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CALLUM CREEK, LANGFORD CREEK, AND GAP MAP-AREAS, ALBERTA

BY

R. J. W. Douglas

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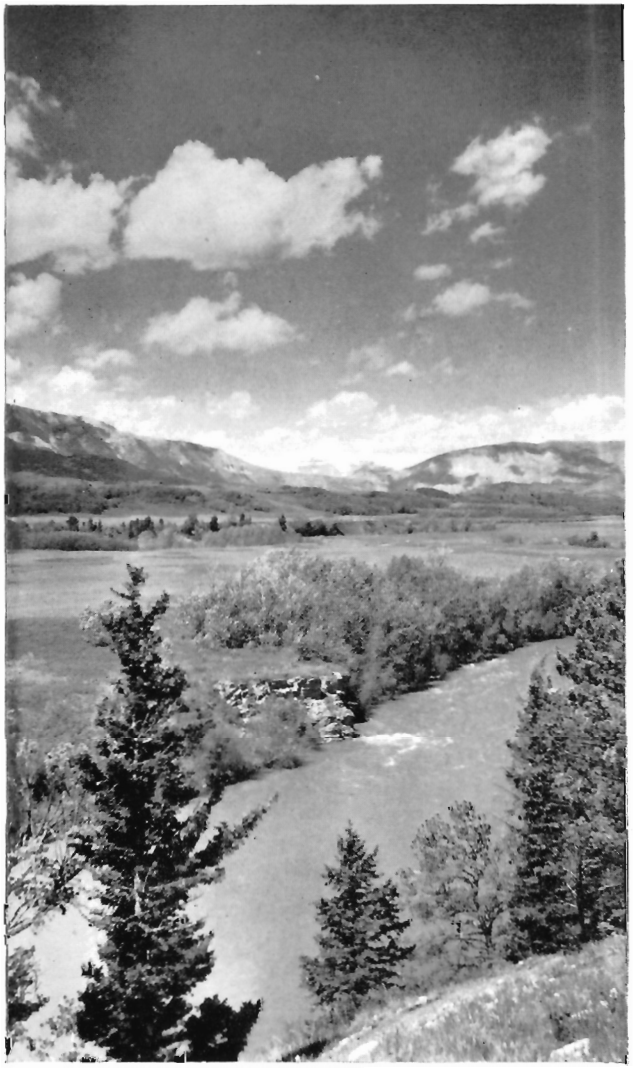

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Looking towards The Gap in the Livingstone Range from sec. 22, tp. 10, rge. 2. Oldman River and exposure of Belly River strata of the Whaleback fault slice in foreground. Cut bank in Wapiabi strata of Watson fault slice in middle distance. Gould Dome in background beyond The Gap. (Page 8.)

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PREFACE

The Foothills belt of the Canadian Rocky Mountains has long been recognized as a great source of coal, petroleum, and natural gas, and for many years systematic geological, 1-mile mapping has been done in an effort to clarify the complex structural conditions under which these substances occur. The present report, one of a series, deals with three adjoining 15-minute map-areas in the southern part of this 'Disturbed belt', and affords a cross-section of the structures from the Great Plains to near the first main range of the Rockies, and a stratigraphic succession from Mississippian to early Tertiary time.

In this report, the author is principally concerned in describing and accounting for the structural features of the three map-areas. The presence of exposed Palæozoic strata afforded an opportunity to study their structural relationship to the Mesozoic strata of a major thrust sheet, and their different response to compressive stresses set up by the Laramide orogeny. It is believed that the nature of the disruption of the strata, as evidenced by the structural characteristics of the faults and their relationship to folds, may serve to facilitate interpretation of the closely faulted Disturbed belt of southern Alberta where search for petroleum is in progress.

The report contains chapters on stratigraphy and economic geology, and an appendix, which lists complete logs of the several wells within the map-areas. It is accompanied by geological maps of the three areas, and carries numerous figures illustrating the structural features of these areas.

GEORGE HANSON,
Chief Geologist, Geological Survey of Canada

OTTAWA, March 15, 1949

Geology of Callum Creek, Langford Creek, and Gap Map-Areas, Alberta

CHAPTER I

INTRODUCTION

GENERAL STATEMENT

This report deals mainly with the stratigraphy and structural geology of Callum Creek, Langford Creek, and Gap map-areas in the Foothills of southwestern Alberta. The structure is discussed in an effort to reveal the nature of the deformation the strata have undergone. This is of prime importance in the search for petroleum in the highly faulted Disturbed belt of Alberta, for knowledge of the structural characteristics of the thrust faults and the relationship of the productive Palæozoic strata to them is necessary for the successful extrapolation at depth of the structures observed at the surface.

A lithological subdivision of the Mississippian Rundle formation has proved useful in interpreting the structure of the Livingstone Range of Gap map-area, and may be found applicable in adjoining areas. An unconformity between the Paleocene Porcupine Hills formation and the underlying Willow Creek formation was observed in Callum Creek and Langford Creek map-areas.

LOCATION AND ACCESSIBILITY

Callum Creek map-area lies between latitudes 49° 45′ and 50° 00′ and longitudes 114° 00′ and 114° 15′, and is adjoined on the north and west by Langford Creek and Gap 15-minute map-areas respectively (*See* Figure 1). It is accessible along motor roads leading northward from the towns of Lundbreck and Cowley on Crowsnest River. Poor roads extend through the Porcupine Hills to the town of Claresholm on the highway between Calgary and Macleod.

A road along the south side of Oldman River leads through "The Gap" to west of the Livingstone Range. The northwest part of Gap map-area may be reached by car, depending on the condition of the fords across Oldman and Livingstone Rivers. The remainder is readily accessible by pack-horses along numerous, well-cut Forestry trails.

Langford Creek and Callum Creek map-areas are connected by a poorly graded road that extends up the valley of Callum Creek. The northern area is, however, more easily reached from the northeast via the town of Nanton, south of Calgary. A road west of the Chain Lakes meets others that lead northward into Turner Valley.

FIELD WORK

A reconnaissance survey of Callum Creek and Langford Creek areas, and part of the Gap area east of the Livingstone Range was made by J. S. Stewart (1919)[1] during his regional study of the Disturbed belt.

[1] Dates, in parentheses, are those of publications listed in Bibliography at end of this chapter.

The remainder of Gap map-area was mapped by B. Rose (1918), and was used in the compilation of the Calgary sheet, Map 204A, of the Geological Survey of Canada.

Mapping of Callum Creek and the south half of Langford Creek map-areas was begun by George Shaw of the Geological Survey in the summer of 1944. The north half of Langford Creek map-area was mapped by G. S. Hume in 1940, appearing as a special preliminary map of the Geological Survey of Canada in 1943.

Field work in Callum Creek map-area was completed by the writer in the summer of 1945. Part of Langford Creek area was also examined in 1945, and was completed in 1946. Gap map-area was mapped, in part, during the remainder of the summer of 1946, and was completed early in the field season of 1947.

Some of the adjoining areas had been previously mapped (*See* Figure 1). These are: the Blairmore sheet south of Gap map-area, by B. Rose (1920); Cowley map-area south of the Callum Creek, by C. O. Hage (1943); and Stimson Creek map-area north of Langford Creek map-area, by G. S. Hume (1943a).

ACKNOWLEDGMENTS

Some of the geological observations by G. S. Hume in the northern part of Langford Creek map-area and by George Shaw in Callum Creek and Langford Creek map-areas have been embodied in the accompanying maps. Such changes as have been made in the interpretation of the structures are the responsibility of the writer.

The report and maps were prepared under the direction of Professor W. H. Bucher of Columbia University, to whom the writer is indebted for much valuable advice and critical discussion of the chapters on structural geology.

The Mesozoic invertebrate fossils were examined by F. H. McLearn and the fossil flora by W. A. Bell, both of the Geological Survey of Canada. Able assistance was rendered in the field by D. G. Crosby, H. W. Wonfor, and E. I. K. Pollitt in 1945; by G. E. P. Eastwood, E. I. K. Pollitt, and W. L. Godley in 1946; and by R. Thorsteinson, W. H. Allen, and R. F. Bailey in 1947.

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CHAPTER II

PHYSICAL FEATURES

PHYSIOGRAPHY

Callum Creek, Langford Creek, and Gap map-areas are divisible, physiographically, into two major units, the Porcupine Hills and the Foothills, the line of demarcation lying along the broad, subsequent valley now occupied by Oldman River, Callum Creek, Swanson Creek, and the Chain Lakes.

The Porcupine Hills are a local subdivision of the Great Plains of the interior. They are underlain mainly by gently dipping early Tertiary strata, which form a broad, synclinal structure called the Alberta syncline. The Foothills are underlain by disrupted Mesozoic and Palæozoic strata of the Disturbed belt of the Rocky Mountains. They extend from the Porcupine Hills on the east to the High Rock Range of the Rocky Mountains along the boundary between Alberta and British Columbia some 6 miles west of Gap map-area. The Livingstone Range, which passes through the middle of Gap map-area in a northerly direction, divides the Foothills into three parts; an eastern part about 10 miles in width, the Livingstone Range, and a western part about 12 miles wide.[1]

The western front of the Porcupine Hills is a west-facing cuesta, underlain by the Porcupine Hills formation, which dips eastward at 15 to 25 degrees. Lack of laterally persistent and resistant beds results in a poorly defined crest. The cuesta is best developed in the southern part of the Langford Creek map-area, where it reaches an elevation of 5,900 feet. The obsequent streams there are quite short, but to the north and south they are longer, producing a deeply crenulated front. East of the front, the streams exhibit a typical dendritic drainage pattern.

The Porcupine Hills are cut through only in the north, where the north and south branches of Willow Creek flow from their headwaters in the northern part of the Livingstone Range eastward through the eastern Foothills and the Porcupine Hills to the Plains.

The broad, subsequent valley that separates the Porcupine Hills from the eastern Foothills is developed upon the easily eroded Willow Creek formation. It is partly filled with glacial moraine, outwash, and lake deposits, and was the locus of south-flowing meltwater streams during Pleistocene time.

West of this valley lie the typical strike ridges and valleys of the Foothills, admirably reflecting the underlying thrust slices of alternating hard and soft strata. The crests of the ridges are, for the most part, underlain by the resistant basal beds of the Belly River formation, whereas the valleys are formed on the softer strata of the upper part of that formation or on the Alberta and Bearpaw marine shales.

[1] South of Gap map-area, Livingstone Range decreases in elevation so that the eastern and western parts of the Foothills merge. North of Gap map-area, the Livingstone Range joins the Highwood Range to form the eastern ranges of the Rocky Mountains east of Banff, and the western Foothills decrease in width until they form only a broad valley west of them.

Adjacent to the east flank of the Livingstone Range, the drainage is transverse to, rather than parallel with, the regional strike of the strata, due in part to the increased complexity of the structures in the underlying rocks, and also to the proximity to the local height of land along the Livingstone Range.

The Livingstone Range is a narrow, north-south lineament of resistant Palæozoic limestones and dolomites. Its maximum elevation of 8,000 feet is reached in the south, and, reflecting the north plunge of the structures, decreases northward to where some of the hills both to the east and west exceed it in height. That part of the range south of The Gap was the site of small alpine glaciers that have scalloped both its east and west flanks.

At The Gap, the Livingstone Range is traversed by Oldman River. The stream flows from the northwest, where it heads against the High Rock Range of the Rocky Mountains, diagonally southeast across the regional strike, with only minor parts directly transverse to or parallel with the strike. The river system is probably superimposed, but there is little direct evidence.

South of The Gap, the resistant Palæozoic strata underlying the Livingstone Range form a local drainage divide, but north of The Gap the range is cut through from the west by three short creeks, namely, Snake Creek and those immediately north and south of it. These streams have short courses to the base level of Oldman River west of the range in comparison with those flowing off the east flank of the range, and have, accordingly, extended the drainage divide to the east of the Palæozoic strata.

Along White Creek, 2½ miles north of Snake Creek, the drainage divide between east- and west-flowing waters lies still farther east. White Creek joins Livingstone River, a tributary of the Oldman, at an elevation of about 4,900 feet, but extends through the Livingstone Range to head some 6 miles to the east, less than 2 miles west of the headwaters of streams at 4,900 feet elevation that flow eastward to join the Willow Creek drainage system. A second creek, north of Gap map-area, is similarly situated. Such long, west-flowing streams appear to owe their present position to superposition, and perhaps indicate that the Oldman River system is also of superimposed origin.

In the western part of the Foothills, west of the Livingstone Range, many of the main drainage elements are transverse to the structure of the bedrock, in contrast with the typical longitudinal valleys of the eastern part of the Foothills. The longitudinal valleys of Vicary and Daisy Creeks are, however, also conspicuous, and a broad, subsequent valley, now occupied by part of Oldman River and Livingstone River, lies parallel with the Livingstone Range. These valleys were all occupied by glaciers in Pleistocene times, during which morainal and outwash materials were deposited in them. The rivers now flow in bedrock for much of their lengths, and in places follow narrow canyons as much as 150 feet deep.

Relief in the western part of the Foothills is, for the most part, about 1,500 feet, but increases to the north to more than 2,000 feet. The higher hills, above 7,000 feet in elevation, have been the sites of small alpine glaciers.

GLACIAL GEOLOGY

The glacial geology of Callum Creek, Langford Creek, and Gap map-areas presents several interesting features that warrant more thorough investigation than the writer has been able to make. Although primarily engaged in a study of the bedrock formations, an attempt was made to note some of the glacial features pertaining to drainage and the distribution of moraines and outwash. The results are far from complete; field data are limited and have been supplemented by studies of available air photographs. The present purpose is, therefore, to set forth what is known to the writer, and, so far as he is able, to point out problems that merit further study.

CONTINENTAL GLACIATION

The former presence of continental ice within the map-areas is indicated by till containing boulders of metamorphic gneiss and granite. These deposits lie only in restricted parts of Callum Creek and Langford Creek map-areas, and are taken to represent the western limits of the continental ice-sheet. Most of the till is fresh, and was probably deposited during the last or Wisconsin stage of Pleistocene glaciation. Some, however, may have been left during an earlier stage.

The continental ice-sheet invaded the Porcupine Hills and eastern Foothills in three major lobes. The northern lobe lay mainly in Stimson Creek map-area (Hume, 1943a) north of Langford Creek map-area. The southern lobe extended into the southern part of Callum Creek map-area from Cowley map-area (Hage, 1943) to the south. The central lobe extended up the valley of Willow Creek in Langford Creek map-area, branching at the forks of that stream into two minor lobes.

The southern minor lobe of the central main lobe pushed up the valley of South Willow Creek. Fresh till containing many boulders of metamorphic gneiss and granite was observed along the creek as far west as sec. 36, tp. 13, rge. 2, about a mile east of its junction with Langford Creek. Air photographs show morainal material was deposited along the sides of the valley to an elevation of about 4,500 feet.

Much till containing gneissic and granitic boulders was found on the west flank of the hill in sec. 17, tp. 13, rge. 2, close to the west border of Langford Creek map-area, to an elevation of 4,850 feet, and on the west slope of the hill in sec. 8, tp. 13, rge. 2, to an elevation of 5,000 feet. A single boulder of granite, much weathered and very friable, was found in Ropeo Gap, sec. 10, tp. 13, rge. 2, at an elevation of 4,400 feet. These occurrences may indicate that the southern minor lobe extended up South Willow and Langford Creeks at least as far as the west border of Langford Creek map-area, but these deposits may have been left by an earlier and more extensive continental ice-sheet for some occur at higher elevations than the till along the sides of South Willow Creek and the boulder found at Ropeo Gap is much weathered.

The northern minor lobe of the central main lobe does not appear to have extended beyond the sharp bend in the course of the main, or northern, branch of Willow Creek. Till containing granitic debris was observed only as far north as sec. 28, tp. 14, rge. 1, but air photographs show evidence of further advance up the main valley and into that of Big Jim Creek. Although the valley of the north branch of Willow Creek is the broader,

that of South Willow Creek is the direct westward continuation of the main valley to the east. Westward penetration of the continental ice-mass, accordingly, met with less resistance in its course up the valley of South Willow Creek, but was unable to reach a comparable distance in the valley of the north fork because of the sharp bends in the valley.

Except for this penetration, the westernmost or higher parts of the Porcupine Hills acted as a buttress against the westward movement of the continental ice-mass. To the north, in Stimson Creek area (Hume, 1943a), and to the south, in the Cowley area (Hage, 1943), the Porcupine Hills are lower, with the result that the continental ice-sheet passed over them and penetrated the Foothills belt itself. The northern lobe, enveloping the northern end of the Porcupine Hills in Stimson Creek map-area, probably extended down the valley now occupied by the Chain Lakes. Granite boulders were found east of the Chain Lakes about half a mile north of Langford Creek map-area. In the south, the ice-mass, skirting the southern part of the Porcupine Hills, extended up the valleys of Oldman River and Todd Creek at least as far as the south border of Callum Creek map-area. Granite boulders were found in Callum Creek map-area, sec. 24, tp. 9, reg. 2, at 4,400 feet elevation on the south slope of the ridge, and in sec. 21, tp. 9, rge. 1, just off the south border, at an elevation of 4,200 feet. Dawson (1884) reports granite boulders in the vicinity of the junction of Callum Creek and Oldman River.

