GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 68-24

PRELIMINARY ACCOUNT OF THE GEOLOGY OF LIMESTONE MOUNTAIN MAP-AREA, SOUTHERN FOOTHILLS, ALBERTA

(Report, 3 figures, 3 plates, and map 8-1968)

N. C. Ollerenshaw

Price, $1.50

1968

CANADA

GEOLOGICAL SURVEY
OF CANADA

PAPER 68-24

PRELIMINARY ACCOUNT OF THE GEOLOGY OF LIMESTONE MOUNTAIN MAP-AREA, SOUTHERN FOOTHILLS, ALBERTA

N. C. Ollerenshaw

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Available by mail from the Queen's Printer, Ottawa,

from Geological Survey of Canada,
601 Booth St., Ottawa,

and at the following Canadian Government bookshops:

HALIFAX
1735 Barrington Street

MONTREAL
Æterna-Vie Building, 1182 St. Catherine St. West

OTTAWA
Daly Building, Corner Mackenzie and Rideau

TORONTO
221 Yonge Street

WINNIPEG
Mall Center Bldg., 499 Portage Avenue

VANCOUVER
657 Granville Street

or through your bookseller

Price $1.50 Catalogue No. M44-68-24

Price subject to change without notice

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, Canada
1968

CONTENTS

Illustrations

ABSTRACT

Limestone Mountain map-area is a region of about 200 square miles in the southern foothills of the Rocky Mountains of Alberta. The area is underlain by marine and non-marine sedimentary rocks deposited in a shelf environment and ranging in age from Middle Cambrian to Late Cretaceous. Carbonate sequences predominate in the Paleozoic strata, whereas arenaceous, lutaceous and rudaceous rocks are dominant in the Mesozoic.

The rocks of the area have been thrust relatively northeastward along three major thrust faults; the McConnell thrust, Burnt Timber thrust and Fallentimber thrusts respectively from southwest to northeast. Two-thirds of the area lies within the Fallentimber thrust-sheet. The McConnell and Burnt Timber thrust-sheets form southwest-dipping homoclinal sequences at the surface, although the Burnt Timber thrust-sheet is folded at depth. The mountain front coincides with the surface trace of the McConnell thrust fault.

Fallentimber thrust-sheet is divided into three structural units which are, from southwest to northeast, the Limestone Mountain anticlinorium, Bread Creek synclinorium and Marble Mountain anticlinorium, respectively. Fold axes within these structures are arranged en echelon and the folds have profiles ranging from symmetrical to asymmetrical, and overturned. Numerous thrust faults, mainly splays from the Fallentimber thrust, cut the folds and are themselves locally folded. The overall plunge of the structures is northwest toward Tay River and southeast toward James River as a result of the pronounced Limestone Mountain culmination in the Fallentimber thrust-sheet.

Drilling has so far failed to reveal reservoirs of natural hydrocarbons within the area, but there are still some interesting structures to be explored.

PRELIMINARY ACCOUNT OF THE GEOLOGY OF LIMESTONE MOUNTAIN MAP-AREA, SOUTHERN FOOTHILLS, ALBERTA

INTRODUCTION

LOCATION AND ACCESS

Limestone Mountain map-area lies within the southern Foothills of Alberta between latitudes 51° 45' and 52° 00' and longitudes 115° 15' and 115° 30'. It is mainly south of Clearwater River and includes part of the Front Range of the Rocky Mountains in its southwest corner. It adjoins Tay River map-area to the north, Burnt Timber Creek West map-area to the south, Marble Mountain map-area to the east and Scalp Creek map-area to the west.

Limestone Mountain map-area lies within the Alberta Forestry Reserve (Clearwater and Bow River districts). It can be reached from Highway No. 1A, northward along the forestry road nine miles west of Cochrane; southward along the forestry road from Nordegg; and west from Highway No. 2 by way of Olds, Sundre and Bearberry or by way of Innisfail, Caroline and Ricinus.

Main access within the area is by means of the forestry road system in the southwest and northeast corners. A poor quality, gravel road runs diagonally northwestward across the area from James River in the southeast to a forestry fire lookout on the peak of Limestone Mountain. Numerous seismic lines (bulldozed tracks) give rough access to points northeast and southwest of the roads. Most are not suitable even for four-wheel drive vehicles.

FIELD WORK AND ACKNOWLEDGEMENTS

Field work was carried out in 1964, assisted by Messrs. M.E. Atchison, N.L. Ball, K.R. Bygrave, J.S. Morlock and I.J. Sundkuist (cook). The writer is indebted to Messrs. P. Bifano, F. Jones and J. Young of the Alberta Forestry Service for their invaluable cooperation and assistance.

STRATIGRAPHY

MIDDLE CAMBRIAN

Pika and Arctomys Formations

The existence of the Arctomys Formation and a faulted slice of Pika Formation beneath talus cover above the McConnell thrust in the southwest corner of the map-area, is inferred from exposures in Burnt Timber Creek area to the south. Northwest along the mountain front, these two formations are truncated by the McConnell thrust. The Pika Formation is 300 feet thick and the Arctomys 70 feet thick in the Burnt Timber West area (Ollerenshaw, 1965).

TABLE OF FORMATIONS

Era	Period or Epoch	Group	Group or Formation Thickness (feet)	Lithology
Cenozoic	Pleistocene and Recent			Gravel, sand, silt, clay
Unconformity				
Mesozoic	Upper Cretaceous		Brazeau Formation	Greenish-grey and grey sandstone, mudstone, conglomerate and shale; minor bentonite and coal (non-marine)
		Alberta Group	Wapiabi Formation 1,600-1,800	Dark grey shale, calcareous shale, concretionary shale; argillaceous sandstone; laminated siltstone (marine)
		Alberta Group	Cardium Formation 300	Grey, very fine grained sandstone; dark grey shale; conglomerate (marine)
		Alberta Group	Blackstone Formation 1,200-1,400	Dark grey shale, calcareous shale; platy siltstone layers; minor sandstone (marine)
	Disconformity			
	Lower Cretaceous	Blairmore Group	Beaver Mines Formation 700-800	Greenish grey sandstone, siltstone, mudstone; conglomerate; minor shale (non-marine)
		Blairmore Group	Lower part of Blairmore Group 400-450	Grey sandstone and siltstone; dark grey to black shale; minor limestone and coal (non-marine)
		Blairmore Group	Cadomin Formation 30-75	Light grey conglomerate, pebbly sandstone and sandstone (non-marine?)
	Disconformity			

TABLE OF FORMATIONS (Cont'd)

Era	Period or Epoch	Group	Group or Formation Thickness (feet)	Lithology
Mesozoic	Lower Cretaceous and Jurassic		Kootenay Formation 0-3,200	Grey sandstone; dark grey to black, carbonaceous and limonitic sandstone, siltstone and shale; minor coal (non-marine)
	Jurassic	Fernie Group	Upper Members 100	Dark grey to black shale; minor dark grey sandstone and siltstone (marine)
		Fernie Group	Nordegg Member 100-150?	Very dark grey, cherty limestone and oolitic limestone; chert; shale (marine)
	Disconformity			
	Triassic		Sulphur Mountain Formation 0-300	Platy, grey and brown dolomitic siltstone (marine)
Disconformity				
Paleozoic	Pennsylvanian and (?) Permian		Rocky Mountain Group 1 inch - 100 feet	Sandstone; dolomitic sandstone; chert; chert breccia (marine)
	Disconformity			
	Mississippian		Etherington Formation 0-200	Brown, grey and yellow dolomites, commonly cherty; minor chert, sandstone and limestone (marine)
		Rundle Group	Mount Head Formation 122-425	Grey and brown dolomites; dolomitic limestone; minor chert; rare sandstone (marine)
		Rundle Group	Turner Valley Formation 100-245	Crinoidal, light grey limestone and dolomitic limestone; minor calcarenite and oolite (marine)
		Rundle Group	Shunda Formation 155-210	Yellow-brown, recessive dolomite; dolomite breccia; limestone and minor shaly dolomite (marine)

TABLE OF FORMATIONS (Cont'd)

Era	Period or Epoch	Group	Group or Formation Thickness (feet)	Lithology
Paleozoic	Mississippian	Rundle Gp	Pekisko Formation 180-200	Light grey weathering crinoidal limestone; brown dolomite; calcarenite; oolite (marine)
	Mississippian		Banff Formation 675-740	Platy to thin bedded, argillaceous and silty limestone; black chert layers; crinoidal limestone and dolomite (marine)
	Mississippian		Exshaw Formation 0-70	Black shale and yellowish orange weathering, calcareous siltstone (marine)
	Disconformity			
	Upper Devonian		Palliser Formation 640	Massive, grey-brown dolomite; mottled limestone-dolomite; fossiliferous grey limestone of the Costigan Member at the top (marine)
	Upper Devonian		Alexo Formation (Mountains) 165	Brown and grey dolomite; silty dolomite; calcareous dolomite; dolomite breccia and conglomerate; greenish siltstone (marine)
	Upper Devonian		Sassenach Formation (Foothills) Up to 130	Fine grained, yellowish grey, quartz sandstone and dolomitic sandstone (marine)
	Upper Devonian	Fairholme Group	Mount Hawk[1] Formation (Foothills) +300 ?	Fine grained to dense, grey limestone and argillaceous limestone (marine)
	Upper Devonian	Fairholme Group	Southesk Formation (Mountains) 590	Light grey, fine to coarse crystalline dolomite; minor medium to dark brownish-grey dolomite (marine)
	Upper Devonian	Fairholme Group	Cairn Formation 725	Dark brownish-grey and grey dolomite; minor dark grey limestone and dolomitic limestone; minor limestone breccia (marine)

TABLE OF FORMATIONS (Cont'd)

Era	Period or Epoch	Group or Formation Thickness (feet)	Lithology
Paleozoic	Middle Devonian	Yahatinda Formation (Mountains) 0-50	Thin-bedded dolomite and dolarenite; dolomite conglomerate (marine)
	Disconformity		
	Upper Cambrian ?	Lynx Formation 400-600	Dolomite; silty dolomite; dolomitic siltstone; minor shale, calcarenite, oolite and chert (marine)
	Middle Cambrian	Arctomys Formation 70	Platy, dolomitic siltstone and shale; minor evaporitic breccia (marine)
		Pika Formation 300	Thin-bedded, brown and grey dolomitic siltstone and limestone; silty dolomite; conglomerate; calcarenite and oolite (marine)

[1] Lateral facies equivalent of the Southesk and at least part of the Cairn Formation.

