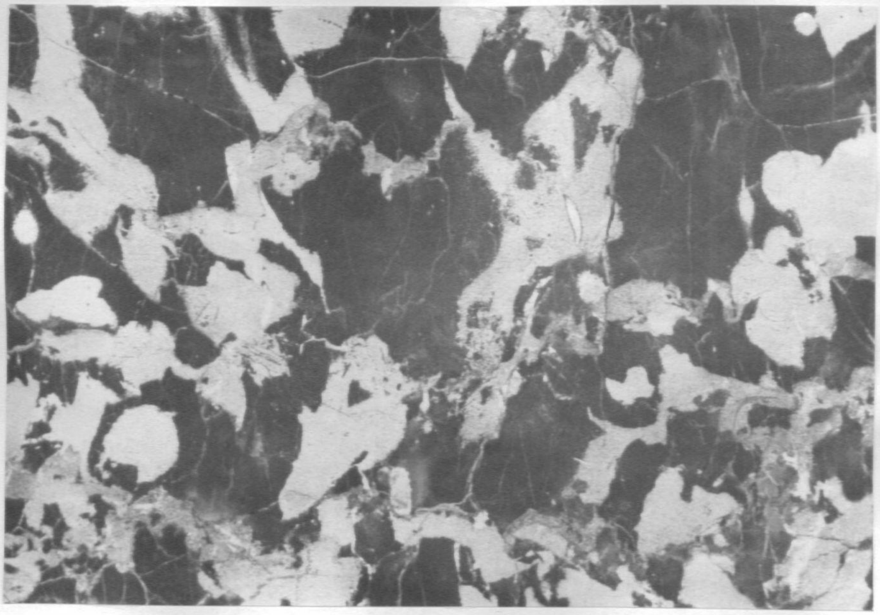

Figure 23. Acid etched polished surface of dolomitic mottling in the Morro member of the Palliser formation. Dolomite is white and medium crystalline, limestone is black and dense

Figure 24. Stylolitic seam separating medium and coarse-grained dolomite. Magnification X35

Plate XIII

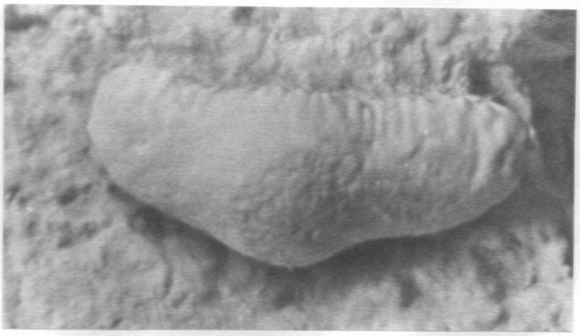

Figure 25. Fish tooth? from the lowermost surface of the Exshaw formation. Magnification 8x

Figure 26. Very thin bedded, platy shales of the Lower Banff member.

Plate XIV

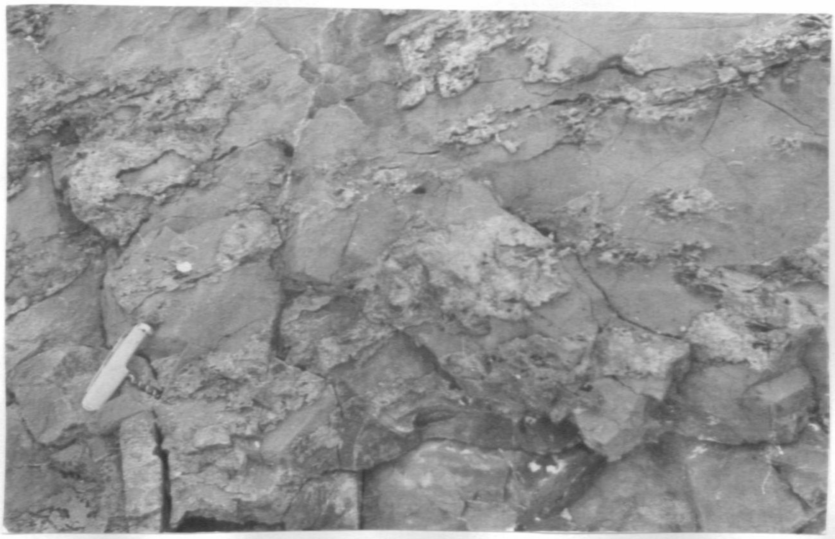

Figure 27. Chert nodules in upper part of the Mt. Head formation. Probably originated by the replacement of the limestone

Figure 28. Very irregular chert masses in dense limestone of the upper Mt. Head formation. Probably secondary in origin

Plate XV

Figure 29. Lenses and layers of black chert in the lower part of the Livingstone formation

Figure 30. Bedding surface of figure 29 showing donut-shaped black chert nodules. These suggest a primary origin.

Plate XVI

Figure 31. Glacial till and stream gravels exposed in river terrace. South side of Kananaskis River, north end of Lac des Arcs Ridge

Figure 32. View looking south-southwest from highway at northeast corner of Lac des Arcs Ridge. Most northerly exposure of Palliser in fault-slice on east side of the ridge.

Plate XVII

Figure 33. View looking south at east side of Lac des Arcs Ridge. Wasootch Creek at left.

Figure 34. View looking northwest at southern termination of fault slice of Palliser. Anticlinally folded Palliser is faulted over by Southesk, and itself faulted over west dipping lowermost Palliser. Mt. Lorette in background, Wasootch Creek in foreground.

Figure 35. Synclinally folded Palliser formation, faulted over by steeply Southesk formation. Fault occupies almost vertical, snow-filled gully