The relationship of the continental ice-mass to the alpine glaciers that extended eastward from the Livingstone Range and the Rocky Mountains is not known. Such information would undoubtedly result from a study of the Willow Creek region and the lower part of Oldman River Valley. Some of the features connected with glacial drainage, which will be discussed in the following section, seem best explained as a consequence of the more or less simultaneous presence of continental ice in the east and alpine glaciers in the west.

ALPINE GLACIATION

Glacial drift, moraine and outwash, containing limestone and dolomite boulders was attributed to glaciers heading in the Livingstone Range and the High Rock Range of the Rocky Mountains. Some of the boulders are at least 75 feet square. The drift is not thick, and is confined, for the most part, to the valleys. Limestone erratics were observed on most of the hills, both to the east and west of Livingstone Range. Apparently the entire Foothills were at one time covered by a piedmont ice-sheet, although it may not have covered the Livingstone Range for erratics were not found on the range.

The Livingstone Range, south of The Gap, was the locus of numerous, small, alpine glaciers. These were not deeply incised, and moraine derived from them was not extensive. Small cirques are also present on the high ridges north and south of Oldman River, in tps. 11 and 12, rge. 4, of Gap map-area. All of these cirques are associated with peaks that rise to an elevation of about 7,000 feet or more; other peaks, both in the Livingstone Range and the Foothills, that do not reach this elevation do not appear to have had cirques developed upon them, suggesting that for a considerable interval of time the upper limit of piedmont ice lay below an elevation of 7,000 feet, and that these higher hills projected above it.

In addition to the small centres of accumulation along Livingstone Range and the higher hills west of it, other glaciers originating in cirques along the High Rock Range of the Rocky Mountains west of Gap map-area, and in the northern part of the Livingstone and southern Highwood Ranges, which lie north of the area, coalesced and flowed down the main river valleys, converging towards The Gap in the Livingstone Range. The glaciers from the west occupied the valleys of Oldman River, Dutch Creek, Racehorse Creek, and to a lesser extent those of Vicary and Daisy Creeks. Those from the north flowed down the valley of Livingstone River west of the Livingstone Range and also down White Creek east of the range. Examination of the topographic map and Plate I will show the character of the notch in the Livingstone Range, now occupied by Oldman River, through which these glaciers flowed. The rocks of the two low spurs at The Gap are smoothly polished up to an elevation of about 5,800 feet by the flow of ice over them. The upper limit of these coalesced glaciers, then, as discussed in the preceding paragraph, lay between 5,800 and 7,000 feet, probably closer to the former elevation along the Livingstone Range.

East of The Gap, the ice spread into the valley of Oldman River. South of the river it pushed into the low valleys between the south-trending ridges as far as the divides. Melt waters notched these divides and spread thin deposits of outwash beyond. These notches are located in secs. 10, 11, and 15, tp.10, rge. 3, and secs. 5 and 6, tp. 10, rge. 2, Gap map-area; and in secs. 28 and 34, tp. 9, rge. 2, Callum Creek map-area. The waters of these streams flowed southward into a lake that filled the valley of Todd Creek to an elevation of about 4,650 feet, and remnants of it still exist in the form of numerous sloughs and ponds. The lake may owe its origin to damming of the valley of Todd Creek by the southern main lobe of the continental ice-sheet.

Lobes of the main alpine glacier that occupied the valley of Oldman River extended northward into the valley just east of the Livingstone Range and part way up that of Camp Creek. The ice pushing up Camp Creek was apparently met by a glacier flowing southward down that stream, originating in the northern part of the Livingstone Range, north of Gap map-area. Abundant moraine was left along the valley between Miles and Jacknife Coulées, and melt waters flowed over the divide in sec. 13, tp. 11, rge. 3, into the valley of Bob Creek.

The broad valley lying immediately west of Whaleback Ridge, now drained by the headwaters of Bob, Beaverdam, and Coyote Creeks, was occupied by a valley glacier that left thin deposits of drift and numerous drumlins. Melt waters spilled southward down Eagle Coulée and Coyote Creek, and westward down upper Bob Creek, the creek to the south, and Beaverdam Creek into the lower part of Bob Creek. This lower part of Bob Creek was aggraded by outwash from these streams.

The eastward limit of the glacier down the valley of Oldman River is not known. During its retreat, two recessional moraines were left, one in secs. 35 to 36 and 25 to 26, tp. 10, rge. 3, and the other in secs. 33 and 34, tp. 10, rge. 3. The moraines show well-developed kettles; the hummocks, on the other hand, are remarkably flat-topped, suggesting planation by outwash streams prior to the complete melting of the stagnant ice that produced the kettles.

Breeding Valley and its southward extension, and the valley now occupied by Callum and Swanson Creeks were also occupied by south-flowing glaciers. Moraine was deposited along Breeding Valley and the sides of Callum and Swanson Creeks, and thick deposits of outwash covered the greater part of lower Callum Creek. These glaciers and that in Bob Creek Valley appear to be the southern extension of a main valley glacier system that occupied the upper parts of South Willow, Langford, and Willow Creeks.

Melt waters continued to flow southward down Callum Creek, even after the glaciers had retreated westward up South Willow and Langford Creeks; for the eastward flow of these waters down South Willow Creek, as now takes place, was restricted, producing a large lake in the valley of Swanson Creek, and around the junction between Langford and South Willow Creeks. The level of this lake must have been at least 4,450 feet, which is the elevation of the outlet at the divide between Callum and Swanson Creeks. The restriction that produced the lake was probably due to the presence of the continental ice-mass in the valley of Willow Creek. A recessional moraine of the continental ice-mass could also produce a dam, but the writer was unable to find any evidence of such along South Willow Creek. Presumably, at this time the main southern lobe of the continental ice-sheet had retreated from the valley of Oldman River in the south, permitting easy outlet of the meltwaters in that direction.

A similar distribution of drainage and damming appears again farther north. At least part of the now east-flowing waters of Stimson Creek map-area (Hume, 1943a) flowed southward down the valley now occupied by the Chain Lakes into Willow Creek. At this time, the northern main lobe of the continental ice-sheet prevented eastward drainage in the Stimson Creek area, but the central lobe had retreated from the valley of Willow Creek.

With the retreat of the northern lobe and the abandoning of the Chain Lakes outlet, this outlet was dammed at its junction with Willow Creek by the aggrading of the latter's channel. The long lake filling the abandoned channel was divided, and is in process of being still further divided, into several smaller lakes, by deltas built up by the small streams flowing into it from the Porcupine Hills to the east (*See* Plate II A).

Accordingly, the continental ice-sheet lingered longest in the north, and successive retreat of the southern and then the central lobe took place, accompanied by the formation of temporary south-flowing melt-water streams, until the pre-Glacial drainage was re-established.

While the main glaciers moved eastward down the valleys of Oldman River, Willow Creek, and Stimson Creek, subsidiary lobes from them spread to the south and were restricted to the north. The retreat of these lobes, and the main valley glaciers progressed successively from south to north. The successive northward retreat of the valley glacier system appears synchronous with the unblocking by the continental ice-mass of the pre-Glacial drainage channels to the east, and suggests that the continental and alpine glaciers during this stage were merged along this part of the Foothills belt.

CHAPTER III

STRATIGRAPHY

GENERAL STATEMENT

As much as 23,000 feet of sediments accumulated in or near Callum Creek, Langford Creek, and Gap map-areas from Mississippian to early Tertiary time. Available information on the Mississippian Rundle formation, the Lower Cretaceous Kootenay formation and Blairmore group, and on the Upper Cretaceous Alberta group indicate that they thicken towards the west from 1,410 to 1,965, 50 to 700 feet, 1,000 to 2,200 feet, and 1,560 to 2,900 feet, respectively, within the limits of the three map-areas. The Blairmore group and the Kootenay, Bighorn, and Blackstone formations all show a coarsening of texture and increased arenaceous content towards the west.

Sediments laid down during Mississippian time were mainly limestones and dolomites, the earlier deposits accompanied by the formation of abundant chert. Green and red shales and fine sands appear in the uppermost Mississippian strata and fine sands in beds of possible Pennsylvanian age. The source of these clastic sediments is not known.

Late Palæozoic and early Mesozoic times were represented in this region by only a few feet of unfossiliferous strata. Possible uplift and erosion in Lower Jurassic time was followed by the deposition of black marine shales of the Fernie group, with a basal chert and limestone conglomerate. The pebbles of this conglomerate are similar, lithologically, to some of the underlying rocks.

During late Jurassic and early Lower Cretaceous times, marine conditions of deposition gradually changed to non-marine. Clastic material in the form of muds and sands composed of chert and quartz grains were laid down, and swamps covered large areas in which vegetation flourished, later to be carbonized to form coal. These sediments of the Kootenay formation coarsen towards the west, presenting the first evidence of a land that supplied debris to form the clastic rocks of Cretaceous and early Tertiary times in these map-areas. During the deposition of the succeeding Blairmore group, erosion of this land had evidently exposed some crystalline metamorphic or igneous rocks, as indicated by the presence of abundant feldspar and ferromagnesian minerals in the sandstones of the group. These minerals appear first some 300 feet above the base of the Blairmore group, increasing in proportion upwards. A conglomerate, about 1,200 feet above the base, contains granite and porphyry pebbles. The sandstones close to the top of the group are, like those of the Kootenay and lower part of the Blairmore, composed of chert and quartz grains.

Volcanic activity commenced during the deposition of the upper part of the Blairmore group and culminated with the ejection of the coarse pyroclastic material of the Crowsnest formation. The Alberta marine

shales, deposited in early Upper Cretaceous time, overlapped westward the non-marine Blairmore sediments and the Crowsnest volcanic rocks. The source land in the west lay low, yielding only fine sands and abundant clay material. A second uplift of this land resulted in relatively rapid erosion and the accumulation of the sandstones and shales of the Belly River formation. Like those of the Blairmore group, these sediments contain much feldspar and ferromagnesian minerals, and were deposited under non-marine conditions. The seas returned once more in the eastern part of the map-areas during Bearpaw time, and deposited marine shales and sandstones, but these conditions were soon replaced when non-marine deposition was resumed, and the St. Mary River beds were lain down. These and succeeding beds carry abundant feldspar and ferromagnesian minerals.

In late Upper Cretaceous or early Tertiary time, a change in the climate of the source land or in the non-marine conditions of deposition is reflected in the red and mottled red and green colours of some of the shales of the Willow Creek formation. Uplift subjected the Willow Creek beds to erosion and removed them almost entirely in the northern part of the Langford Creek map-area. Deposition of the succeeding Paleocene Porcupine Hills formation followed, with increased volume of coarse clastic sediments.

TABLE OF FORMATIONS

Era	Period or epoch	Formation or group		Lithology	Thickness Feet
Cenozoic	Paleocene	Porcupine Hills		Non-marine shale and sandstone	4,000+
	Erosional unconformity				
— — — —	Paleocene and/or Upper Cretaceous	Willow Creek		Non-marine sandstone and red, green, and grey shale	2,700-350
Mesozoic	Upper Cretaceous	St. Mary River		Non-marine shale and sandstone; coal	3,188
		Bearpaw		Marine black shale and sandstone	600±
		Belly River		Non-marine shale and sandstone; coal	3,000-4,200
		Alberta	Wapiabi	Marine grey shale and sandstone	1,080-1,600
			Bighorn	Marine sandstone, conglomerate, and sandy shale	30-300
			Blackstone	Marine grey shale and sandstone; basal grit	450-1,000
	Upper Cretaceous?	Crowsnest		Volcanic agglomerate and tuff	0-350
	Lower Cretaceous	Blairmore		Non-marine shale, sandstone, and conglomerate; basal conglomerate	1,000-2,200

TABLE OF FORMATIONS—*Con.*

Era	Period or epoch	Formation or group	Lithology	Thickness Feet
		Unconformity?		
		Kootenay	Non-marine sandstone and carbonaceous shale; coal	50-700
	Jurassic	Fernie	Marine black shale and sandstone; basal conglomerate	480-700
	Disconformity?			
	Triassic	Spray River?	Dolomite and limestone	26-40
	Disconformity?			
Palæozoic	Pennsylvanian?	Rocky Mountain?	Arenaceous dolomite and limestone	66-375
	Unconformity or disconformity?			
	Mississippian	Rundle	Limestone, dolomite, and shale	1,410-1,965
		Banff	Limestone and dolomite	800+

DESCRIPTION OF FORMATIONS

MISSISSIPPIAN

Banff Formation

The rocks of the Banff formation are the oldest known in Callum Creek, Langford Creek, and Gap map-areas, outcropping only at The Gap and along the southeast flank of Livingstone Range. The base, and, consequently, the thickness, of the formation are unknown.

At least 800 feet of beds are exposed on the east flank of Livingstone Range 6 miles south of The Gap. This figure may represent nearly the complete thickness, as the lowest beds are banded, dark and light grey weathering, fine-grained, black dolomites, similar to beds directly overlying the Exshaw formation in the High Rock Range of the Rocky Mountains, west of the Gap map-area.

The remainder of the formation consists of fine-grained, cherty, grey dolomites and limestones, weathering buff to light brown. Bedding is poorly developed, but the abundant chert gives the rock a distinctive banded appearance. Some of the basal beds of the Rundle formation are of similar appearance, but in these the chert is less abundant and commonly in the form of nodules and stringers. The contact with the

overlying Rundle formation is placed arbitrarily at the base of the lowest massive bed of coarsely crystalline, light grey weathering limestone. Rundle fossils were found in this basal bed at The Gap[1].

Rundle Formation

The Rundle formation underlies the greater part of Livingstone Range in Gap map-area. It has been divided into four members, which have been mapped separately. This subdivision is based solely on lithologic characteristics, and has been used primarily in the interpretation of the structure of the complicated eastern flank of Livingstone Range. Study of fossils collected from the Rundle has not been completed.

The total thickness of the Rundle formation at The Gap is 1,720 feet. A summary of the section on the north and south sides of Oldman River there is as follows:

	Thickness Feet
Overlying beds—Rocky Mountain formation?	
Contact disconformable?	
Rundle formation	
Member D:	
Fine-grained, blocky, grey limestones; fine-grained, buff dolomite; chert and limestone breccias; crossbedded, arenaceous dolomite; thin, porous limestone; green shale	250
Member C:	
Massive to thin-bedded, fine-grained, black limestone, very hard, dense, and brittle, breaking with a conchoidal fracture; some thin, black, calcareous shale and buff, coarsely crystalline limestone	200
Member B:	
Thin-bedded to platy, fine-grained, argillaceous dolomite, weathering buff to dark brown; massive, fine-grained, cherty, grey limestone and dolomite	480
Member A:	
Massively bedded, grey dolomite, grey weathering, with chert in stringers and blebs; massively bedded, buff, coarsely crystalline, grey limestone, light grey weathering; with basal bed 80 feet thick	790
Total thickness of Rundle formation	1,720
Contact conformable	
Underlying beds—Banff formation	

The porosity conditions of the upper part of Member A were studied in detail by G. S. Hume of the Geological Survey, on the south bank of Oldman River at The Gap. His section[2] follows:

[1] Brown, R. A. C.: personal communication.
[2] Personal communication.