The main features of the Pika Formation are its banded, rhythmic alternations of limestone and silty dolomite in beds up to 1½ inches thick; abundant flat-pebble conglomerate; thin to very thin bedding; and, locally, beds of dolomite, oolite and calcarenite. Trilobite fragments occur in the lower third of the formation and brachiopods in the lower half. *Paterina* sp. and ?*Pegmetreta* sp. were collected by the writer in Burnt Timber Creek West area. These fossils from GSC localities 58789 and 58790 were identified by W. H. Fritz, May, 1967, and assigned to the Middle Cambrian.

The Arctomys Formation consists of platy, yellowish to greenish grey and local, pinkish grey, dolomitic siltstones and fissile, shaly siltstone, containing ripple-marks, mud-cracks, cross-ripple lamination, casts and impressions of salt crystals, and local solution breccias. The rocks were deposited in warm, shallow water and in an evaporitic environment.

UPPER CAMBRIAN

Lynx Formation

The Lynx Formation is variably exposed above the talus cover at the mountain front and an incomplete section, 500 feet thick, was measured. The actual thickness probably ranges between 400 and 600 feet. The Lynx overlies the Arctomys Formation conformably and gradationally.

The Lynx is a relatively resistant formation, typically massive to thick-bedded, but with local, incipient medium bedding and becoming commonly thin-bedded in the upper part. It is locally laminated. Fine- to very fine-grained silty dolomites and dolomitic siltstones form the predominant lithology with medium- to coarse-grained, commonly saccharoidal dolomites abundant in the upper part. Oolites, calcarenites, intraformational conglomerates and chert lenses occur in places. The rocks are typically light to medium yellowish grey, grey and yellow-brown, with local greenish grey, pink and reddish hues. Minor, local structures include ripple-marks, mud-cracks, small erosion channels and evidence of penecontemporaneous deformation. No fossils have been found in the formation within the area other than a few poorly preserved stromatolites. Small pockets of green clay occur sporadically in the upper beds.

MIDDLE DEVONIAN

Yahatinda Formation

The Cambrian-Devonian contact is marked by an erosional disconformity between the Lynx and Yahatinda Formations. The layering of these formations is essentially parallel and the contact is commonly vaguely defined. In some places the contact is sharp, with a relief of up to 40 feet where large, conglomerate-filled erosion channels cut down into the Lynx Formation and clearly define the break.

The Yahatinda Formation typically varies from a feather edge to 20 feet in thickness, but increases locally to more than 50 feet across the channels. The upper surface of the Lynx displays evidence of weathering and solution, including open joints, solution channels and the scattered pockets of green clay. Local evidence of minor erosion as well as the presence of red beds within the upper part of the Lynx Formation, suggest temporary, local emergence prior to the major Cambrian-Devonian break. These features make it difficult to place the contact exactly.

The channel conglomerates commonly consist of angular to sub-rounded phenoclasts, closely set in a sandy or silty dolarenitic matrix. The composition of the phenoclasts suggests derivation from the underlying Lynx Formation and they range in size from pebbles to boulders. The largest phenoclast noted had dimensions of 6 feet by 15 feet. A few of the larger blocks consist of bedded material. Local derivation and short transport are indicated.

Up to 10 feet of thin-bedded to platy, grey and yellow-brown, fine-grained dolomites and dolarenites commonly overlie the channel deposits and occur where the channels are absent. These beds are commonly silty or sandy (quartz).

UPPER DEVONIAN

Fairholme Group

The Fairholme Group is represented in the area by the Cairn and Southesk Formations above the McConnell thrust in the Mountains and by the Mount Hawk Formation on Limestone Creek in the Foothills.

Cairn Formation

The Cairn-Yahatinda contact was not seen in the Limestone Mountain area. Exposures in the Burnt Timber Creek West area, immediately to the south, indicate that the formations are essentially conformable with a gradual change to bedded, darker grey, calcareous dolomite, containing Amphipora beds.

The Cairn Formation is about 750 feet thick in Limestone Mountain area. A section on a spur at the mountain front, one mile northwest of line of section C-D, consists of two main facies; a lower or limestone facies, and an upper or dolomite facies.

The limestone facies consists of the basal 200 feet of the formation and can be subdivided into three units. The lower 40 feet consist of medium crystalline, dark grey and brownish grey dolomite with minor amounts of dolomitic limestone. The middle 60 feet consist of very fine-grained, dark grey, light grey-weathering limestones with subordinate dolomitic limestone and calcareous dolomite. In the upper 100 feet the proportion of dolomite increases at the expense of the limestone and the unit consists of dolomite, mottled limestone-dolomite, calcareous dolomite, dolomitic limestone and some limestone. Dark grey chert lenses and stringers occur locally in the beds of the limestone facies.

Beds of limestone and dolomite breccia occur at two places in the limestone facies. One such breccia bed, 5 to 10 feet thick, consistently occurs about 40 to 50 feet above the base of the formation, whereas another bed, 10 feet thick, was noted in one section 25 feet above the base. The uppermost breccia bed consists of angular fragments (mainly 2-8 inches in length) of fine-grained, dark grey, dolomitic limestone. A few small, dark grey, chert fragments also occur. The breccia is overlain and underlain by dolomitic limestones of the same type as that forming the breccia. The lower breccia consists of angular fragments of medium crystalline, dark brownish grey dolomite, in a light grey-weathering limestone matrix. The writer concurs with Aitken (1966) that these breccias are not tectonic and most probably originate through the solution of evaporites and subsequent collapse. Stromatoporoids first appear about 35 feet above the top of the upper breccia bed and occur as both chert-replaced and limestone masses.

The dolomite facies of the Cairn Formation occupies the interval between 200 and 750 feet above the base of the formation and consists mainly of medium crystalline, dark grey and brownish grey, crystalline dolomites with local stromatoporoid beds. Poorly preserved corals and gastropods were also observed. Many beds are vuggy and porous and some are honeycombed with cavities from ¼ of an inch to 5 inches in diameter. Alternating medium to thick beds of lighter and darker dolomite occur in the upper part of the formation.

Southesk Formation

The contact between the Cairn and Southesk Formations is a gradational one, with dark (Cairn) and light (Southesk) beds alternating in the contact zone.

The Southesk Formation is 590 feet in thickness in the section at the mountain front 3/4 mile southeast of line of section C-D and is typically a medium to coarsely crystalline, saccharoidal, light grey, massive to thick-bedded dolomite that is commonly porous and vuggy. Units of dark grey dolomite occur locally within the Southesk and increase in abundance and merge northwestward until the formation is almost entirely dark coloured at the western edge of the map-area. Stringers and nodules of grey and black chert occur locally. In places poorly preserved corals and rare brachiopods were observed.

Mount Hawk Formation

(Foothills Only)

In the Foothills, below the McConnell and Burnt Timber thrusts, a different facies of the Fairholme Group is exposed on Limestone Creek, north of Limestone Mountain. This facies has been assigned to the Mount Hawk Formation. No detailed stratigraphic work has been attempted at this locality, owing to poor, scattered exposure, as well as folding and faulting. The upper 300 to 400 feet only of the formation occur above the present erosion surface, so that the thickness of the formation has not been established.

Integration of scattered outcrop data suggests that three main units of the formation are exposed on the creek. The upper part of the formation consists of more than 100 feet of dense to very fine-grained, hard and splintery, medium-dark grey, light to light-medium grey-weathering limestone, containing scattered brachiopods. This limestone is fairly uniform. The middle unit consists of at least 40 feet of interbedded limestone and dolomitic limestone. The limestone is very fine-grained and medium grey. The dolomitic limestone is very fine-grained, light-medium yellow-brown and light yellowish grey-weathering. Beds are wavy, $\frac{1}{4}$ to 1 inch apart, with common pinching and swelling. Some beds are lenticular. The lowest unit exposed comprises more than 100 feet of argillaceous, fine-grained, medium grey limestone. This limestone is massive and weathers to a conspicuous light yellowish grey. It has a pronounced platy cleavage.

According to drilling data, additional Devonian strata, including some Cairn Formation, occur below the Mount Hawk in the subsurface.

Alexo Formation

(McConnell thrust sheet only)

In the McConnell thrust sheet, a recessive interval separating the Southesk and Palliser Formations has been loosely referred to the "Alexo Formation" because the lack of diagnostic evidence precludes more specific identification at the present time. Strata equivalent to the Sassenach Formation may be also included in this interval. The "Alexo" is 165 feet thick (measured three quarters of a mile southeast of line of section C-D on a spur at the mountain front), and overlies the Southesk Formation with apparent conformity.

The upper and lower parts of the formation display some lithological differences. Silty dolomites and siltstones predominate in the lower 100 feet, calcareous dolomites in the upper 65 feet. A few limestone beds occur in the upper part. The lower 85 feet consist mainly of light to light-medium grey and yellowish grey beds, and include 19 feet of green siltstone. The upper 80 feet consist of medium-dark to dark brownish grey beds with minor amounts of coloured light grey and light yellow-brown. The formation is mainly fine-grained, with scattered medium- to coarse-grained beds increasing in proportion upwards.

The rocks are very commonly laminated with minor banding and rare, small-scale, cross-lamination. The lamination is based mainly on colour, partly on grain size and to a lesser extent on composition. Bedding separation is typically thin and locally platy with a few thick, massive beds. The calcareous dolomite beds are commonly porous and vuggy.

Beds of breccia and intraformational conglomerate are common throughout the formation. The constituents of both are derived from strata within the formation. The breccias are attributed to collapse owing to solution of evaporitic material. Breccia 'dykes' locally cut across the bedding. The conglomerates indicate shallow-water conditions and wave or current erosion. Phenoclasts are angular to sub-rounded, flat, and pebble- to cobble-size. The bedding is locally truncated by erosion surfaces and channels, with a relief ranging from a few inches to seven feet. One or two beds show evidence of penecontemporaneous deformation in the form of plastic foliation.

Sassenach Formation

(Foothills only)

Outcrops of sandstone, on the hillside, southeast of Limestone Creek, have been assigned to the Sassenach Formation. This section, including covered intervals, is 130 feet thick, but may be thickened by faulting.

The sandstones are quartzose, commonly dolomitic, very fine-grained, light yellowish grey, yellow-brown and grey in colour, with a poorly developed separation at from 1-inch to 12-inch intervals. The clastic grains are sub-angular to sub-rounded.