—	Thickness	Height above base
Rundle formation	Feet	Feet
Member B:		
Thin-bedded dolomite	5·0	787·0
Member A:		
Limestone, cherty	9·0	778·0
Dolomite, grey	2·0	776·0
Limestone, black	3·0	773·0
Dolomite, cherty	5·0	768·0
Limestone, cherty	10·0	758·0
Limestone, crystalline	3·0	755·0
Limestone, porous	1·0	754·0
Limestone, fine-grained; a few vugs	5·0	749·0
Limestone, dark, fine-grained	9·0	740·0
Limestone, porous—poor porosity	2·0	738·0
Limestone, massive, fine-grained	5·0	733·0
Limestone, thin-bedded	18·0	715·0
Limestone, fine-grained	4·0	711·0
Limestone, poorly porous	2·0	609·0
Limestone, fine-grained	20·0	689·0
Limestone, crystalline	1·0	688·0
Limestone, fine-grained	1·0	687·0
Limestone, crystalline	1·0	686·0
Limestone, fine-grained	2·5	683·5
Limestone, crystalline and fine-grained	8·5	675·0
Limestone, vuggy	4·0	671·0
Limestone, dark, crystalline	9·0	662·0
Limestone, fine-grained	4·0	658·0
Limestone, crystalline, poorly porous	7·0	651·0
Limestone, dark, fine-grained	14·0	637·0
Limestone, crystalline, porous	2·5	634·5
Limestone, fine-grained	3·0	631·5
Limestone, crystalline, porous	3·0	628·5
Limestone, fine-grained	4·0	624·5
Limestone, poorly porous	3·0	621·5
Limestone, vuggy	12·0	609·5
Limestone, fine-grained	10·0	599·5
Limestone, vuggy (vugs up to 1 inch in diameter)	5·0	594·5
Limestone, fine-grained	25·0	569·5
Limestone, vuggy	3·0	566·5
Limestone, fine-grained	2·0	564·5
Limestone, vuggy	2·0	562·5
Limestone, fine-grained	3·0	559·5
Dolomite, fine-grained	3·0	556·5
Covered	15·0	541·5
Limestone, crystalline, porous	5·0	536·5
Dolomite, grey, fine-grained	1·0	535·5
Limestone, fine-grained	12·0	523·5
Limestone, vuggy, porous	3·0	520·5
Limestone, fine-grained	4·0	516·5
Limestone, vuggy	0·5	516·0
Limestone, fine-grained	5·0	511·0
Limestone, vuggy	8·0	503·0
Limestone, crystalline (end of good exposure along road)	3·0	500·0
Limestone, crystalline	60·0	440·0
Dolomite and limestone; chert in nodular masses or irregular layers	360·0	80·0
Limestone, massive, crystalline	80·0	00·0
Total thickness of Member A	787·0	
Contact conformable		
Underlying beds—Banff formation		

The following section of Member D was measured along the south bank of Oldman River, in sec. 33, tp. 10, rge. 3:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Rocky Mountain formation?		
Contact disconformable?		
Rundle formation		
Member D:		
Limestone and dolomite, dark grey, rubbly, fine-grained	15·0	199·0
Dolomite, dark grey, massive	4·0	195·0
Covered	6·0	189·0
Limestone, grey, massive, fine-grained	2·0	187·0
Dolomite, greenish grey, argillaceous	3·0	184·0
Interbedded, rubbly, irregularly bedded, grey limestone and dolomite; thin, porous limestones, and green shale	10·0	174·0
Covered	2·0	172·0
Limestone, porous, and brecciated chert	1·0	171·0
Dolomite, buff, fine-grained	3·0	168·0
Limestone, porous	1·0	167·0
Dolomite, buff	2·0	165·0
Chert, bedded	0·5	164·5
Dolomite, buff	3·0	161·5
Covered	5·0	156·5
Dolomite, grey, blocky fracturing, fine-grained	3·0	153·5
Covered	5·0	148·5
Dolomite, buff	5·0	143·5
Limestone, porous	2·0	141·5
Dolomite, buff; with *Archimedes*	3·0	138·5
Limestone, porous	2·0	136·5
Dolomite, buff	3·0	133·5
Dolomite, grey, argillaceous, fine-grained	3·0	130·5
Limestone, porous	3·0	127·5
Shale, green, calcareous	6·0	121·5
Limestone, arenaceous, cherty	2·0	119·5
Dolomite, grey, fine-grained, and chert breccia	3·0	116·5
Dolomite, grey, blocky fracturing	10·0	106·5
Limestone, porous	1·0	105·5
Limestone, with chert nodules, 2 to 4 inches in diameter	2·0	103·5
Dolomite, grey, fine-grained, arenaceous	18·0	85·5
Shale, green	3·5	82·0
Dolomite, brown, with capping of dolomite breccia	1·0	81·0
Shale, green	1·0	80·0
Dolomite, grey	6·0	74·0
Shale, green	3·0	71·0
Dolomite and limestone breccia	3·0	68·0
Dolomite, buff	5·0	63·0
Limestone, porous	4·0	59·0
Dolomite, buff	3·0	56·0
Shale, green	6·0	50·0
Dolomite, buff, and green shale, inaccessible, broken by minor fault, overlying member C	50·0	00·0
Total thickness of member D	214·0	

Southward, Member D increases in thickness, and contains red and mottled red and green shale in its lower part. Member A also increases in thickness to the south as the coarsely crystalline, buff limestones increase in thickness and proportion. Members B and C vary little in thickness and lithology. The upper three members and part of the lower member were measured on the west flank of the Livingstone Range, 5½ miles south of The Gap. Their description follows:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Rocky Mountain formation?		
Contact unconformable		
Rundle formation		
Member D:		
Shale, calcareous, with large, calcite-filled vugs	1·0	1,964·0
Interbedded, fine-grained, grey limestone and grey shale	25·0	1,939·0
Dolomite, grey, cherty	15·0	1,924·0
Dolomite, white, finely crystalline, granular	15·0	1,909·0
Limestone, grey, fine-grained, massive bedded, with calcite-filled vugs	10·0	1,899·0
Limestone, brecciated, cherty	5·0	1,894·0
Dolomite, buff, fine-grained, sparsely cherty	60·0	1,834·0
Dolomite, buff, fine-grained, cherty, thin-bedded	25·0	1,809·0
Mostly covered; green shale and lenticular, porous limestone	45·0	1,764·0
Dolomite, buff, medium-grained, massively bedded	30·0	1,734·0
Shale, green	10·0	1,724·0
Dolomite, grey, thin-bedded, finely crossbedded; fine sand grains occur along crossbeds	20·0	1,704·0
Mostly covered; some green shale	15·0	1,689·0
Dolomite, grey, thin-bedded, finely crossbedded; fine sand grains occur along crossbeds	10·0	1,679·0
Shale, green	1·0	1,678·0
Limestone, dirty grey, fine-grained	3·0	1,675·0
Covered	80·0	1,595·0
Shale, green and red, variegated, chert nodules	2·0	1,593·0
Limestone, brown, fine-grained, chert nodules up to 2 feet in diameter	3·0	1,590·0
Thickness of Member D	375·0	
Member C:		
Dark grey to black limestone, massive to thinly bedded, fine-grained, hard, dense, and brittle, breaking with a conchoidal fracture; some brown, coarsely crystalline limestone and cherty, dark grey limestone; thin beds of black, calcareous shale; basal 20 feet, thin-bedded, grey, dolomitic limestone weathering dark brown	195·0	1,395·0
Member B:		
Dolomite, argillaceous, grey, thinly bedded to platy, brown weathering	85·0	1,310·0
Limestone, grey, fine-grained, massive	5·0	1,305·0
Limestone, brecciated, calcite cement	10·0	1,295·0
Dolomite, grey, platy, partly covered	25·0	1,270·0
Dolomite, grey, medium-grained, massive	10·0	1,260·0
Dolomite, as above, cherty	15·0	1,245·0
Covered	10·0	1,235·0

——	Thickness	Height above base
	Feet	Feet
Member B:—Con.		
Limestone, brown, medium-grained, porous	12·0	1,223·0
Limestone, vuggy	3·0	1,220·0
Limestone, brown, medium-grained, porous	15·0	1,205·0
Dolomite, brown, massive, cherty	25·0	1,180·0
Limestone, brown, medium-grained, cherty	5·0	1,175·0
Limestone, dark grey, fine-grained	10·0	1,165·0
Breccia of chert and limestone fragments; vugs up to 2 inches in diameter	5·0	1,160·0
Dolomite, argillaceous, grey, platy, weathering dark brown	100·0	1,060·0
Dolomite, grey, fine-grained, massive	10·0	1,050·0
Dolomitic limestone, grey, medium-grained, cherty	60·0	990·0
Limestone, grey, fine-grained, thin-bedded	25·0	965·0
Dolomite, argillaceous, brown, platy to massive	75·0	890·0
Thickness of Member B	505·0	
Member A:		
Massively bedded, grey limestone and dolomite, grey weathering; massively bedded, coarsely crystalline, buff limestone, grey weathering, composed partly of fragments of crinoids, some zones very porous; a total of 640 feet was plane-tabled, and an estimated 250 feet to the contact with the Banff formation is inaccessible	890·0	000·0
Total thickness, Rundle formation	1,965·0	.....

The Rundle formation was penetrated by the Socony Vacuum, Stimson No. 1 well in northwest Langford Creek map-area between 3,490 and 5,040 feet drilling depth, which, allowing for the probable dip of the strata, yields a true thickness of about 1,410 feet. Of this thickness, the upper 375 feet of beds are believed equivalent to the greater part of Member B, with the underlying 1,035 feet equivalent to Member A. Member B is overlain by a coarse-grained sandstone probably of the same age as the basal conglomerate of the Fernie group observed on the outcrop in Gap map-area to the southwest. Description of the samples recovered during drilling is given in the Appendix. The sequence of strata encountered correlates closely with that found in the wells drilled to the north in the Pekisko Creek map-area.

PENNSYLVANIAN (?)

Rocky Mountain Formation (?)

The beds that overlie the Rundle formation are separated from it on the basis of their arenaceous and cherty character. In the type area of the Rocky Mountain formation at Banff, Alberta, Warren (1947) has subdivided the formation into two parts; the lower part being probably of Pennsylvanian age and the upper part probably Permian in age. The strata herein ascribed to the Rocky Mountain formation correspond best

with Warren's description of the lower or Pennsylvanian part, which he says consists "principally of dolomite and sandstone with chert nodules". No fossils were obtained from these strata.

The thickness of the formation is variable: 200 feet, on the west flank of the Livingstone Range at The Gap; 66 feet, 1 mile east of The Gap; 101 feet on White Creek; and 280 feet, on the west flank of the Livingstone Range 5½ miles south of The Gap.

At the last locality the basal, arenaceous dolomite bed of the Rocky Mountain formation overlies Member D of the Rundle with angular unconformity (*See* Plate II B). About 3 feet of calcareous shale and grey limestone of Member D are missing.

The following section was measured on the south bank of Oldman River, 1 mile east of The Gap, sec. 33, tp. 10, rge. 3:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Spray River formation?		
Contact disconformable?		
Rocky Mountain formation (?)		
Dolomite, dark grey; chert nodules and breccia	1·5	64·5
Dolomite, dark grey, fine-grained; thin chert bands	8·0	56·5
Dolomite, brownish grey, fine-grained	2·0	54·5
Chert breccia	0·5	54·0
Dolomite, brownish grey, coarsely crystalline	3·5	50·5
Chert, thinly bedded	3·0	47·5
Dolomite, grey, arenaceous	5·5	42·0
Dolomite, grey, arenaceous, with thinly bedded chert	4·5	37·5
Dolomite, grey, arenaceous, with chert bands and lenses	4·0	33·5
Dolomite, brown, arenaceous	4·0	29·5
Limestone and dolomite, light grey, arenaceous, pitted weathered surface; the limestone matrix is in the form of large crystals up to 1 inch in diameter; the dolomite is granular and fine-grained; the pits are developed in the limestone matrix, whereas the dolomite matrix is more resistant to erosion	3·0	26·5
Dolomite, grey, arenaceous, cherty base	15·5	11·0
Dolomite, grey, arenaceous, massive bedded	4·0	7·0
Limestone and dolomite, grey, arenaceous, with vugs 2 to 4 inches in diameter filled with pink and white calcite	7·0	0·0
Total thickness of Rocky Mountain formation	66·0	.....
Contact disconformable?		
Underlying beds—Rundle formation, Member D		

The associated arenaceous and cherty characters of these strata render them quite distinctive in the field. The beds weather pink or grey, and, being more resistant to erosion than the underlying and overlying strata, form cliffs and dip-slopes, especially along the west flank of Livingstone Range.

TRIASSIC

Spray River Formation (?)

The strata ascribed to the Spray River formation are distinct lithologically from those of overlying and underlying formations, from which they may be separated by disconformities. An arenaceous grey limestone, with disseminated, well-rounded chert pebbles up to ¼ inch in diameter, marks the base of the Spray River formation. The basal bed of the overlying Fernie group is a chert and limestone conglomerate and coquina that rests with apparent conformity on the Spray River beds. No fossils were found in these strata, but they occupy a similar stratigraphic position to that of the Spray River formation of Triassic age in its type area at Banff (Warren, 1927).

A thickness of 26 feet was measured on White Creek; 40 feet on the west flank of Livingstone Range 5½ miles south of The Gap; and 32 feet on the south bank of Oldman River 1 mile east of The Gap. The section at the last locality is as follows:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Fernie group		
Contact disconformable?		
Spray River formation?		
Limestone, dark grey, finely crystalline, massive	4·0	28·0
Limestone, dolomitic, with disseminated vugs filled with calcite	1·0	27·0
Dolomite and limestone, thin-bedded, alternating light and dark grey dolomite and limestone	3·5	23·5
Dolomite, dark grey, massive, mottled with light grey limestone	3·5	20·0
Dolomite, dark grey, rubbly weathering	1·5	18·5
Dolomite, argillaceous, fine-grained, massive to platy, variegated pale pink, yellow, and green, grey weathering	13·5	5·0
Limestone, black, coarsely crystalline, forms capping on underlying beds	0·5	4·5
Dolomite, fine-grained, variegated pink and green	3·0	1·5
Limestone, grey, fine-grained, arenaceous, with disseminated, well-rounded chert pellets up to ¼ inch in diameter	1·5	0·0
Total thickness of Spray River formation	32·0	.....
Contact disconformable?		
Underlying beds—Rocky Mountain formation?		

The Spray River formation is too thin to be mapped separately on the accompanying maps, and has been grouped with the Rocky Mountain formation for mapping purposes.

JURASSIC

Fernie Group

The Fernie group outcrops along both flanks of the Livingstone Range and in two small inliers along the north boundary of Gap map-area. As it is poorly exposed and commonly contorted, no complete section could be measured.

The lower 256 feet of Jurassic strata are well exposed on the south bank of Oldman River, in sec. 33, tp. 10, rge. 3:

—	Thickness	Height above base
	Feet	Feet
Fernie group		
Shale, black, fissile, with nodular and lenticular, fine-grained, black limestone in beds 1-2 feet thick....	140·0	116·5
Bentonite.....	0·5	116·0
Limestone, massive, black; *Belemnites* conglomerate...	3·0	113·0
Covered.....	5·0	108·0
Sandstone, black, thin-bedded, fine-grained, slightly calcareous; top 2 feet pyritic.....	70·0	38·0
Covered.....	35·0	33·0
Coquina of shell fragments, and chert and limestone pebble-conglomerate; matrix of dark grey limestone; pebbles up to ½ inch diameter.....	3·0	0·0
Total thickness.....	256·5	
Contact disconformable (?)		
Underlying beds—Spray River formation (?)		

Fossils collected from the black limestone and belemnite conglomerate bed have been identified by F. H. McLearn of the Geological Survey as follows: *Stephanoceras* sp., *Fanninoceras* ? sp., "*Belemnites*" sp., *Inoceramus ferniensis* Warren, *Pleuromya* sp., *Trigonia* sp., and cf. *Praeconia* ? *burnsi* Warren. McLearn dates this fauna as early Middle Jurassic.

The upper part of the Fernie group is exposed about 1½ miles downstream from the above locality, along the north bank of Oldman River, sec. 3, tp. 11, rge. 3. The contact with the overlying Kootenay formation appears transitional. Typical, fissile, black, marine shales of the Fernie change to grey, silty shales and intercalated, thin-bedded, fine-grained, finely laminated, grey sandstones. The sandstone beds increase in thickness and proportion upwards, forming a transitional zone 90 feet thick. The top of the Fernie is drawn at the base of a light grey, carbonaceous and micaceous, medium-grained sandstone 20 feet thick. As no repetition of strata was detected in this and the section on Oldman River already mentioned, a minimum of 346 feet of strata must be represented.

On the west flank of the Livingstone Range, 5½ miles south of The Gap, the contact with the Kootenay is placed where brown, Fernie sandstones change to dark grey, coarse-grained, crossbedded sandstone. The Fernie section is as follows:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Kootenay formation		
Contact conformable, transitional		
Fernie group		
Shale, dark grey, silty	1·0	803·0
Sandstone, brown, fine-grained, thin-bedded, laminated	25·0	778·0
Interbedded, fine-grained, finely laminated, grey and brown sandstones in beds 1-6 inches thick, and dark grey, poorly bedded shale; shale increases in proportion downwards	240·0	538·0
Strata not exposed; faulted	400·0	138·0
Shale massively bedded, conchoidally fracturing, soft, brown	2·0	136·0
Covered	20·0	116·0
Coquina of *Pecten* shells and fragments in fine-grained, argillaceous, grey limestone	6·0	110·0
Sandstone, dark grey, fine-grained, thinly bedded	20·0	90·0
Shale, dark grey, hard, and thin siltstone	25·0	65·0
Covered	65·0	0·0
Total thickness of exposed strata	404·0	
Total thickness between upper and lower contacts of Fernie group	804·0	
Underlying beds—Spray River formation (?)		

The basal Fernie conglomerate was oberved a short distance to the south of this section. It consists of subangular fragments of black chert and grey dolomite up to 1 inch in diameter embedded in silty black dolomite.

The brown sandstones at the top of the above section are believed to mark the top of the Fernie group. Similar sandstones were observed below Kootenay strata on both flanks of the Livingstone Range on White Creek.

Pale green, rubbly shales with fragments of belemnites occur in the crest of an anticline, about 250 feet below the contact with the Kootenay on White Creek, in sec. 15, tp. 12, rge. 3. Strata of this lithology were not observed elsewhere in the map-area, and may lie either above or below the sections described in the preceding paragraphs. The total thickness of the Fernie group in the Gap map-area is probably between 500 and 700 feet,.

The Socony Vacuum, Stimson No. 1 well in northwest Langford Creek map-area encountered the Fernie group between depths of 2,960 and 3,490 feet, which, allowing for the dip of the strata, indicates a thickness of about 480 feet (*See* Appendix for description of the samples). The brown sand at the top of the group is quite thick, occurring between 2,960 and 3,110 feet drilling depths. In the Northwest Company, Willow Creek well, only 1½ miles to the southeast, no brown sand was drilled (*See* Appendix). The base of the Fernie group in the Stimson well is marked by a calcareous, coarse-grained, white, quartz sandstone, probably equiva-

lent to the basal conglomerate observed on the west flank of the Livingstone Range in the Gap map-area. This sandstone overlies strata ascribed to Member B of the Rundle formation. The intervening strata, the Spray River and Rocky Mountain formations and Members C and D of the Rundle formation, which are present on the outcrop in the Gap map-area, are absent in this well and are presumed to have been removed by pre-Fernie erosion.

LOWER CRETACEOUS

Kootenay Formation

The Kootenay formation is exposed only in Gap map-area, where it is adjacent to many faults, and along the flanks of the Livingstone Range. A thickness of 450 feet was measured along the north bank of Oldman River, in sec. 3, tp. 11, rge. 3, but, due to minor faults in the basal part of the section, this may be excessive. The following undisturbed section, 370 feet thick, was measured on the west flank of the Livingstone Range, 5½ miles south of The Gap:

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Blairmore group		
Contact unconformable		
Kootenay formation		
Shale, dark grey, thin-bedded, finely laminated	20·0	350·0
Sandstone, coarse to medium-grained, dark grey, thin to massively bedded, crossbedded, laminated with carbonaceous material	95·0	255·0
Interbedded, fine-grained, dark grey sandstone and dark grey shale	25·0	230·0
Mostly covered, about 9 feet of coal	20·0	210·0
Interbedded, dark grey, silty shale and lenticular, fine-grained, crossbedded, dark grey sandstone	62·0	148·0
Sandstone, fine-grained, dark grey	3·0	145·0
Shale, dark grey, carbonaceous	1·0	144·0
Coal	3·0	141·0
Interbedded shale and sandstone as above	76·0	65·0
Sandstone, dark grey, massive to thin-bedded, coarse-grained, crossbedded	65·0	0·0
Total thickness Kootenay formation	370·0	
Contact conformable, transitional		
Underlying beds—included with Fernie group		

The Kootenay formation is much thicker in the western and northwestern parts of Gap map-area. No reliable determinations could be made, but the thickness there is of the order of 700 feet.

In the northwestern part of Langford Creek map-area, the Northwest Company, Willow Creek well penetrated the Kootenay formation between depths of 3,050 and 3,200 feet, or a drilling thickness of 150 feet. A short distance to the northwest in the Socony Vacuum, Stimson No. 1 well, only a drilling thickness of 60 feet of Kootenay strata was encountered. These drilling thicknesses represent maximum thicknesses unless thinning through deformation has taken place, and indicate a general eastward thinning of the formation from Gap map-area to northwest Langford Creek map-area.

Blairmore Group

Blairmore strata outcrop over the greater part of Gap map-area, west of the Livingstone thrust. Except for two small areas in the northern part of Langford Creek map-area, the Blairmore group is known in the east only through drilling.

No complete section was studied in detail, but certain generalities concerning the stratigraphic succession were found to be consistent throughout the map-area. The base of the group is marked by 10 to 30 feet of conglomerate, the pebbles of which are of black, grey, and green chert and white and yellow quartzite. They are well rounded, with a maximum diameter of about 2 inches, where observed east of the Livingstone Range, but become coarser in the west, where locally cobbles 6 to 8 inches in diameter may be found. In the wells in the east the basal beds of the Blairmore are a light grey, medium- to coarse-grained, sparsely conglomeratic sandstone, commonly called the Dalhousie sand by drillers.

Overlying the basal conglomerate and grading into it are coarse-grained, white to grey sandstones. Dark grey sandstones and dark grey shales, with two, massive, fine-grained, grey limestone beds near the top were observed in the overlying 250 feet of strata.

Above the black shales and limestones is a bed of coarse- to medium-grained, crossbedded, white to grey, pure chert and quartz sandstone. This sandstone becomes coarser westward. West of the Livingstone Range it contains chert and quartzite pebbles up to 1 inch in diameter. The top of this sandstone, commonly termed the Home sand in well logs, lies from 300 to 400 feet above the base of the Blairmore group.

The remainder of the Blairmore consists of interbedded light greenish grey, fine- to coarse-grained, crossbedded sandstones with a high feldspar and ferromagnesian content, and grey, green, and maroon shales and silty shales. Some 1,200 feet above the base, as measured on Oldman River, in sec. 34, tp. 10, rge. 3, is a massive, cliff- and ridge-forming sandstone. It is grey, medium to coarse grained, crossbedded, and weathers dark to light brown. This bed is fairly persistent, and was used to some extent in the interpretation of the structure. It is believed to be equivalent to the McDougall-Segur sand of the Turner Valley area (Hume, 1938). A small florule was collected from the top of this bed on Oldman River, and, according to W. A. Bell of the Geological Survey, contains *Cladophlebis parva* Fontaine and *Ruffordia goepperti* (Dunker) Seward of Aptian (early upper Lower Cretaceous) age. A pebble-conglomerate was observed in numerous places in the western part of Gap map-area, at or about 100 feet above the McDougall-Segur sandstone. The pebbles may be as much as 2 inches in diameter, and consist of grey, white, and green chert, white and yellow quartzite, and, rarely, of fine-grained granite and porphyry. The stratigraphic relationship of this conglomerate to the sandstone was difficult to ascertain as the conglomerate is not persistent along strike.

Maroon shales occur mostly above the McDougall-Segur sandstone, but may be present below. Lenticular, dark brown weathering, fine-grained, grey, argillaceous limestones are common in the overlying 300 feet of strata.

Microscopic examination of the samples from wells drilled within or close to the map-areas shows brown, bentonitic shales and fine-grained tuff or tuffaceous shale interbedded with typical maroon and green shales and green sandstones above the McDougall-Segur sandstone. These tuffaceous and bentonitic shales were not observed in outcrops; they are probably too fine grained to be recognized in the field without very careful examination of a well-exposed section, which, unfortunately, the writer was unable to do as he had completed the field work prior to studying the well samples.

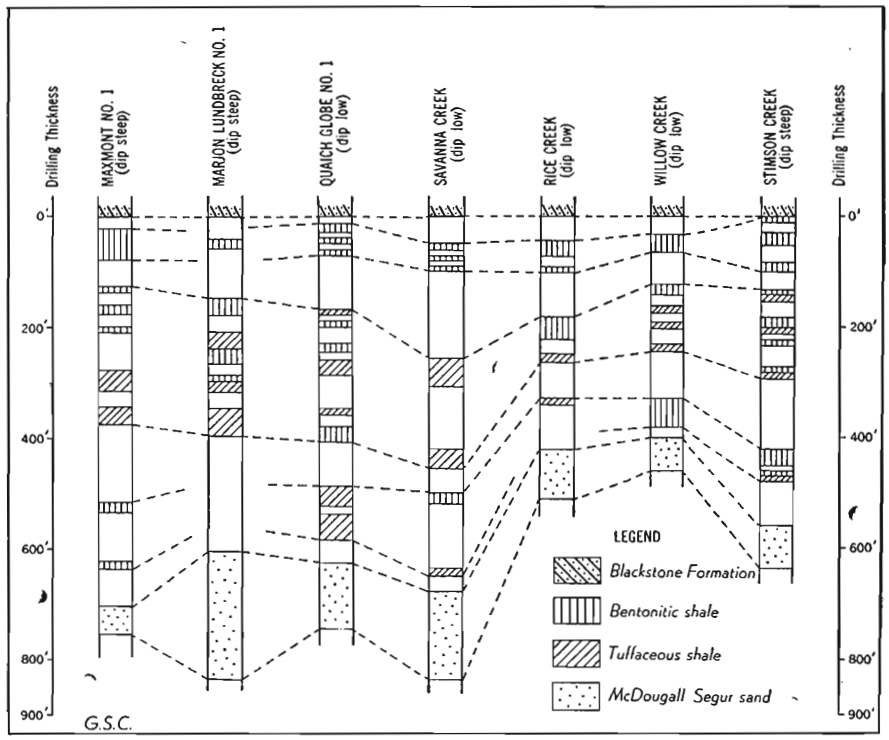


Figure 2. Partial logs of wells penetrating the upper part of the Blairmore group, showing relationship of tuffaceous and bentonitic shales to the McDougall-Segur sand and the overlying Blackstone formation.

It has been suggested by MacKenzie (1914), who was among the first to study the Crowsnest formation in the Blairmore region, that that formation, which is composed mainly of volcanic rocks in the western part of the area, interfingers with the shales and sandstones of the Blairmore group in the east. Hage (1940 and 1943) reaches the same conclusion from a study of the Cowley and Beaver Mines areas. The writer wishes to point out that the occurrence of tuffaceous beds interbedded with upper Blairmore strata does not necessarily indicate these strata are equivalent in age to the Crowsnest formation. The Crowsnest formation in Gap map-area definitely overlies the Blairmore group, and tuffaceous and bentonitic shales, considerably older, occur within the Blairmore group as low as the top of the McDougall-Segur sandstone. Figure 2 illustrates

the relationship of the bentonitic shales and tuffaceous beds to the contact between the Blairmore group and the overlying Blackstone formation and also to the McDougall-Segur sandstone, as shown by a study of the wells listed in the figure.

The McDougall-Segur sandstone lies about 1,000 feet below the top of the Blairmore group in Gap map-area. The group as a whole, there, is about 2,200 feet thick, and is overlain by the Blackstone formation or, in the southwest part of the map-area, by the Crowsnest formation. The Blairmore group is thinner in the east, about 1,400 feet in Callum Creek map-area and 1,000 feet in Langford Creek map-area, with the McDougall-Segur sandstone lying about 500 to 400 feet, respectively, below the contact with the Blackstone formation. The Crowsnest formation, as mapped in Gap map-area, is, accordingly, underlain by the tuffaceous and bentonitic shales above the McDougall-Segur sandstone (*See* Figure 2). The Crowsnest formation thins northward and eastward, becoming progressively finer, but remains as a distinctive lithologic unit that does not interfinger with the Blairmore group. It should be noted, however, that if the tuffaceous beds of the upper part of the Blairmore were to increase in thickness and become coarser, as would be expected in areas closer to their source, they would in all probability be mapped as part of the Crowsnest formation.

The uppermost distinctive bed of the Blairmore group is a coarse-grained sandstone composed of angular to subangular fragments of chert and quartz, locally becoming a conglomerate with pebbles of chert and quartzite up to 1 inch in diameter. It was observed only in Gap map-area, and is best developed west of the Livingstone Range. This bed lies at, or close to, the top of the group, lying at greater depths in the west. The following data will serve to illustrate its stratigraphic relationship with the overlying Blackstone and Crowsnest formations; the occurrences cited are arranged in order of location from east to west across Gap map-area; on Camp Creek, in sec. 24, tp. 11, rge. 3, 6 inches of chert and quartzite pebble-conglomerate underlie 10 feet of medium-grained sandstone, which is in contact with the overlying marine shales of the Blackstone formation; on Dutch Creek, in sec. 17, tp. 11, rge. 4, 5 feet of chert and quartzite pebble-conglomerate are separated from the Blackstone formation by a covered interval of 20 feet and 25 feet of fine-grained sandstone of the Blairmore group; on the east flank of Fly Hill, in sec. 35, tp. 10, rge. 4, coarse-grained sandstone, 10 feet thick, with scattered pellets of chert up to ¼ inch in diameter, is overlain by about 75 feet of green shales and fine-grained, green sandstones, in turn overlain by fine-grained agglomerate of the Crowsnest formation; in sec. 15, tp. 10, rge. 4, a conglomerate 10 feet thick, consisting of pebbles of chert and quartzite up to 1 inch in diameter, is overlain by about 150 feet of Blairmore strata underlying the Crowsnest formation. In some of the wells in Callum Creek and Langford Creek map-areas, a coarse-grained sandstone with angular grains of quartz lies at, or close to, the top of the Blairmore group (*See* Appendix; logs of Northwest Company, Willow Creek, Marjon Lundbreck No. 1, and Socony Vacuum, Stimson No. 1 wells).

Although correlation of these sandstones and conglomerates with one another is based solely on lithologic characteristics, they are quite distinctive, differing from the underlying sandstones in that they contain little or no feldspathic or ferromagnesian minerals, which are abundant in

beds lower in the Blairmore group. If these sandstones and conglomerates are of the same age throughout the map-areas, then it is apparent that there is a progressive thickening of Blairmore strata above them, and that, whereas in the eastern part of Gap map-area and in Callum Creek and Langford Creek map-areas they are directly overlain by the Blackstone formation, they are in the western part of Gap map-area separated from that formation by as much as 150 feet of Blairmore strata and the Crowsnest formation. These uppermost Blairmore strata and the Crowsnest volcanic rocks may thin eastward through non-deposition, or by removal by erosion preceding the deposition of the Blackstone formation, or by grading laterally, with possible interfingering, into the marine Blackstone shales. The last interpretation finds little support, as microscopic examination of the samples from the same wells, discussed above, does not show the abundant bentonitic or volcanic material that would be expected in the basal Blackstone shales if the uppermost Blairmore strata and Crowsnest formation were to grade laterally into them. Data are insufficient at this time to determine which of the first two interpretations may be correct.

The Blairmore group is about 2,200 feet thick on Dutch Creek, 4 miles above its junction with Oldman River. This figure holds, so far as could be determined, for the exposed Blairmore of Gap map-area. A drilling depth of 1,400 feet was encountered in the Willow Creek well in Langford Creek map-area, indicating a thinning to the east. If an allowance is made for the probable dip in this well (*See* Structure-section A-B, Langford Creek map), a true thickness of about 1,000 feet is obtained. The group is a little thicker in the Socony Vaccuum, Stimson No. 1 well, a short distance to the northwest, where a drilling thickness of 1,300 feet or, allowing for dip, 1,100 feet true thickness was encountered.

UPPER CRETACEOUS (?)

Crowsnest Formation

The Crowsnest formation consists of agglomerate and tuff. It is limited to the southwest part of Gap map-area, where it lies conformably below the marine shales of the Blackstone formation and above the non-marine shales and sandstones of the Blairmore group. Neither Blackstone nor Blairmore strata were observed interbedded with them.

The Crowsnest formation reaches a maximum thickness of 350 feet in the extreme southwestern part of Gap map-area. It thins rapidly to the north, so that in sec. 33, tp. 11, rge. 4, only 5 to 10 feet of feldspathic tuff remains. No volcanic beds were found between the Blackstone and Blairmore on Oldman River, in sec. 36, tp. 11, rge. 4, nor on Dutch Creek, in sec. 13, tp. 11, rge. 4. The eastern limit of pyroclastic strata could not be determined owing to lack of exposures.

The stratigraphic relationship of the Crowsnest formation to the underlying Blairmore group has already been discussed to some extent (*See* pages 24 to 26). The Crowsnest overlies the non-feldspathic sandstones and conglomerates in the uppermost part of the Blairmore group. Beneath these sandstones in the eastern part of the map-areas, as shown in Figure 2, tuffaceous and bentonitic shales are found in the upper 600 to 400 feet of Blairmore strata above the McDougall-Segur sand. The

Crowsnest formation is not equivalent to these tuffaceous shales, but is considerably younger, as the Blairmore encountered in the wells may be overlain by younger non-marine strata in the southwestern part of Gap map-area. McLearn (1929) has collected an Albian flora from the upper 260 feet of Blairmore strata overlain by the Crowsnest formation at Ma Butte in the Blairmore area, 2 miles southwest of the southwest corner of Gap map-area. As the Crowsnest formation does not interfinger with these Albian strata, it may be late Albian or post-Albian in age. The oldest known fauna from the basal part of the Blackstone formation being of lower Turonian age (Webb and Hertlein, 1934, the *Acanthoceras? albertense* fauna from 50 feet above the base on Castle River south of Crowsnest River), the Crowsnest formation may be as young as Cenomanian (early lower Upper Cretaceous). No fossils were found in the Crowsnest formation in Gap map-area. Hage (1940) reports a fossil flora from the Crowsnest formation that W. A. Bell (personal communication) states has early Upper Cretaceous affinities.