Palliser Formation

The Palliser Formation shows little change in general lithology across the map-area from the Mountains to Limestone Creek in the Foothills. The Palliser Formation in Limestone Mountain area is, however, more recessive and contains a greater proportion of dolomite and less mottled dolomitic limestone than is the case farther south around Bow River valley.

The Palliser Formation is 640 feet thick above the McConnell thrust (section measured is one mile northwest of line of section C-D, on a spur at the mountain front) and is estimated to have a similar thickness on Limestone Creek. The contact with the underlying "Alexo Formation" is conformable and gradational, and is arbitrarily placed where thin-bedded, recessive rocks change to massive, resistant strata (Palliser). In one section, the contact coincides with an erosion surface having a relief of from 3 to 4 inches, overlying a thin conglomerate bed in the "Alexo". Fossiliferous, resistant, grey limestones of the Costigan Member occur at the top of the Palliser Formation throughout the area, forming a small but conspicuous cliff, 30 to 40 feet high.

Above the McConnell thrust fault, the Exshaw-Palliser contact is conformable, but abrupt and slightly uneven. A bed of sandstone, 6 inches to 12 inches thick, forms the top of the Palliser. In a gully on the northwest side of the summit of Limestone Mountain, the upper surface of the Palliser is also uneven and silty and contains scattered, large, fish bone fragments (GSC locality 70731) that Dinely, D.L. (personal communication, 1966) identified as "...from a large pachyosteid arthrodire such as Dinichthys." Dinely also comments that, "...these pachyosteids are of Middle and Upper Devonian distribution," and that the size of the specimen found suggests a Late Devonian age. The sandstone or siltstone bed at the top of the Palliser is probably a lag concentrate.

MISSISSIPPIAN

Exshaw Formation

Above the McConnell thrust, the Exshaw Formation consists of a recessive lower unit of black shale and a resistant upper unit of calcareous siltstone. The writer previously included the siltstone as the basal unit of the Banff Formation in the Burnt Timber Creek West area to the south (Ollerenshaw, 1965). The siltstone is medium brownish grey to bluish grey and platy to thin-bedded. It weathers to a conspicuous light-medium yellow- to orange-brown. Scattered sub-spherical, iron-stained cavities from $\frac{1}{4}$ inch to 3 inches in diameter occur locally and some are filled with finely crystalline pyrite. Two sections were examined, one on Eagle Creek and one at the mountain front six miles to the north. On Eagle Creek, the Exshaw is 70 feet thick, including a 20-foot covered interval at the base overlain by 50 feet of the siltstone unit. At the mountain front, the Exshaw has thinned to 41 feet, and consists of 16 feet of shale overlain by 25 feet of siltstone.

The Exshaw Formation was not observed in the Foothills. It could occur in a covered interval between the Palliser and Banff Formations north of Limestone Mountain, but would have a maximum thickness of only 12 feet.

Banff Formation

The Banff Formation is 675 feet thick on Eagle Creek, in the McConnell thrust-sheet, and 740 feet thick on the northwest side of Limestone Mountain in the Fallentimber thrust-sheet. The Banff Formation is apparently conformable with the Exshaw strata and the upper siltstone unit of the latter has a strong lithological affinity with the Banff.

In the Rocky Mountains, that is, on Eagle Creek in the McConnell thrust-sheet, the Banff Formation is divisible into three major units, that can be clearly differentiated on air photographs.

The basal unit consists of 330 feet of light yellow-brown-weathering, platy (beds between 1/8 inch to 2 inches thick), locally laminated and banded, calcareous siltstone, with scattered black or brown chert layers and lenses commencing about 65 feet above the base.

The middle unit is 150 feet thick and is darker weathering than the basal unit. The lower 80 feet consist of relatively resistant and solid, medium reddish brown-weathering, calcareous siltstone, with an incipient platy separation changing upward to thin, wavy-bedded siltstone. The overlying beds are typically brownish weathering, calcareous siltstones, with a thin, wavy bedding. Scattered layers and lenses of black or brown chert occur throughout the middle unit.

The upper unit consists of recessive intervals of platy to thin-bedded and locally shaly, argillaceous and calcareous siltstone or silty limestone, separated by ledges of resistant limestone 2 to 30 feet thick. The resistant limestones are commonly coarse-grained and crinoidal, light grey-weathering, with a 2- to 6-inch separation and reflect a transition to the carbonate deposition in the overlying Rundle Group.

A minor facies change occurs northwestward in the Banff Formation above the McConnell thrust. The light weathering character of the basal unit changes 5 miles northwest of Eagle Creek and the formation assumes a uniform darker hue. In the same direction, the base of the middle unit becomes less resistant and distinct.

In the Foothills section of the Banff Formation, outcropping in the Fallentimber thrust-sheet, there is no obvious distinction into basal and middle units and the two are combined. The rock is generally less platy and more commonly thin-bedded than is the case in the McConnell thrust-sheet. The upper unit is still distinct but changes lithologically to consist of about 50 per cent dolomite in the Foothills. Mud-cracks occur locally in these dolomites, reflecting shallow-water deposition.

Rundle Group

The Rundle Group is 1,300 feet thick (graphic estimate) above the McConnell thrust and is divisible into the Pekisko, Shunda, Turner Valley, Mount Head and Etherington Formations. The Group thins eastward to 650 feet at the summit of Limestone Mountain (composite section) and 554 feet in the northeast corner of the map-area on Clearwater River. This thinning is partly the result of the absence of the Etherington Formation east of and below the McConnell thrust and the thinning of the Mount Head Formation.

In the Fallentimber thrust sheet the Pekisko Formation is 200 feet thick, the Shunda 155 feet thick, and the Turner Valley 100 feet thick (from sections on Limestone Mountain and Clearwater River, ½ mile upstream from the bridge). The Mount Head

Formation thins from 223 feet on Limestone Mountain to 122 feet on the Clearwater River at the northeast edge of the map-area.

The Pekisko Formation consists largely of limestone which is commonly crinoidal, light grey-weathering and typically cliff-forming. Calcarenites, pelletal limestones, oolites, pisolites and chert layers occur locally. On Limestone Mountain Pekisko beds form three distinct limestone cliffs, separated by recessive, dolomite units.

The Shunda Formation is recessive and seldom exposed. It includes common collapse breccias that are attributed to the solution of evaporitic material. The best section of the Shunda Formation is exposed on the Clearwater River.

The Turner Valley Formation consists predominantly of resistant, light grey-weathering, coarse-grained crinoidal limestones. In the Fallentimber thrust-sheet, dolomitization has obliterated much of the primary crinoidal texture. Crinoidal limestones are clearly visible in the basal 30 to 50 feet, but original textures are progressively obscured above this interval by dolomitization that has produced a fine-grained, porous to vuggy, yellow-brown dolomite with only sporadic coarse-grained, relict crinoid debris. The top of the Turner Valley is placed where the relict crinoidal texture disappears and the rock becomes a dense dolomite typical of the Mount Head Formation. Above the McConnell thrust, the Mount Head includes some fine-grained dolomites and sporadic beds of sandstone. Cherts and banded cherts are common in the Mount Head Formation and, in the Fallentimber thrust-sheet, these cherts commonly show slump fold structures typical of penecontemporaneous deformation.

The Etherington Formation consists of very fine-grained, cherty, brown, grey and yellow dolomites, with scattered beds of chert, and sandstone. Mud-cracks occur in one bed.

All the formations within the Rundle Group are conformable, at least on a local scale, and largely gradational. The Pekisko Formation overlies the upper unit of the Banff Formation conformably and the crinoidal limestones of the latter reflect the gradual introduction of the Pekisko environment.

PENNSYLVANIAN AND ? PERMIAN

Rocky Mountain Group

In the McConnell thrust sheet, about 100 feet of partially exposed strata, including sandstone and chert, have been assigned to the Rocky Mountain Group. These beds overlie the Etherington Formation with apparent conformity.

In the Fallentimber thrust-sheet, the top of the Mount Head Formation is an erosional disconformity, overlain by sandstone of unknown but possibly Pennsylvanian and ?Permian age. This sandstone unit varies from ½ inch to 30 feet in thickness. It contains chert beds locally in its upper part and pebbly sandstone in places near the base. At an outcrop several miles north of Marble Mountain, in Marble Mountain map-area, the sandstone is 16 inches thick and contains scattered chert pebbles. Sharks' teeth and bone fragments are scattered amongst the phenoclasts. The upper surface of the Mount Head Formation is commonly cracked and penetrated by the sandstone, and the sandstone locally contains angular to rounded phenoclasts of the Mount Head dolomite. It would appear that the sandstone is a lag concentrate. Similar quartz sandstone occurs as the matrix to small pockets of breccia or as laminae and beds within the Mount Head dolomites in the top 10 to 20 feet of the formation.

TRIASSIC

Spray River Group

Sulphur Mountain Formation

The Sulphur Mountain Formation typically consists of platy to thin-bedded and locally medium-bedded, light yellowish brown to medium brown, medium reddish brown-weathering, dolomitic siltstones and very fine-grained sandstones. These rocks are commonly finely laminated. The laminae are dark grey and locally concentrated into bands 1/16 inch to 1 inch thick. One bed, 15 inches thick, near the base displays convolute bedding structures indicating penecontemporaneous slumping. Pelecypods are common in some beds and have been identified (E.T. Tozer, personal communication, 1965) as cf. Eumorphotis multiformis Bittner, of Early Triassic age (GSC locality 65062).

A thickness of 260 feet was measured on the line of section C-D. The total thickness of the Sulphur Mountain Formation is estimated to be about 300 feet. The lower contact with the Rocky Mountain Group was not observed, but the two formations appear conformable. Strata of the Whitehorse Formation may underlie the talus-covered dip-slope in the extreme southwest corner of the map area.

Triassic strata are absent in the Fallentimber thrust sheet.

JURASSIC

Fernie Group

The Fernie Group is poorly exposed in Limestone Mountain map-area. Accessible outcrops occur on the ridge one mile south of Limestone Mountain (Nordegg Member) and on Willson Creek about three quarters of a mile west of the eastern edge of the map-area (upper members).

The Fernie Group is estimated to be between 200 and 250 feet thick. It overlies the Rocky Mountain Group (?) sandstones conformably and may include at least part of these sandstones. Where the sandstone veneer is very thin, the Fernie Group virtually rests on the Mount Head Formation.

Owing to the small thickness involved, it was only practicable to map the Fernie Group as two units; the Nordegg Member at the base, with a collective unit, informally designated the "upper members", above.