The tuffs, and most of the agglomerates, show fairly well-developed bedding, but the coarser agglomerates, which may contain bombs up to 2 feet in diameter, exhibit little stratification. Marked lateral variations in the proportion of tuff to agglomerate were noted, with the coarse agglomerate being of only restricted occurrence. Most of the agglomerate and all the coarser phases were found only in the southwestern corner of Gap map-area. On Vicary Creek, 1 mile north of the south border, most of the section is coarse agglomerate, but the upper 10 feet appears to have been reworked by streams, as well-rounded pebbles of agglomerate were found embedded in crossbedded tuff.

Much of the Crowsnest formation is composed of an orthoclase tuff formed of angular fragments of pink orthoclase embedded in a fine-grained, dark to light green groundmass. Some of the fragments are more than 1 inch long and exhibit good crystal form, so that the rock resembles an orthoclase porphyry, but all under microscopic examination were found to be of pyroclastic origin.

Microscopically, the orthoclase tuff is composed of fragmental orthoclase crystals, some partly altered to kaolin, others clear, with rare Carlsbad twinning. Fragments of titanite, garnet, and magnetite occur embedded with the orthoclase in a fine-grained goundmass of orthoclase fragments and interstitial chlorite, some of which exhibits fine needle-like form, suggesting that the chlorite is an alteration product of an original pyroxene, possibly aegerine-augite, which is reported by MacKenzie (1914) in many of his primary rock types.

Embedded in the tuffs, and usually observable only under the microscope, are numerous, small, rock fragments, many composed of minute plagioclase crystals with varying amounts of interstitial chlorite. The plagioclase shows single, and rare polysynthetic twinning, which exhibits extinction angles of Albite (An_5). They are commonly closely intergrown and without crystal form. In other fragments, the plagioclase occurs in chlorite as very thin, needle-like crystals, rarely twinned, and alined parallel with their long axes. They show flow structures about phenocrysts of orthoclase, titanite, garnet, magnetite, and pyroxene (?) now altered to chlorite.

The tuffs are commonly vuggy, filled with calcite, or lined, in some cases with chlorite and crystals of a zeolite?, with the centre filled with calcite. The zeolite? shows parallel extinction in thin, needle-like crystals and is stained with brownish red hematite.

A few specimens of consolidated lava, occurring as bombs from 1 inch to 2 feet in diameter, were collected from the coarser agglomerate in the southwestern part of Gap map-area. Some containing the mineral analcite were found on the small hill immediately east of Daisy Creek at the south border of the map-area and along a small tributary to Daisy Creek entering from the west 2 miles north of the south border. These bombs contain well-formed trapezohedra of pale green, waxy analcite up to ½ inch in diameter, and tabular pink orthoclase up to ¾ inch long embedded in a dark green groundmass. In the specimens collected, the ratio of analcite to orthoclase varies from about equal proportions to that in a single large bomb in which analcite trapezohedra compose about 60 per cent and orthoclase about 10 per cent of the rock.

Under microscopic examination, the analcite phenocrysts are formed of single crystals with sharp boundaries, commonly dusty and partly altered along cleavage and fractures to chlorite, and in some specimens partly replaced by calcite. The orthoclase is euhedral, with sharp boundaries, clear to slightly kaolinized, commonly untwinned, but Carlsbad twins not rare. The negative sign and small 2V indicate that much, if not all, of the orthoclase is of the high temperature variety, sanidine. Dark brown andradite garnet and titanite are present throughout in small quantity. The groundmass consists of closely interlocking analcite, untwinned orthoclase, and thin laths of plagioclase? with interstitial chlorite. Chlorite also occurs as larger masses, which may have been small phenocrysts of pyroxene.

A single small bomb with pale pink analcite trapezohedra was found, which closely resembles MacKenzie's (1914) description of 'Blairmorite'. The analcite crystals are dusty with rims and fracture fillings of clear analcite. In the groundmass the analcite is clear and in part without crystal form. The orthoclase (sanidine) is euhedral with sharp borders, clear to faintly dusty. Aegerine-augite occurs as small phenocrysts and in the groundmass. Rare, dark green biotite, strongly pleochroic, X–dark green, Z–yellow-brown, is present.

Analcite also occurs in some of the tuffs as broken trapezohedra, dusty, and partly replaced by chlorite along cleavages and fractures. In a small frgament embedded in tuff, analcite, entirely altered to chlorite, appears only as "ghosts" of trapezohedral outline in the chloritic groundmass. Small, unaltered orthoclase phenocrysts comprise the remainder of the fragment.

UPPER CRETACEOUS

Blackstone (Lower Alberta) Formation

Blackstone strata outcrop sparingly in Langford Creek and Callum Creek map-areas, but are well exposed along some of the main streams of Gap map-area.

The formation consists of dark grey shale and silty shale weathering light grey, rubbly, rusty weathering grey shale, and thin-bedded to lenticular, finely laminated and crossbedded, fine-grained, dark grey sandstones

and brown weathering concretionary shale. A rubbly, fine-grained, grey sandstone, 4 feet thick, was observed in Gap map-area, in the lower part of the formation on Oldman River, in sec. 36, tp. 11, rge. 4, on Dutch Creek, in sec. 17, tp. 11, rge. 4, and on Racehorse Creek, in sec. 22, tp. 10, rge. 4. This bed occurs about 300 feet above the base, and may be equivalent to the Jumpingpound sand of Turner Valley (Hume, 1938).

In Langford Creek map-area, the contact with the underlying Blairmore group is marked by 3 feet of massively bedded conglomerate composed of angular to subangular chert fragments up to ¼ inch in diameter embedded in coarse-grained sandstone. This bed is similar, lithologically, to 'The Grit' of the Turner Valley map-area (Hume, 1938). This bed was not observed in Gap map-area, and the Blackstone shales rest directly on the non-marine shales of the Blairmore group or on the volcanic rocks of the Crowsnest formation.

The Northwest Company, Rice Creek well, in Langford Creek map-area, drilled a thickness of 720 feet of black shales and sandy shales attributed to the Blackstone formation. The figure is a maximum, but the actual thickness is probably not much less (*See* structure-section C-D, Langford Creek map). Along the western part of Gap map-area the Blackstone formation is about 1,000 feet thick. In southeast Gap map-area, in sec. 25, tp. 9, rge. 3, 450 feet of strata are represented between the uppermost exposures of Blairmore and the base of the Bighorn sandstones. In the Quaich Globe No. 1 well, in l.s. 12, sec. 35, tp. 9, rge. 3, the Blackstone formation was penetrated between 220 and 650 feet drilling depth. The dip of the strata in this vicinity is believed to be low (*See* Structure-section E-F, Gap map), consequently, the drilling thickness of 430 feet is close to the true thickness.

On Racehorse Creek, in sec. 22, tp. 10, rge. 4, *Prionotropis* cf. *woolgari* Meek and *Scaphites* sp. were collected 250 feet above the base and *Watinoceras ?* about 275 feet above the base. *Inoceramus labiatus* Schlotheim was found in abundance on Wintering Creek, and scattered localities throughout Gap map-area. McLearn states that this fauna is indicative of Turonian (later lower Upper Cretaceous) time.

Bighorn (Cardium) Formation

The Bighorn formation is well exposed throughout the three map-areas, but varies in thickness and lithology. In Gap map-area, on Camp Creek and in the valley of Todd Creek, rubbly, fine-grained, silty shales and sandstones, 30 to 50 feet thick, constitute the formation. Chert-pebble conglomerate was observed close to the southwest border of Langford Creek map-area and in the southern part of Callum Creek area in sec. 4, tp. 9, rge. 2. Chert-pebble conglomerate was encountered in drilling in most of the wells within the map-areas (*See* Appendix to this report).

West of Livingstone Range, in Gap map-area, the formation thickens to about 300 feet. Three sandstones are present on Dutch Creek, in sec. 14, tp. 10, rge. 4, Gap map-area. The lower two beds are about 50 feet thick and are separated by about 35 feet of dark grey silty shale. The upper sandstone is about 25 feet thick. Chert pebbles were found interbedded with the upper sandstone beyond the west border of Gap map-area, north of Dutch Creek.

On Racehorse Creek, in sec. 14, tp. 10, rge. 4, Gap map-area, *Scaphites ventricosus* Meek and Hayden, *Inoceramus inconstans* Woods, *Inoceramus pontoni* McLearn, *Baculites* sp., and *Anomia subquadrata* ? Stanton, were collected. This fauna indicates a Coniacian (lower middle Upper Cretaceous) age, according to McLearn.

Wapiabi (Upper Alberta) Formation

Despite its widespread distribution, the Wapiabi formation is commonly poorly exposed. The best exposed section along Oldman River, in sec. 21, tp. 10, rge. 2, is closely folded and faulted. Specimens of *Scaphites ventricosus* Meek and Hayden, *Baculites* sp., and *Ostrea* sp. of Coniacian age were collected at this locality.

The Wapiabi is composed of thinly bedded, dark grey, marine shale; thinly bedded, finely laminated, fine-grained, dark grey sandstones; and lenticular, dark grey limestones and concretions. Sandstones increase in proportion in the upper part, and are transitional into the overlying Belly River formation. The base is drawn at the top of the uppermost sandstone or conglomerate of the Bighorn formation.

The drilling thickness of 1,080 feet in the Northwest Company, Rice Creek well in Langford Creek map-area is the most reliable indication of the maximum thickness of the Wapiabi formation in the east. It thickens to about 1,600 feet in the western part of Gap map-area.

Belly River Formation

Strata of the Belly River formation underlie most of the western parts of Callum Creek and Langford Creek map-areas, and the eastern and western parts of Gap map-area. The formation is so broken by faults that no complete section is preserved. However, the strata are excellently exposed along Oldman River where their lithological characteristics may be readily studied. The thickness of the formation in Callum Creek map-area is probably not less than 3,000 feet. In the northeastern part of Gap map-area, in a thick thrust slice, the base, but not the top, of the formation is exposed. Unless there are unobserved minor faults, about 4,200 feet of strata are present.

The contact with the underlying Wapiabi formation is transitional. Dark grey, thinly bedded, fine-grained, dark brown weathering sandstones mark the base. These strata are about 100 feet thick and are rarely exposed except along the rivers. Very massive, coarse-grained, thickly crossbedded, light grey sandstones interbedded with grey and green, silty shales overlie the transition beds. This zone is about 500 feet thick, but cannot be closely defined, as the upper sandstones are less massive and lose their persistent and ridge-forming characteristics. The remainder of the formation, with the exception of the uppermost 900 feet, consists of interbedded, fine- to medium-grained, crossbedded, grey to green sandstones, and grey and green, silty shales. The uppermost 900 feet of strata contain pale green weathering, green and grey shales; thin-bedded, fine-grained, grey sandstones; rubbly and concretionary argillaceous limestones; and minor carbonaceous shale and coal seams.

Bearpaw Formation

The Bearpaw formation is only well exposed along Oldman River, in sec. 11, tp. 10, rge. 2, Callum Creek map-area. There the strata are folded and possibly faulted, and have an estimated thickness of 600 feet. The contact between the Bearpaw and the underlying Belly River formation is placed where silty, green and grey shales of the Belly River formation change to rubbly, dark grey, marine shales. *Arctica ovata* Meek and Hayden was collected from the rubbly grey shales, 100 feet above the contact. Thin beds of carbonaceous shale and coal seams occur in the upper 20 feet of Belly River beds.

Dark grey, thin-bedded to fissile shale interbedded with sandstone beds up to 15 feet thick overlie the basal shales. The sandstones are grey, massive to thin bedded, coarse grained, crossbedded, and weather grey to reddish brown. Specimens of *Arctica ovata* Meek and Hayden and *Placenticeras* sp. were collected from the shales, which McLearn states indicate a Lower Maestrichtian (early upper Upper Cretaceous) age of the formation.

The Bearpaw strata become increasingly contorted as the contact with the overlying St. Mary River formation is approached. Dark grey shales, with interbedded, fine- to medium-grained, grey sandstones weathering brown are thrust over basal St. Mary River beds. There is little lithological difference between the basal St. Mary River and upper Bearpaw sandstones, but the shales of the St. Mary River are grey and green, massively bedded and rubbly weathering.

The Bearpaw formation occupies a broad valley between the Belly River ridges on the west and the St. Mary River ridge on the east, extending through Callum Creek and the southern part of Langford Creek map-areas. Exposures are rare, and consist mainly of the sandstones of more resistant character. On Langford Creek, in sec. 28, tp. 13, rge. 2, dark grey, fissile shale and coarse-grained, brown weathering, grey sandstones are believed to be Bearpaw, although no fossils were found in them. Similar sandstones, but with associated green shales and coal seams, were placed in the St. Mary River formation.

St. Mary River Formation

The St. Mary River formation outcrops along a belt that extends about through the middle of Callum Creek and Langford Creek map-areas. The only continuously exposed section is along Oldman River, in secs. 1, 11, and 12, tp. 10, rge. 2, and in sec. 6, tp. 10, rge. 1, but, unfortunately, this section is broken by faults, and the formation is not complete in any one fault slice. The character of the strata, however, may be readily studied. Two sections were examined in detail. The thicker or western section, which extends from the axis of the syncline in sec. 1, tp. 10, rge. 2, westward to the fault contact with the Bearpaw formation in sec. 11, tp. 10, rge. 2, follows:

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)		
(Uppermost beds not present)		
Sandstone, hard, crossbedded, fine-grained, dark grey	1·0	3,022·0
Shale, bluish grey	3·0	3,019·0
Sandstone, hard, crossbedded, medium-grained, grey	6·0	3,013·0
Limestone, 'ironstone', lenticular, fine-grained, grey, brown weathering	1·0	3,012·0
Shale, bluish grey, bentonitic	1·5	3,010·5
Covered	10·0	3,000·5
Sandstone, massive, crossbedded, coarse-grained; shale-pebble conglomerate at base	5·0	2,995·5
Shale, bluish grey and silty	20·0	2,975·5
Sandstone, soft, crossbedded, medium-grained, green	4·0	2,971·5
Shale, dark grey and green, with nodular limestone concretions	7·0	2,964·5
Covered	5·0	2,959·5
Sandstone, pale green, fine-grained; nodular limestone concretions	3·0	2,956·5
Shale, pale green, silty, and dark grey	14·0	2,942·5
Shale, pale green, nodular limestone concretions	3·0	2,939·5
Sandstone, soft, light grey, fine-grained	6·0	2,933·5
Shale, pale green, carbonaceous	2·5	2,931·0
Sandstone, hard, pale green, fine-grained	1·0	2,930·0
Shale, dark grey and green, silty	27·0	2,903·0
Sandstone, massive, hard, fine-grained, pale green	1·5	2,901·5
Shale, dark green	1·5	2,900·0
Limestone, 'ironstone'	1·5	2,898·5
Shale, dark green	3·0	2,895·5
Sandstone, light grey, fine-grained	4·0	2,891·5
Shale, green, silty	4·0	2,887·5
Covered	30·0	2,857·5
Sandstone, hard, grey, thinly bedded, crossbedded, shale pellets and unio fragments in middle	4·0	2,853·5
Covered	15·0	2,838·5
Sandstone, hard, medium-grained, grey	3·0	2,835·5
Shale, brown, with nodular limestone concretions	1·5	2,834·0
Sandstone, thin, irregularly bedded, fine-grained, light grey	2·5	2,831·5
Shale, carbonaceous, dark grey	2·0	2,829·5
Sandstone, thin-bedded, fine-grained, light grey; basal shale pellets	8·0	2,821·5
Shale, light grey, carbonaceous, and green	3·0	2,818·5
Sandstone, hard, lenticular, fine-grained, light grey	4·0	2,814·5
Shale, dark grey	1·5	2,813·0
Sandstone, massive, hard, fine-grained, pale green	2·5	2,810·5
Sandstone and shale; similar sandstone to above, and dark grey shale	11·0	2,799·5
Limestone, 'ironstone'	2·0	2,797·5
Shale, grey and green	6·0	2,791·5
Sandstone, massive, soft, green	4·0	2,787·5
Covered	3·0	2,784·5
Shale, silty, green and grey	11·0	2,773·5
Sandstone, hard, grey	2·0	2,771·5
Shale, grey, silty	1·0	2,770·5
Shale, pale green, bentonitic	3·5	2,767·0
Sandstone, massive, fine-grained, grey	4·0	2,763·0
Shale, carbonaceous	1·5	2,761·5
Sandstone, hard, fine-grained, grey	1·5	2,760·0
Covered	4·0	2,756·0

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Sandstone, hard, fine-grained, grey	2·0	2,754·0
Shale, olive-green, silty, grey, carbonaceous	9·0	2,745·0
Limestone, 'ironstone'	1·5	2,743·5
Sandstone, soft, thin-bedded, fine-grained, grey	3·0	2,740·5
Shale, carbonaceous	1·0	2,739·5
Sandstone, fine-grained, grey	5·0	2,734·5
Limestone, 'ironstone'	1·5	2,733·0
Shale, light grey, silty	2·0	2,731·0
Sandstone, massive, irregularly crossbedded, medium-grained, grey	4·5	2,726·5
Sandstone and shale, lenticular and nodular sandstone in grey, green, and silty shale	27·0	2,699·5
Sandstone, massive, hard, fine-grained, grey	12·0	2,687·5
Covered	6·0	2,681·5
Shale, pale green	3·0	2,679·5
Limestone	1·5	2,677·0
Shale, silty, grey, partly covered	5·0	2,672·0
Limestone	1·5	2,670·5
Sandstone, thin-bedded, grey	2·0	2,668·5
Shale, dark grey, silty	1·5	2,667·0
Top of 'blocky' sandstone zone	.....	2,667·0
Sandstone, massive, fine-grained, hard, blocky, breaks with conchoidal fractures	31·0	2,636·0
Shale, dark green, bentonitic	2·0	2,634·0
Sandstone, massive, hard, fine-grained, light grey	6·0	2,628·0
Shale, dark grey	4·0	2,624·0
Sandstone, hard, light grey	5·0	2,619·0
Shale, dark grey; thin sandstone, with *Elatocladus intermedia*, *Typha* sp., *Nymphaeites angulatus*, *Carpolithus ceratops*	3·0	2,616·0
Sandstone, massive, beds 3 feet thick, fine-grained, light green, and covered shale	16·5	2,599·5
Shale, dark grey	5·0	2,594·5
Sandstone, thin-bedded, light grey	3·0	2,591·5
Shale, dark grey	5·0	2,586·5
Sandstone, thin-bedded, fine-grained, light grey	14·0	2,572·5
Shale, greenish grey	2·0	2,570·5
Sandstone, thin-bedded, crossbedded, grey, medium- to coarse-grained; shale pellets and shell fragments near base	12·0	2,558·5
Base of 'blocky' sandstone zone	.....	2,558·5
Covered	12·0	2,546·5
Sandstone, hard, fine-grained, grey; some grey shale	18·0	2,528·5
Shale, dark grey; thin green sandstone beds	12·0	2,516·5
Limestone	2·0	2,574·5
Covered	6·0	2,508·5
Shale, dark grey, silty	10·0	2,498·5
Sandstone, massive, breaks with conchoidal fracture, fine-grained, light grey; upper part contains limestone nodules	10·0	2,488·5
Shale, green, silty; thin, hard, sandstone interbedded	24·0	2,464·5
Sandstone, thin-bedded, medium-grained, hard, grey	15·0	2,449·5
Shale, green, silty; limestone lenses	8·0	2,441·5
Sandstone, greyish green, medium-grained; basal shale pellets	9·0	2,432·5
Limestone	6·0	2,426·5
Covered	3·0	2,423·5

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Sandstone, grey, fine-grained	6·0	2,417·5
Covered	2·0	2,415·5
Shale and sandstone; hard, grey, platy sandstone and grey shale	11·0	2,404·5
Covered	4·0	2,400·5
Sandstone, soft, thin-bedded, crossbedded, medium-grained, grey	5·0	2,395·5
Covered	15·0	2,380·5
Sandstone, platy, crossbedded, hard, medium-grained, grey, and some minor shale	32·0	2,348·5
Shale, dark green, silty	9·0	2,339·5
Sandstone, platy, pale green, fine-grained, hard	12·0	2 327·5
Shale, grey; shell fragments	16·0	2,311·5
Sandstone, light grey, hard, thin-bedded, partly covered	16·0	2,295·5
Shale, dark grey	3·5	2,292·0
Sandstone, soft, thin-bedded, medium-grained, light grey, crossbedded; base, hard, thinly bedded, fine-grained	19·0	2,273·0
Covered	8·0	2,265·0
Sandstone, pale green, medium-grained	4·0	2,261·0
Shale, dark grey, silty green	5·0	2,256·0
Sandstone, soft, crossbedded, fine-grained, grey	24·0	2,232·0
Shale, green, silty; nodular limestone	10·0	2,222·0
Sandstone, platy, fine-grained, grey	5·0	2,217·0
Shale, dark grey and green; minor sandstone	16·0	2,201·0
Sandstone, soft, spheroidal-weathering, medium-grained, micaceous, grey	8·0	2,193·0
Shale, grey	3·0	2,190·0
Sandstone, hard, fine-grained, grey	1·0	2,189·0
Shale, silty, grey; shell fragments	5·5	2,183·5
Sandstone, soft, crossbedded, green	5·0	2,178·5
Shale and sandstone: carbonaceous shale; hard, fine-grained, grey sandstone	6·5	2,172·0
Sandstone, soft, thin-bedded, fine-grained, grey	14·0	2,148·0
Shale, dark green, with thin, hard, grey sandstones	20·0	2,138·0
Sandstone, hard, blocky fracturing, grey	3·0	2,135·0
Sandstone, soft, speckled grey	8·0	2,127·0
Shale, olive-green and carbonaceous	2·5	2,124·5
Limestone, 'ironstone'	1·5	2,123·0
Sandstone, soft, speckled grey	4·0	2,119·0
Shale, grey, carbonaceous	1·0	2,118·0
Limestone, 'ironstone'	1·0	2,117·0
Shale, grey, silty	10·0	2,107·0
Sandstone, soft, medium-grained, speckled grey	7·0	2,100·0
Shale, grey, bentonitic	2·5	2,097·5
Limestone, 'ironstone'	2·0	2,095·5
Shale, pale green, silty	5·0	2,090·5
Sandstone, fine-grained, grey; top hard, base soft	6·0	2,084·5
Shale, grey, silty	4·0	2,080·5
Sandstone, soft, medium-grained, grey	3·0	2,077·5
Shale, grey	3·0	2,074·5
Sandstone, thin-bedded, fine-grained, grey	6·0	2,063·5
Shale, dark grey; minor sandstones	10·0	2,058·5
Sandstone, soft, medium-grained, speckled grey, spheroidal-weathering	3·0	2,055·5
Shale, grey, silty	10·0	2,045·5

——	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Sandstone, massive, medium-grained, grey	12·0	2,033·5
Shale, green, silty; with minor sandstones	12·0	2,021·5
Sandstone, soft, fine-grained, grey	8·0	2,013·5
Shale, grey, carbonaceous	8·0	2,005·5
Covered	5·0	2,000·5
Sandstone, massive, crossbedded, medium-grained, speckled grey; basal pellets, unios, fossil sticks	20·0	1,980·5
Shale, grey and carbonaceous	5·0	1,975·5
Sandstone, similar to above	8·0	1,967·5
Shale, grey, green and carbonaceous shales	8·0	1,959·5
Sandstone, hard, fine-grained, grey	6·0	1,953·5
Shale, grey, green and carbonaceous shales	13·0	1,940·5
Sandstone, hard, fine-grained, grey	4·0	1,936·5
Covered	10·0	1,926·5
Shale and sandstone: interbedded, hard sandstones and grey, pale green, and carbonaceous shales	15·0	1,911·5
Shale, green, silty	25·0	1,886·5
Sandstone, soft, fine-grained; grey, minor shale	12·0	1,874·5
Sandstone, hard, fine-grained, pale green	8·0	1,866·5
Shale and sandstone: sandstone as above; shale, grey and carbonaceous	9·0	1,857·5
Shear zone, no apparent repetitions of strata; width of zone deleted from section.		
Sandstone, hard, medium-grained, grey; minor shale	18·0	1,839·5
Limestone, 'ironstone'	5·0	1,834·5
Shale, hard, fine-grained, green	9·0	1,825·5
Sandstone, blocky, green, calcareous, with *Antholithus (Nymphaeites) marsiliodes*	4·0	1,821·5
Sandstone, hard, medium-grained, green	4·0	1,817·5
Shale, green, silty	10·0	1,807·5
Sandstone, massive, fine-grained, green	5·0	1,802·5
Shale, green, silty	14·0	1,788·5
Sandstone, thin-bedded, fine-grained, green	5·0	1,783·5
Limestone, 'ironstone'	1·0	1,782·5
Sandstone, soft, pale green and silty shale	12·0	1,770·5
Shale, olive-green, silty	4·0	1,766·5
Sandstone, soft, fine-grained, green	4·0	1,762·5
Covered	5·0	1,757·5
Sandstone, soft, coarse-grained, grey	6·0	1,751·5
Shale, green, silty	4·0	1,747·5
Sandstone, soft, medium-grained, pale green	5·0	1,742·5
Covered	3·0	1,739·5
Sandstone, soft, medium-grained, crossbedded; pale green shale pellets in base	9·0	1,730·5
Shale, grey, silty	2·0	1,728·5
Sandstone, hard, fine-grained, dark grey	13·0	1,715·5
Shale, grey, silty, and pale green	21·0	1,694·5
Shale and sandstone: grey and carbonaceous shale; soft, fine-grained, grey sandstones	28·0	1,666·5
Shale and sandstone: sandstone as above; shale, pale green and silty	17·0	1,649·5
Sandstone and shale: hard, fine-grained, green sandstone and grey shales	33·0	1,616·5

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Limestone, 'ironstone'	2·0	1,614·5
Covered	8·0	1,606·5
Sandstone, medium-grained, green, soft	8·0	1,598·5
Shale, blue-grey, calcareous	2·0	1,596·5
Sandstone, similar to above, with *Typha* sp., *Nymphaeites striatus*	10·0	1,586·5
Shale, dark grey	6·0	1,580·0
Sandstone, hard, medium-grained, green	9·0	1,571·5
Shale, green, silty	12·0	1,559·5
Limestone, 'ironstone'	1·0	1,558·5
Sandstone and shale: hard, medium-grained, green sandstones and grey, silty and carbonaceous shale	11·5	1,547·0
Shale, dark grey, bentonitic	3·5	1,543·5
Sandstone, soft, fine-grained, pale green	8·0	1,535·5
Shale, grey and green	5·5	1,530·0
Limestone, 'ironstone'	1·0	1,529·0
Sandstone, soft, fine-grained, green	10·0	1,519·0
Shale, silty, green; thin sandstones	12·0	1,507·0
Shale, dark grey	6·0	1,501·0
Sandstone, hard, fine-grained, calcareous	2·0	1,499·0
Shale, green, grey, bentonitic	12·5	1,486·5
Sandstone, massive, blocky fracturing, fine-grained, grey	8·0	1,478·5
Shale and sandstone: sandstone as above; shale, grey and carbonaceous	9·0	1,469·5
Sandstone, hard, fine-grained, grey	4·0	1,465·5
Shale, dark grey, carbonaceous, with *Nymphaeites striatus*	7·0	1,458·5
Sandstone, massive, fine-grained, grey	3·0	1,455·5
Shale, grey, carbonaceous and bentonitic	10·5	1,445·0
Sandstone, fine-grained, calcareous, grey	4·0	1,441·0
Shale, green and grey	2·0	1,439·0
Sandstone, fine-grained, grey	3·0	1,436·0
Shale, grey, carbonaceous and bentonitic	3·5	1,432·5
Sandstone, as above	2·0	1,430·5
Shale, grey, silty, contorted	7·0	1,423·5
Sandstone, massive, fine-grained, grey	4·0	1,419·5
Shale, grey, silty	2·5	1,417·0
Sandstone, massive, crossbedded, medium-grained, grey	6·0	1,411·0
Shale, green and grey, bentonitic	5·5	1,405·5
Sandstone, green, fine-grained	2·0	1,403·5
Shale, grey, brown, and carbonaceous	10·0	1,393·5
Shale and sandstone: green, silty shale; thin sandstones	10·0	1,383·5
Shale, reddish, bentonitic	1·0	1,382·5
Shale, green, silty	10·0	1,372·5
Sandstone, soft, massive, crossbedded, grey	17·0	1,355·5
Shale, green, silty, and reddish bentonitic	12·0	1,343·5
Sandstone, hard, lenticular, medium-grained, grey	14·0	1,329·5
Sandstone, soft, fine-grained, grey, with *Adiantum paululum*, *Carpites* sp., *Nymphaeites angulatus*	20·0	1,309·5
Shale, greenish brown, silty	4·0	1,305·5
Sandstone, soft, thin-bedded, fine-grained, grey	5·0	1,300·5
Shale, dark grey, carbonaceous	4·0	1,296·5
Sandstone, hard, calcareous, grey	1·5	1,295·0
Shale, green, silty	3·0	1,292·0
Sandstone, soft, fine-grained, grey, lenticular in part; fossil tree trunks in base	22·5	1,269·5

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Shale, grey, calcareous and nodular	6·0	1,263·5
Sandstone, soft, green	2·0	1,261·5
Shale, grey, carbonaceous	2·0	1,259·5
Sandstone, hard, fine-grained, grey	5·0	1,254·5
Shale, grey, carbonaceous	3·0	1,251·5
Sandstone, hard, medium- to coarse-grained, grey; shale pellets in base; local erosion at base	5·0	1,246·5
Shale, yellowish green, and minor carbonaceous	15·0	1,231·5
Sandstone, fine-grained, green	3·0	1,228·5
Shale, yellowish green; calcareous lenses	6·0	1,222·5
Sandstone, hard, thin-bedded, fine-grained, grey	3·0	1,219·5
Shale, green, silty; nodular limestones	8·0	1,211·5
Sandstone, calcareous, fine-grained, grey	6·0	1,205·5
Shale, green, bentonitic	4·0	1,201·5
Limestone, 'ironstone'	1·0	1,200·5
Sandstone, soft, fine-grained, reddish brown weathering	6·0	1,194·5
Shale, green, silty and carbonaceous	6·0	1,188·5
Sandstone, hard, fine-grained, grey	2·5	1,186·0
Shale, green, silty; thin sandstones	24·0	1,162·0
Sandstone, fine-grained, grey	2·0	1,160·0
Shale, yellow-green, silty	3·0	1,157·0
Sandstone, soft, fine-grained, grey, with *Equisetum perlaevigatum*	3·0	1,154·0
Shale, green and grey, bentonitic	8·5	1,145·5
Sandstone, soft, medium-grained, greenish grey	8·0	1,137·5
Shale, yellowish green, silty and grey	10·0	1,127·5
Sandstone, massive, fine-grained; base coarse, grey	12·0	1,115·5
Shale, grey, carbonaceous	7·0	1,108·5
Shale, green; lenticular ironstones	8·0	1,100·5
Sandstone, soft, fine-grained, crossbedded, grey	6·0	1,094·5
Shale and sandstone: sandstone as above, thinly bedded, with grey and green, silty shales	29·0	1,065·5
Sandstone, hard, fine-grained, dark grey; minor grey shale	12·0	1,053·5
Shale, carbonaceous	3·0	1,050·5
Sandstone, fine-grained, green	8·0	1,042·5
Shear zone, no apparent repetitions of strata; width of zone deleted from section.		
Sandstone, hard, fine-grained, grey	12·0	1,030·5
Shale, dark grey	3·5	1,027·0
Sandstone, as above	4·0	1,023·0
Shale, dark grey, silty	6·0	1,017·0
Sandstone, soft, fine-grained, crossbedded, grey	18·0	999·0
Shale, green	9·0	990·0
Sandstone, hard, medium-grained, crossbedded, grey	7·0	983·0
Shale, grey, silty, bentonitic	6·0	977·0
Sandstone, hard, fine-grained, dark grey	4·0	973·0
Shale, green, silty	3·0	970·0
Sandstone, as above	2·5	967·5
Covered	2·5	965·0
Sandstone, massive, fine-grained, grey, with *Thuites interruptus*, *Elatocladus intermedia*	7·5	957·5
Shale, dark grey, carbonaceous	4·5	953·0

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (upper part)—*Continued*		
(Uppermost beds not present)		
Sandstone, massive, fine-grained, grey	10·0	943·0
Shale, dark grey; minor sandstones	18·0	925·0
Limestone, 'ironstone'	2·0	923·0
Shale, green and grey	10·0	913·0
Sandstone, hard, fine-grained, grey	3·5	909·5
Shale, grey and green; thin sandstones and ironstones	24·0	885·5
Sandstone, soft, fine-grained, grey	4·0	881·5
Shale, green, silty and dark grey	17·0	864·5
Sandstone, hard, fine-grained, grey	6·0	858·5
Shale, grey, silty	5·0	853·5
Sandstone, hard, massive, fine-grained, grey, lenticular	15·0	838·5
Shale, dark grey	3·5	835·0
Sandstone, soft, fine-grained, grey	3·0	832·0
Shale, grey, silty, nodular	3·0	829·0
Sandstone, hard, fine-grained, yellowish green and soft grey	12·0	817·0
Shale, dark grey, bentonitic	1·5	815·5
Sandstone, soft, fine-grained, grey	10·0	805·5
Shale, dark grey; lenticular ironstone	18·0	787·5
Sandstone, hard, fine-grained, crossbedded, grey	5·0	782·5
Shale, dark grey, silty	4·0	778·5
Sandstone, rubbly, grey	4·0	774·5
Shale, grey, silty, bentonitic	2·0	772·5
Sandstone, very soft, unconsolidated, fine-grained, grey	3·5	769·0
Shale, yellowish green and grey	9·0	760·0
Limestone, 'ironstone'	1·0	759·0
Covered	35·0	724·0
Sandstone, hard, fine-grained; pelecypod fragments	1·0	723·0
Shale, dark grey, silty	8·0	715·0
Sandstone, soft, fine-grained, grey	6·0	709·0
Limestone, 'ironstone'	3·0	706·0
Shale, dark grey, bentonitic	4·5	701·5
Sandstone, hard, fine-grained, grey	1·5	700·0
Shale, dark grey, silty	14·0	686·0
Sandstone, coarse-grained, grey; unio shells	3·0	683·0
Covered	11·0	672·0
Limestone, 'ironstone'	2·0	670·0
Sandstone, hard, fine-grained, thin-bedded, grey	6·0	664·0
Covered	4·0	660·0
Limestone, 'ironstone'	1·0	659·0
Covered	17·0	642·0
Limestone, 'ironstone'	3·0	639·0
Covered	40·0	599·0
Sandstone, hard, thin-bedded, fine-grained, green	1·0	598·0
Shale, dark grey, bentonitic	3·0	595·0
Covered	3·0	592·0
Shale, dark grey	2·0	590·0
Covered	3·0	587·0
Limestone, 'ironstone'	2·0	585·0
Covered	3·0	582·0
Thickness of upper part of St. Mary River formation present	.....	2,506·0