The Nordegg Member has a minimum thickness of 90 feet at Limestone Mountain and is 105 feet thick to the northeast on the Clearwater River (one half mile upstream from the bridge). In this area, the Nordegg consists of three sub-units.

The basal unit which is recessive and typically covered, consists of at least three feet of soft, medium brown shale on Limestone Mountain and 1.5 feet of platy, argillaceous siltstone, with minor shale layers on Clearwater River.

The middle unit is between 23 and 62 feet thick on Limestone Mountain and 81 feet thick on Clearwater River. This unit typically consists of chert, with subordinate platy, argillaceous, silty and cherty limestone. The chert content varies laterally from 40 per cent to 90 per cent of the unit. The chert is typically dark grey to black, with minor blue tints and occurs in pinching and swelling layers, lenticular beds and nodules. The top of this unit is commonly fossiliferous for several feet, and contains layers of large oysters and other pelecypods, including *Oxytoma* and a few scattered sharks' teeth (GSC locality 65057). This fauna is of Sinemurian age (Frebold, 1966).

The uppermost unit is at least 25 feet thick on Limestone Mountain and 22.5 feet thick on Clearwater River. It consists of platy, commonly oolitic limestones with minor small lenses of chert. The original ooliths are replaced by spherulitic chert and are visible as relict structures only. The limestones are slightly silty, very dark grey, light brownish grey-weathering and locally contain specimens of the ammonite *Amaltheus* sp. (GSC localities 65058 and 65210) of Pliensbachian age (Ollerenshaw, 1965; Frebold, 1966).

In Limestone Mountain area, the Nordegg Member attains its greatest development in terms of age and lithology. To the north, in the Nordegg-Cadomin region of the Foothills, the uppermost Pliensbachian unit of platy limestone is absent, apparently lensing out north of Limestone Mountain area. To the south the situation is reversed and the upper, platy limestone unit constitutes the bulk of the Nordegg Member, the middle chert unit lensing out in that direction. Thus, there are northern and southern facies of the Nordegg Member, both of which are represented in the transitional Limestone Mountain area. The northern facies is characterized by a high chert content and a Sinemurian age, the southern facies by platy limestone of Pliensbachian age, with minor Sinemurian beds at the base. Apart from the relative abundance of chert and the age difference, the middle and upper units possess the same basic lithology, bedding and general appearance, justifying the inclusion of the upper unit in the Nordegg Member. In sections of the southern facies, on Sheep Creek (Burnt Timber Creek area) and along the Cascade River, about one foot of basal sandstone is present, locally filling mud-cracks in the Triassic surface beneath.

The "upper members" of the Fernie Group are mainly dark grey to black shales with minor siltstone and sandstone and local belemnite beds. Details of stratigraphy must be interpreted from small, scattered outcrops, but by comparison with sections in adjoining areas it would appear that the Toarcian Paper Shales, Rock Creek Member and Transition Beds are present, with estimated thicknesses of 30 feet, 85 feet and 11 feet respectively.

JURASSIC-LOWER CRETACEOUS

Kootenay Formation

The top 200-300 feet only of the Kootenay Formation remain in the hanging wall of the Burnt Timber thrust and the actual thickness of the formation there is unknown. In the Fallentimber thrust-sheet the formation is 150 feet thick along the ridge one and one-half miles southeast of Limestone Mountain and is not present in the northeast corner of the map-area. The absence of the Kootenay in the northeast results from the general eastward thinning and wedging out of the formation, together with erosion prior to the deposition of the overlying Cadomin Formation.

A consistent unit of fine-grained, quartzose sandstone, about 60 feet thick, occurs at the base of the Formation and is considered to be the equivalent of the Moose Mountain Member farther south. The remainder of the Kootenay consists of black, carbonaceous shales and intercalated, platy to thin sandstone beds. Worm borings are common in some of these sandstones. The Kootenay overlies the Fernie conformably, with a gradation from shale to sandstone at the contact.

LOWER CRETACEOUS

Blairmore Group

Cadomin Formation

The Cadomin Formation overlies the Kootenay disconformably on an erosional surface, with a visible local relief of up to 8 feet. Northeast of Limestone Mountain, the erosion surface cuts down through the Kootenay Formation onto the Fernie Group, although scattered remnants of Moose Mountain sandstone remain locally as far as the Clearwater River, demonstrating a change of relief in the order of 100 feet over a distance of three miles.

The Cadomin Formation varies from 30 to 75 feet thick and consists mainly of conglomerate in the lower part and sandstones with pebbly sandstones in the upper part. The sandstones and pebbly sandstones vary from 25 to 75 per cent of the formation.

The sandstones are light grey, medium- to very coarse-grained mixtures of quartz and chert with a siliceous cement. They are massive to medium-bedded and commonly crossbedded.

The conglomerates typically consist of closely packed, well-rounded and sorted, pebble-size phenoclasts of chert (grey, black, brown and green) and minor quartzite and quartz, in a matrix of the sandstone described above. The conglomerates are massive to thick-bedded, with a few thin lenticular beds of sandstone.

Blairmore Group (lower part)[1]

The lower part of the Blairmore Group comprises the interval between the Cadomin Formation below and the Beaver Mines Formation above. This interval has not yet been formally named, although it qualifies as a formation. The lower Blairmore has a thickness of from 400 to 450 feet (graphic estimate) but is commonly folded and faulted to thicknesses up to 1,200 feet. It is conformable with the Cadomin Formation below.

---

[1] Note: the writer does not use Mellon's (1967) "Gladstone Formation" for this interval since it was defined to include the Cadomin Formation as a "member". In the writer's opinion, the Cadomin is a well-established, well-qualified and useful formation.

The lower part of the Blairmore Group consists of thin-bedded sandstones and siltstones with dark grey to black shale layers and beds up to 10 feet thick. A few limestone beds, containing abundant gastropods and pelecypods, occur in the upper half of the unit. The sandstones and siltstones are typically calcareous and commonly contain scattered limonitic grains. They are grey, brownish grey-weathering, commonly laminated and cross-laminated.

A consistent unit of orthoquartzite, about 15 feet thick, occurs within the top 100 feet of the lower Blairmore. The rock consists almost entirely of quartz with a quartz cement. It is fine-grained, very light light grey, weathering light grey to whitish, with common yellowish and brownish discolouration. Bedding separation ranges from thin to medium, with some massive beds in the lower part.

Beaver Mines Formation

The Beaver Mines Formation is readily distinguishable from the lower part of the Blairmore Group on the basis of its massive units of uniform, feldspathic sandstone and rubbly mudstone and its greenish grey colour. This formation is 700 to 800 feet thick (graphic estimate) and its characteristics suggest a change in the non-marine Blairmore environment to a greater availability and influx of coarse clastic material than was the case during the deposition of the lower part of the group. This indicates some tectonic activity, although the lower part of the Blairmore and the Beaver Mines Formation appear to be conformable.

Lenticular beds of conglomerate occur locally near the base and at the top of the Beaver Mines Formation.

The upper conglomerate beds range in thickness from 18 inches to 23 feet where observed. Phenoclasts are mainly of chert, with subordinate quartzite, sandstone and quartz. They are pebble-sized ($\frac{1}{4}$ inch to 3 inches in diameter), moderately well-sorted, rounded to very well rounded, grey, black, brown, green and reddish in colour, and range from closely packed to dispersed in individual beds. The matrix consists of medium- to coarse-grained sandstone, varying from typical greenish to brownish grey Beaver Mines sandstone to Cadomin-type sandstone. The former are demonstrably part of the Beaver Mines Formation, whereas the latter may rest on the top of the formation, and belong to, or actually be within, the basal Blackstone strata. There is evidence of some erosion below certain conglomerate beds and the conglomerates may be in part at least, a lag concentrate. Igneous phenoclasts were not observed in these conglomerates and, if present, must constitute an insignificant amount.

The lower conglomerate beds occur within the lowermost 100 to 200 feet of the formation and, in addition to chert, quartzite, sandstone and quartz, contain common phenoclasts derived from igneous rocks. This "igneous-pebble" conglomerate occurs as lenses, 5 to 30 feet thick, at only a few widely scattered localities within the area, although sandstone beds, at the same general horizon, typically contain a few dispersed phenoclasts. The phenoclasts are well to very well rounded, and mainly $\frac{1}{2}$ inch to 2 inches in length, but ranging up to 5 inches. Packing varies from close to dispersed in different beds (see Plate III, Figures 1 and 2); sorting is moderate; some beds are slightly graded; bedding ranges from 1 inch to 12 inches and in places, up to 6 feet thick. The matrix is of coarse- to very coarse-grained, feldspathic sandstone, containing common chert fragments, but otherwise of greenish to brownish grey sandstone typical of the Beaver Mines Formation.

The stratigraphic position of this "igneous-pebble" conglomerate, in beds of Aptian or early Albian age (W.A. Bell, see below), is older than that of conglomerates with a similar abundance of igneous phenoclasts, recorded in the Blairmore Group (Mill Creek Formation) to the south in the Crows Nest Pass area (Hage, 1943; Norris, 1964; Mellon, 1967), although Mellon reports conglomerates containing some igneous phenoclasts at about the same stratigraphic position.

Coal lenses and beds, 1 to 6 inches thick, occur locally in the formation.

Sandstone and mudstone units are typically 2 to 20 feet thick, but in most sections there is one sandstone unit 50 to 60 feet thick. It is probable that this sandstone unit is at about the same position at all localities but, because of the lenticular nature of the sandstone bodies and in the absence of complete sections, a definite correlation has not been established.

The Beaver Mines Formation is similar in lithology and general characteristics to the Brazeau Formation, and was deposited in a similar non-marine, floodplain environment. The presence of a greater proportion of siltstone beds, with a platy rather than a rubbly separation, and a stronger overall greenish colour, usually serves to distinguish the Beaver Mines Formation from the Brazeau where plant fossils are not available.

Macerated plant debris, showing as flecks and laths of carbonaceous material, carbonaceous films and small lenses of coal are common throughout the formation. Concentrations of the largest stem fragments are typically associated with the coarser grained sandstones and conglomerates.

The following fossil plants were collected by the writer from the Beaver Mines Formation in the Limestone Mountain map-area.