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (lower part)		
Sandstone, soft, massive, fine-grained, grey; basal pellet conglomerate and unio shells	8·0	574·0
Shale, mostly covered, dark grey shale	25·0	549·0
Limestone, 'ironstone'	1·5	547·5
Sandstone, coarse-grained, crossbedded, grey, reddish brown weathering	5·0	542·5
Covered	65·0	477·5
Sandstone, hard, medium-grained, grey, brown weathering	3·0	474·5
Shale, dark grey and green	8·0	466·5
Limestone, nodular ironstone	1·0	465·5
Shale, dark grey	2·0	463·5
Sandstone, soft, medium- to coarse-grained, crossbedded, grey, reddish brown weathering	6·0	457·5
Shale, dark grey	4·0	453·5
Limestone, 'ironstone'	1·5	452·0
Shale, green, silty	4·0	448·0
Sandstone, hard, medium-grained, dark grey	2·0	446·0
Limestone, 'ironstone'	1·0	445·0
Covered	75·0	370·0
Sandstone, thin-bedded, coarse-grained, grey, reddish brown weathering	3·0	367·0
Shale, green, silty	3·0	364·0
Limestone, 'ironstone'	0·5	363·5
Sandstone, crossbedded, coarse-grained, grey, reddish brown weathering	2·0	361·5
Limestone, thin limestones and dark grey shale	2·0	359·5
Sandstone, as above	5·0	354·5
Sandstone, thinly laminated, coarse-grained; carbonaceous shale and ironstone in beds ½ inch to 2 inches thick	3·0	351·5
Shale, dark grey, alternating with thin limestones	25·0	326·5
The section farther up Big Coulée (tributary to Oldman River) consists of contorted coal seams, ironstones, and shale.		
The section continues on south bank to Oldman River, with probably little absence or repetition of strata:		
Sandstone, thin-bedded, fine-grained, grey	1·0	325·5
Shale, grey, rusty weathering, basal unio shells	20·0	305·5
Shale, grey, with nodular limestones	5·0	300·5
Bentonite	0·5	300·0
Shale, olive-green, yellowish weathering	12·0	288·0
Shale and coal: thin coal seams in green shale	8·0	280·0
Bentonite	0·5	279·5
Coal	2·0	277·5
Shale, carbonaceous	1·5	276·0
Sandstone, thin-bedded, green	3·0	273·0
Covered; adit, abandoned, into bank indicates possible coal seam	16·0	257·0
Shale, grey; thin limestones, bentonitic	6·0	251·0
Sandstone, thin-bedded, rusty brown weathering, grey	2·0	249·0
Covered	80·0	169·0
Shale, light grey, contorted; thin limestone bands	30·0	139·0
Coal	1·0	138·0
Shale, brown and carbonaceous	6·0	132·0
Coal	3·5	128·5

—	Thickness	Height above base
	Feet	Feet
St. Mary River formation (lower part)—*Continued*		
Shale, bluish grey, bentonitic	1·0	127·5
Shale, dark grey, rusty weathering; some thin limestones	14·0	113·5
Covered	10·0	103·5
Sandstone, thin-bedded, laminated, micaceous, grey	8·0	95·5
Shale, olive-green	4·0	91·5
Sandstone, massive, thick crossbeds, light grey	10·0	81·5
Shale, bluish green	1·0	80·5
Coquina, lenticular bed of oyster shells	2·5	78·0
Sandstone, fine-grained, light grey, yellow weathering	1·0	77·0
Shale, bluish green	1·0	76·0
Coquina, oyster shells	1·0	75·0
Covered	15·0	60·0
Sandstone, light grey, medium-grained, reddish brown weathering	32·0	28·0
Shale, dark grey; thin sandstones	4·0	24·0
Shale, olive-green; limestone nodules	18·0	6·0
Sandstone, light grey, fine-grained	6·0	0·0
End of good section. There follows contorted sandstones and shales and a fault repeating St. Mary River beds, and a fault thrusting Bearpaw strata over the St. Mary River formation.		
Total thickness of lower part of St. Mary River formation present	582·0	
Total thickness of described section of St. Mary River formation	3,088·0	

The uppermost strata of the St. Mary River formation, missing in the above section, may be observed in the eastern section along the south bank of Oldman River in sec. 6, tp. 10, rge. 1. The zone of 'blocky' sandstones that lies between 2,667·0 and 2,558·5 feet above the base, or between 356·0 and 464·5 from the top of the section in the western fault slice is found to lie between 456·0 and 572·5 feet below the contact with the Willow Creek formation in the eastern fault slice. These sandstone zones are 108·5 and 116·5 feet thick in the western and eastern sections, respectively. Assuming the tops of the sandstone zone to be the same horizon, some 100 feet of beds are, therefore, missing in the previously described western section; their description is as follows:

—	Thickness	Depth below top
	Feet	Feet
Overlying beds—Willow Creek formation		
Contact conformable		
St. Mary River formation		
Shale, calcareous, blocky fracturing, buff	2·0	2·0
Shale, dark grey, carbonaceous	2·0	4·0
Shale, grey, silty	10·0	14·0
Sandstone, grey, fine-grained; with limestone nodules	2·0	16·0
Shale, buff, calcareous, blocky fracturing	1·0	17·0
Shale, grey, silty; with limestone nodules	5·0	22·0

—	Thickness	Height above base
	Feet	Feet
Overlying beds—Willow Creek formation—*Continued*		
St. Mary River formation—*Continued*		
Sandstone, hard, fine-grained, grey, greenish grey weathering	2·0	24·0
Shale, silty, brown	10·0	34·0
Shale, grey, silty; unio coquina	5·0	39·0
Sandstone, grey, hard, fine-grained, calcareous	1·5	40·5
Shale, grey, silty, with thin sandstone lenses	6·0	46·5
Sandstone, grey, medium-grained, massive-bedded	8·0	54·5
Shale, grey, blocky fracturing	1·0	55·5
Shale, grey, calcareous, freshwater shells	3·0	58·5
(Section continues on north bank of river at same horizon)		
Sandstone, fine-grained, calcareous, yellowish green; minor olive-green shale	7·0	65·5
Shale, grey, calcareous	2·5	68·0
Sandstone, grey, hard, massive-bedded, fine-grained	2·0	70·0
Shale, grey, silty, grey-blue weathering	5·0	75·0
Sandstone, grey, hard, fine-grained	4·0	79·0
Shale, dark greenish grey	2·0	81·0
Sandstone, grey, hard, fine-grained	2·0	83·0
Shale, dark grey	4·0	87·0
Sandstone, greenish grey, hard, fine-grained	5·0	92·0
Shale, dark grey	2·0	94·0
Sandstone, grey, thin-bedded, fine-grained, and interbedded light grey, silty shale	6·0	100·0

The total thickness of the St. Mary River formation, assuming the correlation of the 'blocky' sandstone zone in the eastern and western sections, is 3,188·0 feet. The base of the formation is not exposed, but few beds are believed to be missing. The formation is divisible into two parts, a lower part 582·0 feet thick, and an upper part 2,606·0 feet thick.

The lower part of the St. Mary River formation consists of coarse- to medium-grained, reddish brown weathering, grey sandstones, dark grey, green, and carbonaceous shale, coal seams, thin ironstone bands, and oyster coquinas. These strata represent a transitional stage between the underlying marine deposits of the Bearpaw formation and the overlying, upper part of the St. Mary River of freshwater origin. Strata of the lower part were observed in several places, and served as a valuable indication of proximity to the base of the formation.

The oyster coquina that lies 75+ feet above the base of the St. Mary River formation on Oldman River is probably the same, very widely distributed oyster coquina that occupies a similar stratigraphic position in Cowley map-area (Hage, 1943) and in the southwestern Plains of Alberta (Russell and Landes, 1940). A massive, medium-grained, light grey,

crossbedded sandstone varying in thickness between 90 and 135 feet, called the Blood Reserve formation, is present in southwestern Alberta between the marine Bearpaw shales and the oyster coquina of the St. Mary River formation. No such thick, massive sandstone was observed on Oldman River, but the interbedded sandstones and shales lying below the oyster coquina may be its equivalent; no attempt was made to map Blood Reserve equivalents separately, as the oyster coquina was observed only at the one locality.

The upper part of the St. Mary River formation is composed of a series of interbedded lenticular sandstones, shales, and freshwater limestones or 'ironstones'. The sandstones and shales occur in about equal proportions, although either may be more prevalent in certain zones. The shales are olive-green, grey, carbonaceous, silty, and calcareous. The 'ironstones' are massive beds, 1 to 4 feet thick, of dark grey, fine-grained, argillaceous limestone, weathering dark brown. They grade laterally into calcareous sandstones or shales or form caps on underlying sandstones. The sandstones are commonly of two general types: (1) grey, hard, well indurated, massive to thinly bedded, fine- to medium-grained, occasionally crossbedded, and greenish grey weathering; and (2) grey, soft, massively bedded, medium- to coarse-grained, coarsely crossbedded, poorly indurated, weathering to a light grey sand. Sandstones of the second type are proportionately less than the others; occur mainly in the middle of the formation; and are more typical of the Edmonton formation of the north than they are of the St. Mary River, suggesting that the lateral transition from the more highly indurated sandstones of the latter formation to the soft sands of the Edmonton takes place, in part, in this region. Russell (1932) has reported the appearance of Edmonton-like beds in the lower St. Mary River on Oldman River, in tp. 10, rges. 23, 24, and 25, and at Scabby Butte, in secs. 18 and 19, tp. 11, rge. 22.

The zone of 'blocky' sandstones that lies between 456·0 and 572·5 feet from the top of the formation, appears on freshly exposed surfaces to be very massive, and is divided into blocks by joints, but where more weathered looks thin and platy. Shales are scarce in this zone. Individual sandstones may be 25 to 30 feet thick, forming the crests of most of the ridges underlain by the formation, and proved useful in the interpretation of the structure.

Near their contact with the overlying Willow Creek formation, the sandstones of the St. Mary River formation are less common, thinner, and finer grained, and the shales are a bluer grey, less silty, and contain locally a few, small, irregular, limestone nodules typical of much of the Willow Creek formation. The contact appears transitional, and is placed arbitrarily at the base of the lowest sandstone of typical Willow Creek lithology.

Fossil flora found in the St. Mary River formation have been identified by W. A. Bell of the Geological Survey. Their stratigraphic relations are summarized in the following table:

TABLE I

Fossil Flora from the St. Mary River Formation

Species	Height above base Feet
Leguminosites stagnum Bell *Nymphaeites angulatus* (Newberry)	?[1]
Equisetum perlaevigatum Cockerell	3,081·0[2]
Elatocladus intermedia (Hollick) *Typha* sp. *Nymphaeites angulatus* (Newberry) *Carpolithus ceratops* (Knowlton)	2,616·0
Antholithus (Nymphaeites) marsiliodes Bell	1,821·5
Typha sp. *Nymphaeites striatus* (Berry)	1,586·5
Nymphaeites striatus (Berry)	1,458·5
Adiantum paululum Bell *Carpites* sp. *Nymphaeites angulatus* (Newberry)	1,309·5
Equisetum perlaevigatum Cockerell	1,154·0
Thuites interruptus (Newberry) *Elatocladus intermedia* (Hollick)	957·5
Elatocladus intermedia (Hollick)	200 ±[3]

[1] Collected from fault zone on Oldman River, sec. 1, east-central, tp. 10, rge. 2, along which St. Mary River strata have been thrust over Willow Creek; stratigraphic position uncertain.

[2] Collected from eastern section of St. Mary River formation on Oldman River, 107 feet below contact with Willow Creek formation.

[3] Collected on South Willow Creek, sec. 26, tp. 13, rge. 2, from lower part of St. Mary River formation; precise tratigraphic position not known.

Dr. Bell states in regard to this flora that, although diagnostic species are too few to permit precise age correlation, part of the St. Mary River formation is equivalent to the Whitemud formation of southeastern Alberta. The Whitemud flora is represented by *Equisetum perlaevigatum*, *Elatocladus intermedia*, *Thuites interruptus*, and *Nymphaeites striatus*. The presence of very rare *Carpolithus ceratops* from 2,616·0 feet above the base within the 'blocky' sandstone zone, suggests, according to Dr. Bell, that these and higher beds may possibly be equivalent to the Frenchman formation of Lance age. *Equisetum perlaevigatum*, *Elatocladus intermedia*, *Thuites interruptus*, and *Trapa? microphylla* (=*Nymphaeites angulatus* (Newberry)) are held in common with the Edmonton formation into which the St. Mary River formation has been traced.

UPPER CRETACEOUS AND (OR) PALEOCENE

Willow Creek Formation

Dawson (1884) originally separated the Willow Creek beds from the underlying St. Mary River and overlying Porcupine Hills formations primarily on the basis of the red colour of the shales, and to some extent on a contrast in lithology of the sandstones. He believed that the Willow Creek formation graded laterally northward into the basal part of the Paskapoo formation, with loss of the characteristic red colour of the shales. The Willow Creek beds, together with the overlying Porcupine Hills formation, were, accordingly, believed equivalent to the Paskapoo formation. Present work shows that the relationship between the Willow Creek and Porcupine Hills formations in Callum Creek and Langford Creek map-areas is that of an erosional unconformity; the Willow Creek beds are absent a short distance north of Langford Creek map-area through removal by pre-Porcupine Hills erosion. The Porcupine Hills formation was traced laterally northward into the Paskapoo formation of Stimson Creek map-area (Hume, 1943a), and the St. Mary River formation was traced into the Edmonton formation, which underlies the Paskapoo formation in the Stimson Creek map-area. These relationships are shown in Figure 3.

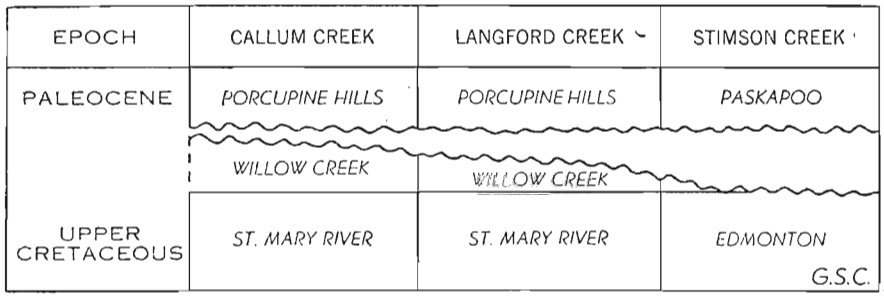


Figure 3. Illustrating stratigraphic relationship of late Upper Cretaceous and Paleocene formations in the Callum Creek, Langford Creek, and Stimson Creek map-areas.

The Willow Creek formation underlies a broad belt in Callum Creek map-area, which narrows northward to where, at the north border of Langford Creek map-area, it is less that 400 feet wide. Where the formation is thickest, in the southern part of Callum Creek map-area, no complete section is exposed. The formation is reported (Hage, 1943) to be 2,700 feet in Cowley map-area to the south. Only 350 feet are present in the northern part of Langford Creek map-area.

Hage modified the definition of the lower contact of the Willow Creek so as to include strata having the lithological characteristics of part of the typical Willow Creek, but lacking the red-coloured shales. The writer has attempted to follow this usage in tracing the contact northward.

On Oldman River, in sec. 5, tp. 9, rge. 2, a soft, massive, grey sandstone is considered to mark the base of the Willow Creek formation. Sandstones of this type are common in the overlying beds. The grey, soft sandstones of the St. Mary River formation are similar, but are less quartz-

ose, and do not weather to as light a grey. They are not common in the uppermost part of the St. Mary River, where, in general, the Willow Creek beds are underlain by hard, fine- to medium-grained sandstones.