GSC locality 7220 Willson Creek; Lat. 51° 49' 50" N; Long. 115° 20' 40" W

Ginkgo pluripartita (Schimper) Heer
Ptilophyllum (Anomozamites) montanense (Fontaine) Bell
Cyparissidium ? gracile ? Heer
Athrotaxites berryi Bell

GSC locality 7227 Tributary of Willson Creek; Lat. 51° 49' 50" N; Long. 115° 20' 40" W

Sagenopteris mclearni Berry
Metasequoia smittiana (Heer) Bell
Athrotaxites berryi Bell
Elatocladus (Cephalotaxopsis) brevifolia (Fontaine) Bell

GSC locality 7228 and 7233 Limestone Mountain road; Lat. 51° 48' 26" N; Long. 115° 18' 28" W

Sphenopteris (Ruffordia) gopperti (Dunker) Heer
Sphenopteris latiloba Fontaine
Gleichenites giesekianus (Heer) Seward
Klukia canadensis Bell
? Metasequoia smittiana (Heer) Bell
Ginkgo pluripartita (Schimper) Heer
Carpites (Ginkgo ?) sp.
Cyparissidium ? gracile ? Heer
Elatocladus (Cephalotaxopsis) brevifolia (Fontaine) Bell
Elatides curvifolia (Dunker) Nathorst
Pityophyllum cf. nordenskioldi (Heer) Krystofovich

GSC locality 7230 Tributary of Willson Creek; Lat. 51° 49' 30" N; Long. 115° 21' 19" W

Cladophlebis virginiensis Fontaine forma acuta
Coniopteris brevifolia (Fontaine) Bell
Ginkgo pluripartita (Schimper) Heer
Cycadocarpidium ? sp.
Elatides curvifolia (Dunker) Nathorst
Elatides splenida Bell
Metasequoia smittiana (Heer) Bell
Elatocladus (Cephalotaxopsis) brevifolia (Fontaine) Bell
Pagiophyllum sp. cf. Sphenocarpidium sterbergianum (Dunker) Heer
Carpites (Ginkgo ?) sp.

GSC locality 7231 Tributary of Willson Creek; Lat. 51° 49' 30" N; Long. 115° 21' 10" W

Ginkgo pluripartita (Schimper) Heer

GSC locality 7232 James River; Lat. 51° 46' 14" N; Long. 115° 18' 26" W

Sphenopteris (Ruffordia) gopperti (Dunker) Heer (Rachis only)
Klukia canadensis Bell
Athrotaxites berryi Bell

GSC locality 7235 Willson Creek; Lat. 51° 49' 15" N; Long. 115° 20' 55" W

Ginkgo pluripartita (Schimper) Heer
Carpites (Ginkgo ?) sp.
Athrotaxites berryi Bell

The identifications above were made by W.A. Bell (GSC unpubl. report No. F1-3-1965-WAB), who described the assemblages as conifers, caytoniales, ferns and ginkgos quite typical of "Lower Blairmore" beds, of an Aptian or early Albian age.

UPPER CRETACEOUS

Alberta Group

Blackstone Formation

The Blackstone Formation consists of 1,200 to 1,400 feet (graphic estimate) of dark to very dark grey shales and siltstones with some sandstone beds. Bentonite seams are scattered throughout the formation. Stott's (1961 and 1963) Sunkay, Vimy, Haven and Opabin Members are recognizable in the map-area.

The Blackstone Formation overlies the Beaver Mines with a sharp contact, marking a change from non-marine to marine conditions. The formations appear to be, at least locally, conformable. As stated above, conglomerate beds occur in the vicinity of and in places possibly at this contact. A somewhat faulted Blackstone-Beaver Mines contact is exposed on Limestone Creek about seven and one-half miles upstream from the Clearwater River. At this locality, dark grey shales of the Blackstone rest against very fine-grained, yellowish green-weathering, Beaver Mines sandstone. A two-foot thick bed of very coarse-grained, pebbly sandstone occurs in the Blackstone, eleven feet above the contact.

Cardium Formation

Shales of the Blackstone Formation and sandstones of the Cardium Formation are conformable and the two lithologies are interbedded across the contact. The Cardium Formation is 320 feet thick on Bridgeland Creek and 301 feet thick on a tributary of Willson Creek (lat. 51° 51' 5", long. 115° 24' 20") a few miles to the north. The Cardium consists of three main sandstone units separated by silty and concretionary shales, corresponding, from base to top, with the Ram, Kiska, Cardinal, Leyland and Sturrock Members respectively (Stott, 1961 and 1963).

The sandstones are typically very fine- to fine-grained, light to medium grey, medium brownish grey-weathering, and commonly finely laminated with dark grey, argillaceous laminae. Beds are normally from ½ inch to 6 inches thick, and some crossbedding occurs. Bedding surfaces in some of the purer, lighter coloured, laminated sandstones are typically flat and even, producing a flaggy talus, but there are intervals of reworked sandstones with a very uneven, wavy separation. These reworked sandstones are light to medium grey, streaked with dark grey argillaceous material, and contain worm tracks and tubes. Sandstones range from fairly pure quartz varieties to argillaceous sandstone. The purer types are typical of much of the Ram and Sturrock Members.

Conglomerate beds occur locally in the Cardium sandstones, and are typically from a few inches to 15 feet thick. A 50-foot thick bed occurs on a tributary of Willson Creek in the south central part of the map-area. Bedding in these conglomerates varies from thin to very thick, based on size and concentration differences of the phenoclasts. Beds and lenses of fine-grained sandstone divide the conglomerate in places. An incipient to open bedding separation of between 2 to 12 inches is common. The phenoclasts are mainly of chert (grey, black and green) with some quartz and quartzite. They are typically 1/8 inch to ½ inch in length, closely packed, rounded to well rounded, ovoid to flattened ovoid in shape. The matrix ranges from fine sand to granule size and consists of a mixture of quartz and chert, varying from light grey to medium brownish grey, owing to limonitic stain. Possible mud cracks were observed in a sandstone layer at the top of one conglomerate bed. The sandstone and conglomerates of the conglomerate units have some resemblance to the Cadomin facies. Minor beds of small-pebble chert-conglomerate and pebbly shale occur in the shale units of the Cardium Formation. Pelecypods are scattered on some bedding surfaces and one 8-inch thick bed of pelecypods was observed in a sandstone unit. They include species of <u>Cardium</u> and <u>Inoceramus</u>.

Wapiabi Formation

Dark grey shales of the Wapiabi Formation overlie the sandstones of the Cardium conformably, on a sharp, slightly uneven and undulating surface. The Wapiabi is 1,600 to 1,800 feet thick (graphic estimate). The Muskiki, Dowling, Thistle, Hanson, Chungo and Nomad Members are recognizable in scattered exposures. The Marshybank Member is not conspicuous.

Thin, platy siltstone layers alternate with shale in the Muskiki, giving the member a fine-combed appearance. It is studded with orange-brown-weathering ironstone concretions. The basal 5 to 10 feet of the Muskiki commonly contain scattered chert pebbles and, in places, beds of conglomerate a few inches to seven feet thick. The phenoclasts are mainly of chert (black, grey and some green) with minor amounts of white quartz. They are rounded to well rounded, 1/8 inch to 1 inch in length, set in a variably argillaceous sandstone matrix. A 6-inch thick concretionary bed occurs in one conglomerate unit.

The Dowling Member is a fissile shale with common platy siltstone layers and some ironstone concretions, characterized by its distinct rusty brown-weathering colour.

Platy, calcareous, intercalated shale and siltstone form the Thistle Member. Siltstone layers range from a fraction of an inch to several inches thick and are typically laminated and cross-laminated (small scale). Ironstone concretions are absent in the Thistle, but lenticular beds of light yellowish grey-weathering, argillaceous limestone or dolomite occur locally. These beds vary from 2 inches to 2 feet in thickness and from 2 feet to more than 30 feet in length and commonly contain pelecypods. Weathered surfaces of the Thistle are commonly coated with a powdery, whitish residue.

The Hanson Member is a silty mudstone, more uniform and less platy than the lower members, with a rubbly to incipient platy separation. Ironstone concretions and beds of discontinuous and scattered concretions are common.

Argillaceous, grey, fine-grained sandstones with scattered ironstone concretions and concretionary beds characterize the Chungo Member. These are overlain by rubbly to platy, grey and greenish grey mudstone of the Nomad Member.

Scattered, very thin bentonite seams occur locally in the Wapiabi.

Brazeau Formation

The youngest strata in the area belong to the non-marine Brazeau Formation. This formation is estimated to be 5,000 feet thick in the Burnt Timber Creek area immediately to the south, but only the lower 3,000 to 4,000 feet are exposed within the Limestone Mountain map-area. The Brazeau-Wapiabi contact shows local erosion channels filled with the non-marine Brazeau sandstone, but the two formations are essentially conformable and minor interbedding of the marine shale and non-marine sandstone occurs at the contact.

The Brazeau Formation consists of alternating units of sandstone, siltstone and mudstone, with minor amounts of shale, bentonite and coal. The sandstones are fine- to coarse-grained, greenish grey and grey, feldspathic, massive to bedded, typically with a 1 inch to 4 inch lenticular separation subparallel to the bedding, and weather to a light brownish grey and yellow-brown. Pebbly layers and conglomerate beds occur locally. The mudstones are greenish grey, olive-grey, green, and grey, with a rubbly, blocky disintegration. Sandstone beds range from a few inches to 50 feet thick but are typically 5 to 20 feet thick. They are separated by intervals of mudstone a few inches to 15 feet thick. Intervals 15 feet to several hundred feet in thickness commonly consist almost entirely of mudstone with only a few, scattered beds of sandstone or siltstone. Harder, medium to medium-dark brown-weathering, concretionary masses of calcareous sandstone, up to 10 feet across and several feet thick are common within the sandstones. These masses commonly form a linked or discontinuous series, suggesting considerable lateral continuity. Many possess a lamination and small scale cross-lamination and range from kettle shapes making abrupt contacts with the surrounding sandstone to irregular masses grading into it. A few ironstone concretions occur locally within the mudstone and shale units.

Sandstone units commonly lens out into the surrounding mudstones and locally fill channels in the underlying beds.

The marine Bearpaw Formation cannot be recognized within the map-area and, when this shale is absent, the Belly River and Edmonton equivalents of the Brazeau Formation cannot be differentiated. The basal 1,000 feet of the Brazeau Formation can be separated from the upper strata, however, on the basis of topographic expression, stratigraphy and lithology as follows: the lower part forms conspicuous, well-developed ridges, whereas the upper beds form depressions with a few scattered ridges; sandstone units in the lower part form the greater proportion of the rock and are more closely spaced than in the upper part; sandstones in the lower part are more consistently greenish grey whereas those in the upper part are typically grey; sandstones in the upper part commonly form 5-foot to 50-foot thick units whereas those in the lower part are typically 5 to 20 feet thick; the upper sandstones are softer and more friable in general than those in the lower; bentonite seams are thicker and more common in the upper part than the lower; pebbly sandstone beds and conglomerates are more common in the lower part and typically have pebble-sized phenoclasts whereas those in the upper part have pebble- to cobble-sized phenoclasts and a greater content of quartzite and sandstone phenoclasts. Despite the validity of the above generalizations, small individual outcrops are often difficult to assign to the upper or lower part and the assignment must always be made on the basis of a consensus of the above criteria rather than one or two features only.

Macerated plant fragments are common in the Brazeau Formation and are preserved as flecks, laths and films of carbonaceous material or thin wisps and lenses of coal after plant stems. A few small plant collections were made. Identifications by W.A. Bell reveal a broad Santonian-Maestrichtian age and no precise Belly River-Edmonton correlation.

STRUCTURAL GEOLOGY

Limestone Mountain map-area lies mainly in the Foothills structural belt, with a small segment of the Front Range of the Rocky Mountains in its southwest corner. Three major, northwest trending and southwest dipping thrusts control the basic structure of the area. From southwest to northeast, these are the McConnell, Burnt Timber and Fallentimber thrusts respectively. The area is divided into three major thrust-sheets, forming the hanging wall segments, west of the surface traces of these thrusts.

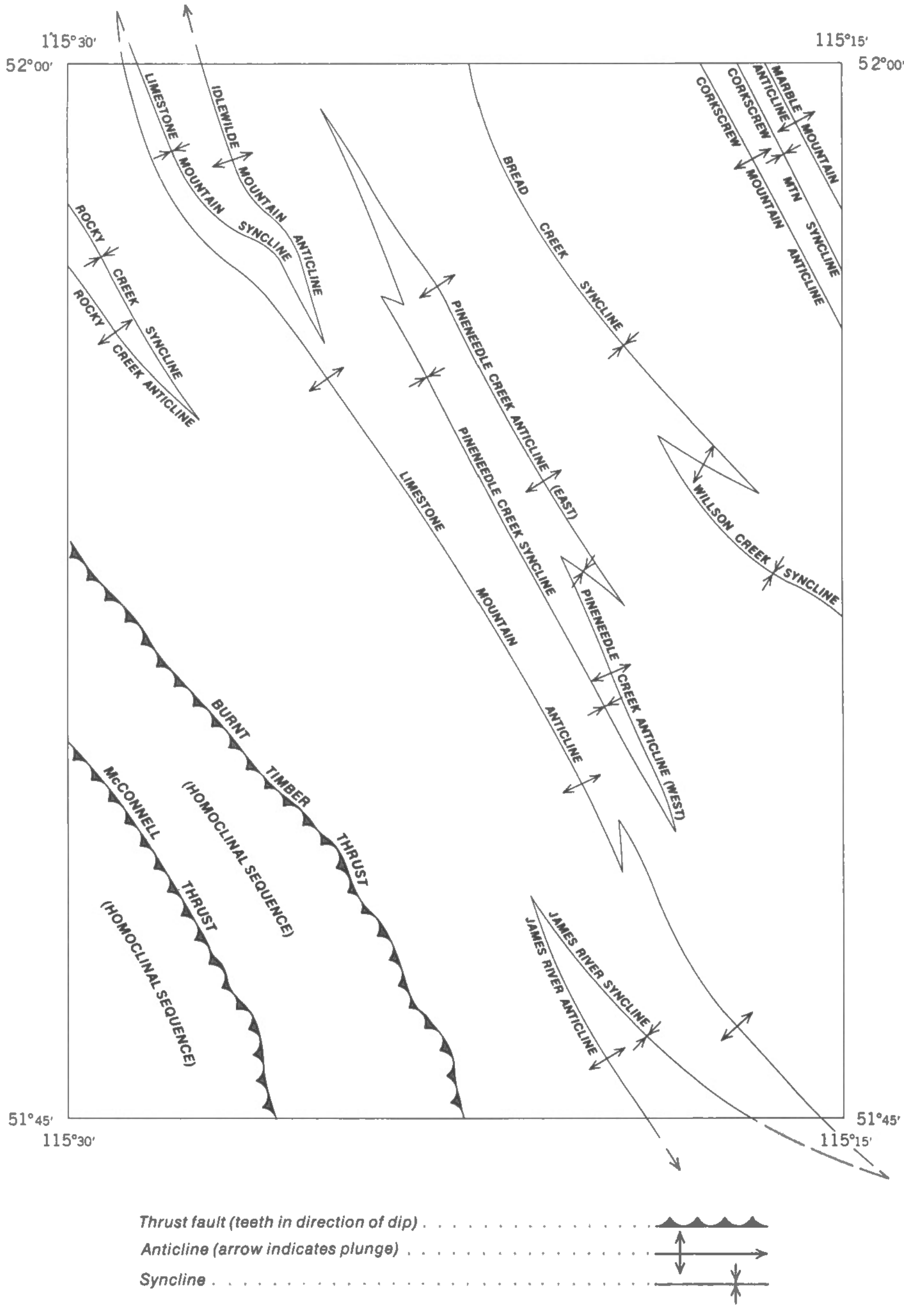

Figure 1. Interpretation of the relationships between the principal folds in Limestone Mountain map-area

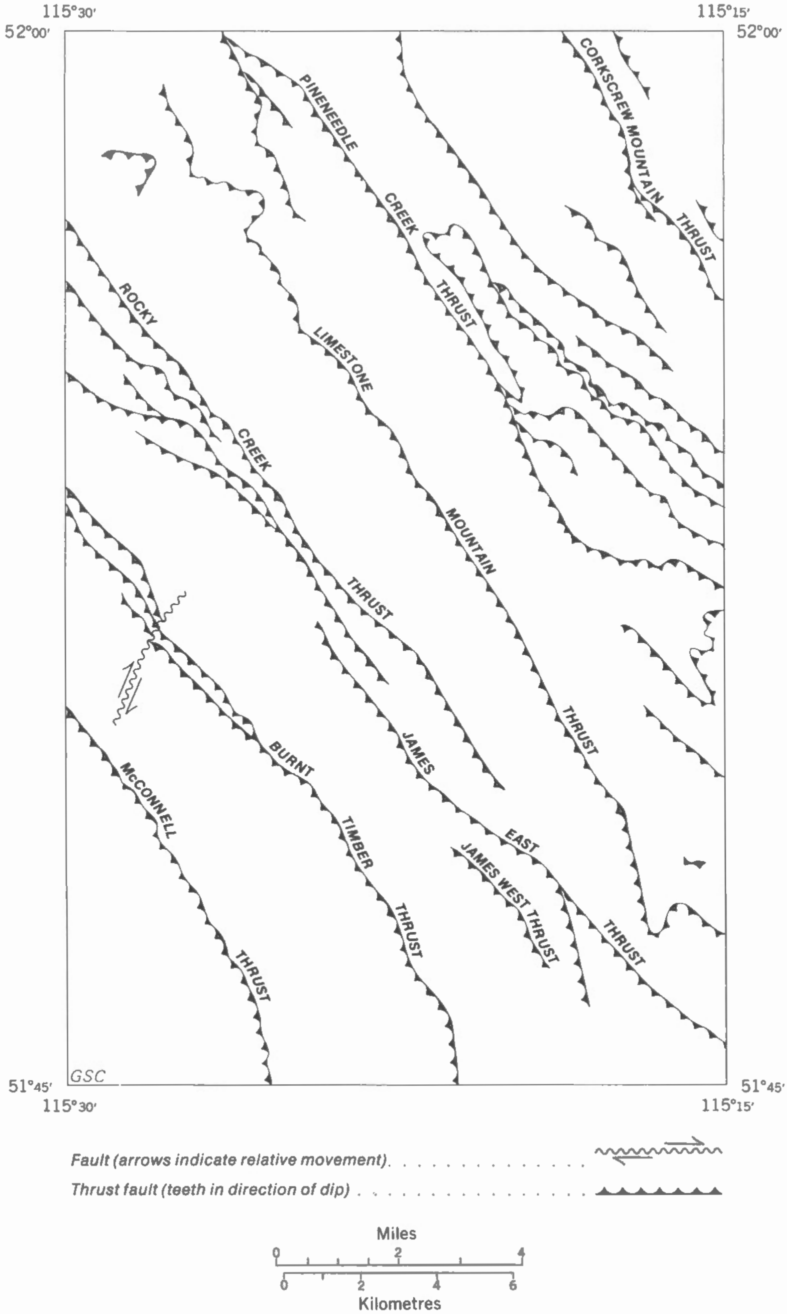

Figure 2. Surface trace distribution of faults in Limestone Mountain map-area

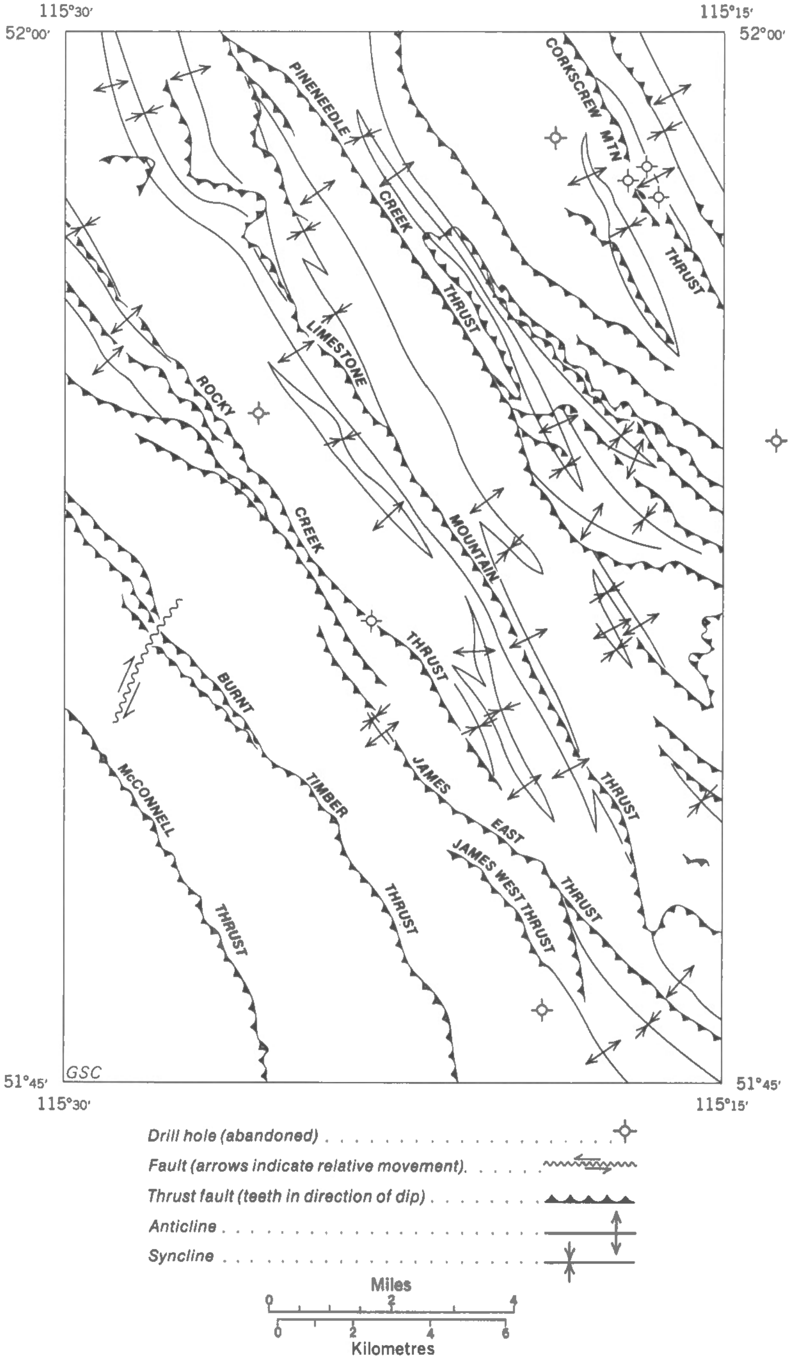

Figure 3. Fold and fault distribution in Limestone Mountain map-area

McCONNELL THRUST-SHEET

The McConnell thrust sheet consists of a southwest dipping, homoclinal sequence of Paleozoic strata. The average dip is 20 to 25 degrees, steepening to 30 to 50 degrees, in the vicinity of the thrust. Along the surface trace of the McConnell thrust, Cambrian strata are in contact with the Upper Cretaceous Brazeau Formation and, in hanging wall, the McConnell thrust cuts up section progressively to the northwest from middle to upper Cambrian.

BURNT TIMBER THRUST-SHEET

The Burnt Timber thrust sheet comprises a southwest dipping, homoclinal sequence with lower and upper Cretaceous strata at the surface. Dips are mainly in the 50 to 60 degree range, decreasing slightly westward. Along the surface trace of the Burnt Timber thrust, Kootenay strata overlie the Brazeau Formation.

Minor structural complications occur northwestward along the Burnt Timber thrust. The Blairmore Group is thickened by a splay from the Burnt Timber thrust, and a slice of the Blackstone (?) and Cardium Formations separates the Kootenay Formation from the Brazeau at the western edge of the area. The main thrust and these subsidiary structures are cut by a northeast trending fault which is interpreted, on the basis of air photograph examination, as a dextral tear fault.

FALLENTIMBER THRUST-SHEET

East of the Burnt Timber thrust another major fault is inferred at depth by extrapolation from surface structures and stratigraphy, using known stratigraphic thicknesses and well data, and based on the estimated position of the Precambrian basement in this region (Bally et al. 1966). This fault has been referred to previously as the Fallentimber Thrust (Ollerenshaw, 1965). Unlike the McConnell and Burnt Timber Thrusts, the major dislocation on the Fallentimber thrust occurs at depth and the surface expression consists of numerous splays, several of which occur within Limestone Mountain area. The lowermost splays occur at the surface a few miles northeast of Limestone Mountain area, within the Brazeau Formation. Their traces converge northwestward in the Tay River map-area to the north. In other words, the Fallentimber thrust is apparent as a major thrust in Tay River map-area but splays southeastward into Limestone Mountain and Marble Mountain areas as a series of moderate to minor thrusts at the surface.

The Fallentimber thrust and a culmination along it are responsible for the structural elevation of Paleozoic inliers within the Mesozoic in the Foothills around Limestone, Corkscrew and Marble mountains, although the actual configuration and distribution of these strata is modified by subsidiary folds and thrusts. The thrust-sheet can be divided, on the basis of these subsidiary structures, into the Limestone Mountain anticlinorium (in the southwest), the Bread Creek synclinorium (in the centre) and the Marble Mountain anticlinorium (in the northeast). The detailed pattern and relationships of folding and faulting in Limestone Mountain area are illustrated in figures 1-3 and sections A-B and C-D.

LIMESTONE MOUNTAIN ANTICLINORIUM

The Limestone Mountain anticlinorium consists of a composite sequence of folds and thrust faults involving both Mesozoic and Paleozoic strata. The fold system consists of three principal elements, illustrated in Figure 1. On the east, Pineneedle Creek anticline and syncline link together to form a closed system. In the centre, Idlewilde Mountain anticline links west through Limestone Mountain syncline to Limestone Mountain anticline, which in turn links west through James River syncline to James River anticline. This Idlewilde-Limestone-James structure continues as an anticline northwest and southeast beyond the area and is the principal element of the Limestone Mountain anticlinorium. In effect, there is one anticlinal structure, interrupted by several en echelon offsets. In the northwest, the third element consists of the Rocky Creek anticline and syncline which link and die out southeastward but continue northwestward beyond the map-area.

Figure 3 shows the fold-fault relationship in Limestone Mountain anticlinorium. Limestone Mountain thrust fault cuts the Idlewilde Mountain-Limestone anticline system at the point of linkage, cuts the southeast end of the Pineneedle Creek structure and severs the linkage between Limestone Mountain anticline and James River syncline. On the west flank of the anticlinorium, numerous thrust faults cut the succession. Rocky Creek thrust severs the linkage between Rocky Creek anticline and Rocky Creek syncline, and James East and James West thrusts cut the James River syncline and anticline, again in the linkage zone.

It is apparent that thrusting occurs preferentially where fold axes converge to form linked systems of folds.

Linked systems of folds in this part of the Foothills region are of three basic types:

1. Simple linkage: where the axes of a single syncline and a single anticline converge and join at one end, and the folds compensate one another to produce a homoclinal sequence beyond.

2. Closed system linkage: where the axes of a syncline and anticline converge and close at both ends. Such a system may include some offset linkage.

3. Offset linkage: where a series of offset or en echelon anticlines (synclines) are linked together by relatively short synclines (anticlines). Anticlinal linkage occurs in anticlinoria, synclinal linkage in synclinoria.

Campbell (1958) analyzed similar en echelon folding in Australia and referred to offset linkage as "zig-zag" folds. Mendelsohn (1958a and 1958b) referred to similar structures as "anticlinal echelon" and "synclinal echelon" folds.

BREAD CREEK SYNCLINORIUM

The Bread Creek Synclinorium has been overthrust by the Limestone Mountain anticlinorium along the Pineneedle Creek fault. This thrust splays southeastward, repeating folded segments of the Alberta Group core of the synclinorium. The folding appears to involve branches of the thrust in a complex fold-fault relationship. Bread Creek synclinorium basically consists of two synclines, designated Bread Creek syncline and Willson Creek syncline respectively. In a southeast direction, Bread Creek syncline probably links westward to Willson Creek syncline through a short anticline, but once again the zone of linkage is severed and the anticline obscured by thrusting. The west flank of Willson Creek syncline is repeated and thickened by faulting and folding. The east flank of Bread Creek syncline is also repeated by thrusting. Local smaller folds occur within the main structures.

MARBLE MOUNTAIN ANTICLINORIUM

A portion of Marble Mountain anticlinorium crosses the northeast corner of the Limestone Mountain area, again bringing Paleozoic strata to the surface. The structure consists of twin anticlines, designated the Corkscrew Mountain anticline on the southwest and Marble Mountain anticline on the northeast, separated by Corkscrew Mountain syncline. Some minor thrusting occurs. Corkscrew Mountain anticline is cut by a southwest dipping thrust, whereas Corkscrew Mountain syncline has a northeast dipping thrust in its axial region at higher structural levels.

The folds in Limestone Mountain area change rapidly along their axes and in a vertical direction. At different places along the axis a fold may be symmetrical, asymmetrical, locally overturned to the northeast, or form a broad box structure. For example, Limestone Mountain anticline has elements of a box fold and local overturning.

It is the writer's observation that a box fold profile may occur at a specific structural level. This is the level of vertical transition from a twin fold to a single fold. For example, in section C-D, the axial planes of Pineneedle Creek anticline east and Pineneedle Creek anticline west converge downwards to form a single anticline. The transition from twin folds to a single fold is marked by the development of the box fold profile, essentially a double monocline and the last downward expression of the twin folds above.

The Limestone Mountain and Marble Mountain structures plunge northwest towards Tay River and southeast towards James River thus forming a pronounced culmination. Local variations in and reversals from these directions of plunge are caused by individual elements of the subordinate _en echelon_ folding.

Structure sections A-B and C-D illustrate the writer's interpretation that the Pineneedle Creek thrust system has been folded across this culmination from southwest to northeast; anticlinally across the Limestone Mountain anticlinorium and synclinally beneath the Bread Creek synclinorium. Culminations such as Limestone

Mountain culmination and Panther River culmination (Ollerenshaw, 1968) are flanked by depressions on the southeast and northwest and have structural continuity therefore in those directions. They are essentially structures within one thrust-sheet, although adjacent parts of adjoining thrust-sheets are modified and folded in conformity with them. They do not cut across the structural grain of the Foothills in a southwest to northeast direction and are in no sense cross fold structures. In fact, culminations may be adjacent to depressions in a northeast-southwest direction. For example, Panther River culmination is bounded by Williams Creek depression on its northeast side. The implication is that the folding of thrust-sheets into culminations and depressions occurs at right angles to the direction of motion of the thrust and that the development of these culminations and depressions is related to the primary thrust and fold development, possibly as an adjustment to localized drag along the underlying thrust.

The structures of Limestone Mountain area emphasize the regional style of thrusting in which stratigraphic displacement decreases rapidly from southwest to northeast at the surface and increases with depth.

In summary, the main structural features of Limestone Mountain area are:

1. The McConnell, Burnt Timber and Fallentimber thrust faults.
2. The existence of a culmination in the Fallentimber thrust-sheet.
3. The folding of faults across the Limestone Mountain and Bread Creek structures.
4. The en echelon arrangement of the folds.
5. Local box profiles of the folds.
6. General asymmetry and local overturning of folds towards the northeast.

ECONOMIC GEOLOGY

In the search for oil and gas, seven sites have been drilled in the area between 1939 and 1961. These sites consist of four on Corkscrew Mountain anticline along Clearwater River and three along the west flank of Limestone Mountain anticlinorium. The latter group are the most recent. All sites have been abandoned as dry holes. Several possible structural traps are still to be explored within the area. Wells designated numbers one and two on the accompanying map were apparently drilled down the western flank of the Limestone Mountain anticlinorium away from the crestal region of the anticline, so that the structure itself remains a possible trap. Other possible structural traps include the Pineneedle Creek anticlines (in the vicinity of line of section A-B); the anticlinal structures flanking the Bread Creek synclinorium on its west side (see structure sections on accompanying map); and structures beneath the Burnt Timber thrust.

Scattered seams of coal were observed in the Cretaceous rocks, but none of economic potential. Structural deformation and stratigraphic changes in the Kootenay Formation of this area severely curtail its coal-bearing potential. Coal seams occur in the lower part of the Blairmore Group and in the Beaver Mines and Brazeau Formations, but are scattered and thin.

Abundant gravel and sand deposits occur along the valley of the Clearwater River, and scattered deposits along the valley of the James River and other smaller streams. The gravels are pebble, cobble to boulder mixtures with a sandy matrix, suitable for rough fill. Sand bodies are scattered and small.

SELECTED BIBLIOGRAPHY

Aitken, J.D.

1966: Sub-Fairholme Devonian rocks of the eastern Front Ranges, southern Rocky Mountains, Alberta; Geol. Surv. Can., Paper 64-33.

1968: Cambrian sections in the easternmost southern Rocky Mountains and the adjacent subsurface, Alberta; Geol. Surv. Can., Paper 66-23.

Bally, A.W., Gordy, P.L., and Stewart, G.A.

1966: Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains; Bull. Can. Petrol. Geol., vol. 14, No. 3, pp. 337-381.

Beach, H.H.

1942: Marble Mountain map-area, Alberta; Geol. Surv. Can., Paper 42-3.

Bell, W.A.

1949: Uppermost Cretaceous and Paleocene floras of western Alberta; Geol. Surv. Can., Bull. 13.

1956: Lower Cretaceous floras of western Canada; Geol. Surv. Can., Mem. 285.

1965: Lower Cretaceous floras of western Canada; Geol. Surv. Can., Paper 65-5.

Campbell, J.D.

1959: En echelon folding; Econ. Geol., vol. 53, pp. 448-472.

Douglas, R.J.W.

1956: Nordegg Alberta; Geol. Surv. Can., Paper 55-34.

Frebold, H.

1966: Upper Pliensbachian beds in the Fernie Group of Alberta; Geol. Surv. Can., Paper 66-27.

Harker, P.J., and McLaren, D.J.

1958: The Devonian-Mississippian boundary in the Alberta Rocky Mountains; in Jurassic and Carboniferous of Western Canada; Am. Assoc. Petrol. Geol., Symposium pp. 244-259.

Henderson, J.F.

1945: Tay River; Geol. Surv. Can., Map 840A (and marginal notes).

1946: Fall Creek; Geol. Surv. Can., Map 883A (and marginal notes).

Mellon, G.B.

1967: Stratigraphy and Petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains; Res. Council Alberta, Bull. 21, 270 p.

Mendelsohn, F.
1959a: En echelon folding (disucssion); Econ. Geol., vol. 54, pp. 505-509.

1959b: Structure of the Roan Antelope deposit; Inst. Mining and Met., B. no. 628 (Tr. v. 68, pt. 6), pp. 229-263.

Norris, D.K.
1964: The Lower Cretaceous of the southeastern Canadian cordillera; Bull. Can. Petrol. Geol., vol. 12, Field conference guide book issue, pp. 512-535.

Ollerenshaw, N.C.
1965: Burnt Timber Creek; Geol. Surv. Can., Map 11-1965 (with marginal notes).

1968: Panther River culmination; Geol. Surv. Can., Map 24-1967 (with marginal notes).

Stott, D.F.
1961: Summary account of the Cretaceous Alberta Group and equivalent rocks, Rocky Mountain Foothills, Alberta; Geol. Surv. Can., Paper 61-2.

1963: The Cretaceous Alberta Group and equivalent rocks, Rocky Mountain Foothills, Alberta; Geol. Surv. Can., Mem. 317.

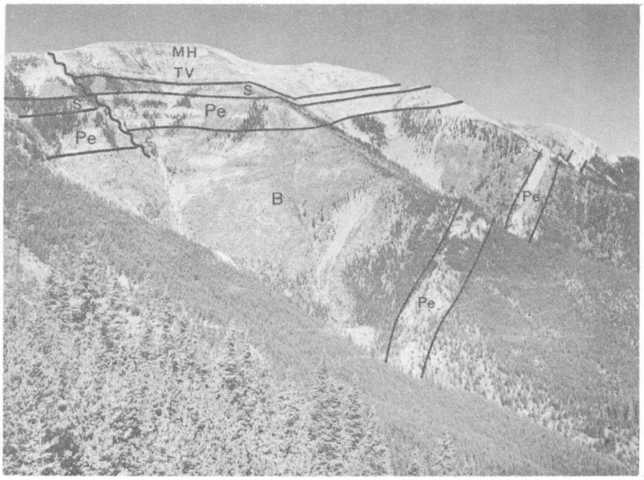

Plate IA. Looking northwest across Limestone Creek along the crest of Idlewilde Mountain anticline. MHk, Mount Hawk and Sassenach Formations; Pa, Palliser Formation; B, Banff Formation; Pe, Pekisko Formation; LMT, Limestone Mountain thrust.

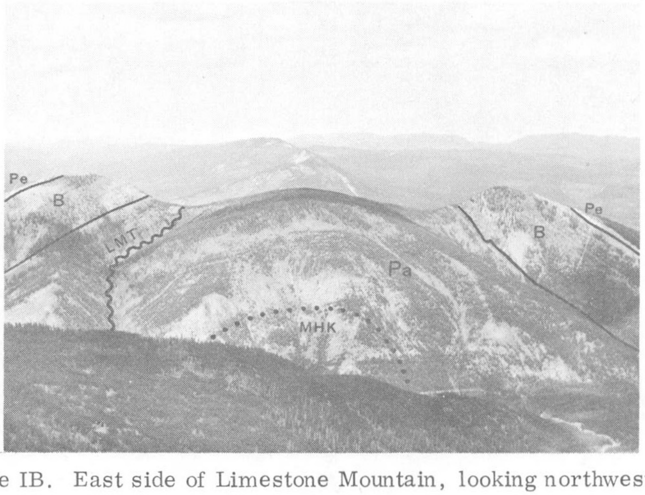

Plate IB. East side of Limestone Mountain, looking northwest along the overturned Limestone Mountain anticline. B, Banff Formation; Pe, Pekisko Formation; S, Shunda Formation; TV, Turner Valley Formation; MH, Mount Head Formation.

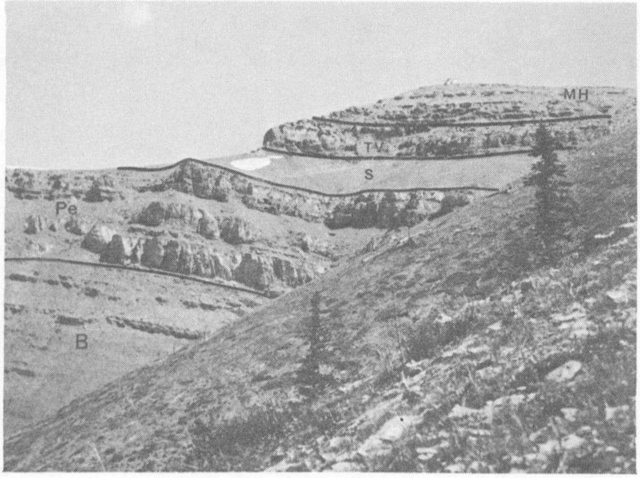

Plate IIA. The Mississippian section on the southwest face of Limestone Mountain. Note the triple cliffs in the Pekisko Formation. B, Banff Formation; Pe, Pekisko Formation; S, Shunda Formation; TV, Turner Valley Formation; MH, Mount Head Formation.

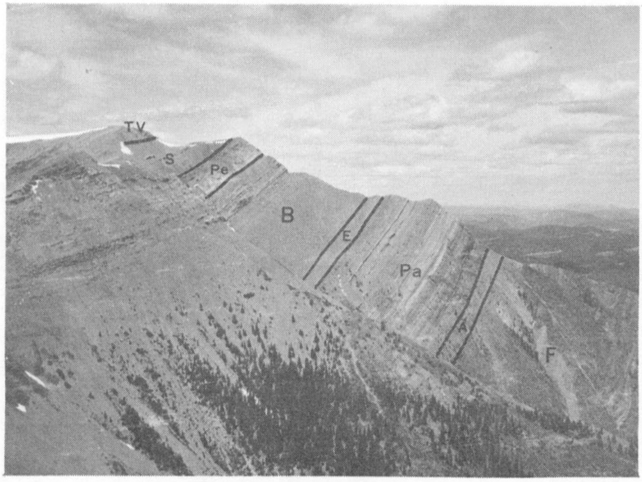

Plate IIB. Part of the Devonian-Mississippian section at the Mountain Front, above the McConnell thrust in the southwest corner of Limestone Mountain area. Looking northwest. F, Fairholme Group; A, "Alexo Formation"; Pa, Palliser Formation; E, Exshaw Formation; B, Banff Formation; Pe, Pekisko Formation; S, Shunda Formation; TV, Turner Valley Formation.

Plate IIIA. Interbedded sandstone and comglomerate beds in a unit of conglomerate containing common igneous phenoclasts, near the base of the Beaver Mines Formation.

Plate IIIB. Closely packed phenoclasts showing graded bedding, in a unit of conglomerate containing common igneous phenoclasts, near the base of the Beaver Mines Formation.

ERRATUM

To be inserted in G.S.C. Paper 68-24

Page 3 - thickness of Kootenay Formation should read 0-200+ and not 0-3,200 as printed.

Page 35 - captions for Plate 1A and Plate 1B are reversed. The upper photograph shows the east side of Limestone Mountain.

On Map 8-1968 - the NTS designation is 82 O/14 W and not 83 O/14 W as printed on lower right hand corner of map.