This contrast in lithology of the sandstones formed the basis upon which the contact between the St. Mary River and Willow Creek formations was traced northward, where exposures were less continuous and usually showed only the sandstones. The contact was not observed north of sec. 35, tp. 12, rge. 2. On the map, its position is based on the thickness of St. Mary River strata above the zone of 'blocky' sandstones near the top of that formation, and the thickness below a conglomeratic horizon (zone C) within the Willow Creek formation.

Below the lowest occurrence of red shale, the writer has included in the Willow Creek formation 536 feet of green, grey, and purplish shale, with interbedded sandstones, most of which are massively bedded, cross-bedded, fine-grained, soft, and grey, but include some hard, thin-bedded, fine-grained layers of calcareous character. Limestone concretions occur as large lenticular masses from 6 inches to 2 feet in diameter, or as very prolific zones of small, irregular, white weathering concretions, 1 inch to 3 inches in diameter. Shale is considerably more abundant than the sandstones, in contrast with the almost equal proportions in the St. Mary River formation.

The Willow Creek formation may be divided into several zones. The basal zone (A), discussed above, is 536·0 feet thick. Overlying it is zone B of green, red, and mottled green and red shales and soft grey sandstones, 246·0 feet thick. Zone C consists of coarse-grained, cross-bedded, conglomeratic, grey sandstone, 15 to 30 feet thick. The pellets are commonly about ¼ inch in diameter and consist of grey and white chert and quartzite.

These three lower zones of the Willow Creek are well exposed along Oldman River. The following section begins on the north bank, in secs. 5 and 6, tp. 10, rge. 1:

—	Thickness	Height above base
	Feet	Feet
Willow Creek formation (Uppermost beds not exposed)		
Zone C:		
Sandstone and conglomerate: coarse-grained, cross-bedded, soft sandstone, locally conglomeratic on crossbeds in zones; pebbles commonly about ¼ inch in diameter, with a maximum of 1 inch....	15·0	782·0
Zone B:		
Sandstone, evenly bedded, medium-grained, hard.....	7·0	775·0
Shale, green.....	6·0	769·0
Sandstone and shale: fine-grained grey sandstone and red and green shale.....	10·0	759·0
Shale, green.....	3·0	756·0
Shale, mottled red and green.....	3·0	753·0
Sandstone, soft, grey, medium-grained.....	1·0	752·0
Shale, mottled, nodular.....	0·5	751·5
Sandstone, soft, fine-grained, hard base.....	3·0	748·5

—	Thickness	Height above base
	Feet	Feet
Willow Creek formation—*Continued*		
Zone B:—Continued		
Shale, blocky, calcareous, pale green and red	14·0	734·5
Sandstone, hard, calcareous, fine-grained, green, irregularly indurated	1·5	733·0
Shale, mottled	6·0	727·0
Shale, nodular, banded green and red	6·0	721·0
Shale, green	3·0	718·0
Covered: section continues on south bank	10·0	708·0
Sandstone, soft, grey, fine-grained	5·0	703·0
Shale, mostly covered, mottled green and red	50·0	653·0
Sandstone, soft, thinly bedded, fine-grained	2·0	651·0
Shale, dark grey, bentonitic	7·0	644·0
Shale, mottled, nodular, red and green	50·0	594·0
Sandstone, hard, nodular, fine-grained, grey	2·0	592·0
Shale, mottled	6·0	586·0
Sandstone, soft, medium-grained, grey	4·0	582·0
Shale, mottled red and green	30·0	552·0
Sandstone, massive, crossbedded, soft, medium-grained, with thin red shale interbedded 7 feet above the base. This shale is the lowest red shale in the section	16·0	536·0
Total thickness of Zone B	246·0	
Zone A:		
Shale, green	3·0	533·0
Shale, dark grey, purplish	1·0	532·0
Sandstone, thin-bedded, green	4·0	528·0
Shale, grey	4·0	524·0
Shale, pale green, nodular	8·0	516·0
Sandstone, calcareous, fine-grained, grey	6·0	510·0
Shale, dark grey, purplish	1·0	509·0
Shale and sandstone: grey, calcareous and nodular shale; lenticular, fine-grained, soft, grey sandstone	12·0	497·0
Shale, dark grey, purplish	3·0	494·0
Shale, green	2·0	492·0
Sandstone, soft, pale green, fine-grained	2·0	490·0
Shale, dark grey	4·0	486·0
Sandstone, pale green, fine-grained, soft	1·5	484·5
Bentonite	0·5	484·0
Shale, dark grey, purplish, and nodular	8·0	476·0
Sandstone, soft, massive, medium-grained	8·0	468·0
Shale, dark grey, purplish	1·0	467·0
Sandstone, calcareous, fine-grained, grey	6·0	461·0
Shale, dark grey, purplish	1·0	460·0
Shale, pale green, silty, calcareous	6·0	454·0
Shale, dark grey, purplish	1·0	452·0
Sandstone, calcareous, fine-grained; nodular limestone	3·0	449·0
Shale, pale green	6·0	443·0
Sandstone, hard, calcareous, fine-grained, grey	2·0	441·0
Shale, dark grey, purplish	1·0	440·0
Shale, pale green, nodular	25·0	415·0
Sandstone, soft, irregularly indurated, crossbedded, fine-grained, grey, basal unio bed	5·5	409·5
Sandstone and shale: soft, grey sandstone; nodular and silty shale	5·0	404·5
Sandstone, soft, grey, nodular, coarse-grained to gritty in its upper part, basal unio bed	3·5	401·0

—	Thickness	Height above base
	Feet	Feet
Willow Creek formation—*Continued*		
Zone A:—Continued		
Shale, dark grey, purplish	4·0	397·0
Shale, pale green	3·0	394·0
Sandstone, hard, massive, crossbedded, grey	1·0	393·0
Shale, grey, silty; shell fragments	6·0	387·0
Sandstone, soft, massive, crossbedded, medium- to coarse-grained	15·0	372·0
Shale, pale green, silty	4·0	368·0
Shale, dark grey, purplish; shell fragments	3·0	365·0
Shale, pale green, silty	8·0	357·0
Shale, dark grey, purplish	1·0	356·0
Shale, pale green, silty	8·0	348·0
Shale, dark grey, purplish	1·0	347·0
Shale, pale green, nodular	2·0	345·0
Shale, dark grey, purplish	7·0	338·0
Shale, grey, silty; shell fragments	6·0	332·0
Sandstone, soft, fine-grained, grey	8·0	324·0
Shale, dark grey, bentonitic	8·0	316·0
Shale, green, nodular	15·0	301·0
Shale, dark grey, purplish	1·0	300·0
Shale, pale green	6·0	294·0
Shale, dark grey, carbonaceous, and light grey	8·0	286·0
Sandstone, soft, fine-grained, thin-bedded, grey	2·0	284·0
Shale, grey, nodular, bentonitic	8·0	276·0
Sandstone, soft, medium-grained, grey	2·0	274·0
Shale, grey, silty	2·0	272·0
Sandstone, soft, grey, medium-grained, nodular	5·0	267·0
Shale, grey, nodular, and purplish	9·0	258·0
Sandstone, hard, calcareous, fine-grained, lenticular	1·0	257·0
Shale, green, silty	21·0	236·0
Shale, pale green	10·0	226·0
Sandstone, hard, fine-grained, green	3·0	223·0
Sandstone, soft, fine-grained, grey	4·5	218·5
Shale, pale green, nodular	3·5	215·0
Sandstone, soft, nodular, fine-grained, grey	2·0	213·0
Shale, grey, bentonitic	3·0	210·0
Shale, nodular, green and purplish	8·0	202·0
Sandstone, calcareous, fine-grained, dark grey	1·5	200·5
Shale, dark grey and green, silty	18·0	182·5
Sandstone, lenticular, medium-grained, crossbedded; shale pellets in base, soft, grey	4·0	178·5
Shale, carbonaceous	1·0	177·5
Sandstone, soft, crossbedded, fine-grained	4·0	173·5
Shale, green	8·0	165·5
Sandstone and shale, silty grey shales, and thin sandstones	3·0	162·5
Sandstone, hard, dark grey, fine-grained	2·0	160·5
Shale, dark grey, purplish	1·0	159·5
Sandstone and shale: lenticular, soft, fine-grained sandstones and pale green, silty shale	11·0	148·5
Limestone, nodular zone	2·0	146·5
Shale, dark grey, purplish; shell fragments	7·0	139·5
Sandstone, lenticular, medium-grained, green	1·5	138·0
Shale, silty, green, nodular at top	10·0	128·0
Sandstone, hard, fine-grained, crossbedded, grey	1·0	127·0
Shale, dark grey, bentonitic	4·0	123·0

—	Thickness	Height above base
	Feet	Feet
Willow Creek formation—*Continued*		
Zone A:—Continued		
Sandstone, soft, fine-grained, grey; shell fragments....	18·0	105·0
Shale, pale green and grey.....	7·0	98·0
Sandstone, massive, fine-grained, grey.....	1·0	97·0
Shale, grey, calcareous; shell fragments.....	9·0	88·0
Sandstone, soft, fine-grained, grey; weathers to sand..	6·0	82·0
Covered.....	4·0	78·0
Sandstone, as above.....	6·0	72·0
Shale, grey, calcareous, nodular.....	5·0	67·0
Sandstone, soft, crossbedded, fine-grained, grey.....	5·0	62·0
Covered.....	3·0	59·0
Sandstone, hard, medium-grained, grey.....	8·0	51·0
Sandstone, hard, fine-grained, dark grey.....	18·0	33·0
Shale, blocky, calcareous, grey.....	3·0	30·0
Sandstone and shale: lenticular beds of fine-grained, crossbedded, soft grey sandstone and calcareous grey shale.....	10·0	20·0
Sandstone, coarse to medium-grained, crossbedded; irregularly indurated, spheroidal-weathering grey sandstone, with basal unio coquina.....	20·0	00·0
Total thickness of Zone A.....	536·0	
Total thickness of described section of Willow Creek formation.....	807·0	
Contact conformable		
Underlying beds—St. Mary River formation		

The overlying, and greater, part of the formation is not exposed in the Oldman River section, as the river turns southward to follow the strike of the Willow Creek beds. Sections farther north are poorly exposed and incomplete at the top, but indicate that red, green, mottled, and nodular shales with soft, massive, crossbedded, light grey weathering, grey sandstones overlie zone C. These beds will be referred to as zone D. Thin beds of harder sandstone are present, but become more massive and abundant towards the top of the formation. This uppermost zone (E) is better developed and thicker in the Cowley map-area to the south. Hage (1943) reports a gradational contact there with the overlying Porcupine Hills formation: "Within the transitional zone the sandstone beds become thicker, coarser, and harder, and form pronounced cliffs and ledges along the river banks. The shale beds likewise change gradationally to darker and harder rocks, with fewer calcareous concretions and red beds".

Only a small part of these transitional beds of zone E are present on Sharples Creek, in sec. 32, tp. 10, rge. 1, and in secs. 4 and 5, tp. 11, rge. 1, the southernmost exposure of the contact with the Porcupine Hills in Callum Creek map-area. Typical shales and sandstones of the Willow Creek are exposed near the junction with Callum Creek. Farther upstream no red shale is exposed, and the sandstones are hard, medium- to coarse-grained, light brown weathering, much resembling the transitional beds of Cowley map-area, or the sandstones of the Porcupine Hills formation.

However, still farther upstream, a small exposure of red shale and mottled red and green shale occurs a short distance below a massive, crossbedded, hard, grey sandstone, 15 feet thick. Dark carbonaceous material and shale pellets occur on some of the cross laminations. The base of this sandstone is considered to be the base of the Porcupine Hills formation.

On North Creek, in sec. 19, tp. 11, rge. 1, in Callum Creek map-area a massive bed of hard, medium-grained, crossbedded, grey sandstone that weathers light brown overlies with angular unconformity thin-bedded, fine-grained, grey sandstones, blocky, dark grey shale, and red, nodular limestone and shale, typical of zone D (*See* Plate III A). The base of this bed is coarse-grained, and contains shale pellets. The bed is lenticular, reaching a maximum thickness of 20 feet on the south side of the creek, but is represented by only a few feet of thin-bedded, crossbedded sandstone on the north side. It gives the appearance of being a stream channel filling, to which may be attributed the apparent angular unconformity at the base.

On Adair Creek, in sec. 12, tp. 12, rge. 2, Callum Creek map-area, the base of the Porcupine Hills is marked by a massive bed of very coarse-grained, arkosic sandstone 5 feet thick, with pebbles of hard shale, shell fragments, and rounded limestone nodules typical of the Willow Creek, from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches in diameter. This bed overlies poorly exposed red shale.

On Rice Creek, in secs. 10 and 15, tp. 14, rge. 2, Langford Creek map-area, red and green nodular shale of zone B and the coarse-grained conglomeratic sandstone of zone C are overlain by the basal bed of the Porcupine Hills formation. This is a massive, coarse-grained, brown weathering, conglomeratic sandstone. The pebbles are $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches in diameter and consist of polished chert and quartzite. This conglomerate was mapped by G. S. Hume (1943b) as the base of the Paskapoo formation, which he had traced southward from Stimson Creek and Turner Valley map-areas. A similar sandstone with pebbles up to $\frac{1}{4}$ inch in diameter is exposed just east of the road, in sec. 11, tp. 14, rge. 2.

East of the Chain Lakes, in sec. 3, tp. 15, rge. 2, Langford Creek map-area, the base of the Porcupine Hills formation is marked by a massive, very coarse-grained, arkosic, yellowish green sandstone. Underlying this bed are soft, medium-grained, grey sandstones and pale green, light grey, and purplish shales, with small, white weathering, irregular, limestone nodules. These strata are typical of zone A of the Willow Creek.

In summary, Porcupine Hills strata, with a basal, coarse-grained sandstone, in places conglomeratic, overlie in progressive order northward, older zones within the Willow Creek formation. This relationship is that of an erosional unconformity, as the lithological characteristics of each zone, when traced northward, remain unchanged to where it is in contact with the basal bed of the Porcupine Hills formation.

The Porcupine Hills formation has been traced northward into the Paskapoo formation and the St. Mary River into the Edmonton formation. The Willow Creek formation thins northward through loss of beds from the top by erosion, from 2,700 feet in Cowley map-area to where it is absent a short distance north of Langford Creek map-area. The erosional

unconformity between the Porcupine Hills and Willow Creek formations, accordingly, is the same as that that lies between the Paskapoo and Edmonton formations in Stimson Creek map-area.

No fossils were found in the Willow Creek formation in Callum Creek and Langford Creek map-areas. East of these map-areas, along Willow Creek west of the town of Granum, Williams and Dyer (1930) report a non-marine invertebrate fauna from the upper part of the formation. These authors state that this fauna is closely allied to that of the Paskapoo formation of Upper Paleocene age and correlative with part of the Fort Union formation. Russell (1932) referring to the non-marine invertebrate fauna from the upper Willow Creek states that it is similar to the Paskapoo and Fort Union faunas. He correlates the Willow Creek formation with the lower 700 feet of the Paskapoo, but suggests that the lower part of the Willow Creek formation in southwestern Alberta, where the formation is thicker, is pre-Paskapoo in age, and may possibly represent Lower and Middle Paleocene, thereby implying that the unconformity between the Paskapoo and Edmonton formations passes into the contact between the Willow Creek and St. Mary River formations. In Callum Creek and Langford Creek map-areas, the unconformity between the Porcupine Hills and Willow Creek formations passes into that between the Paskapoo and Edmonton formations (*See* Figure 3). The entire Willow Creek formation, then, is older than the Paskapoo formation; the upper part containing the invertebrate fauna of Russell and of Williams and Dyer, of which many species are held in common with the fauna of the Upper Paleocene Paskapoo formation, could be Lower or Middle Paleocene in age. W. A. Bell of the Geological Survey (personal communication) has collected a small flora, dated as Paleocene in age, from the upper part of the Willow Creek formation along Willow Creek. The age of the remainder, or lower part, from which no fossils have been collected, may be Upper Cretaceous in age, as suggested by the transitional contact with the underlying St. Mary River formation and the absence of definite latest Upper Cretaceous (Lance) fossils from the uppermost beds of the St. Mary River formation.

TERTIARY

PALEOCENE

Porcupine Hills Formation

The Porcupine Hills is the youngest formation exposed in the areas mapped, covering the eastern parts of Callum Creek and Langford Creek map-areas. The strata have been deeply dissected by streams, but about 4,000 feet are preserved.

The formation consists of fine- to coarse-grained, crossbedded, yellowish brown to brown weathering, grey and green sandstones and massive, rubbly, grey and brown shales. The sandstones are commonly very massive, locally forming prominent ridges or ledges, but are lenticular and grade laterally into shale. Shale is more common in the lower part of the formation with sandstone increasing in proportion upwards.

The base of the formation is marked by a coarse-grained, grey sandstone, commonly conglomeratic, with pebbles of shale, chert, and quartzite up to 1½ inches in diameter. The lateral variations of this basal bed, and the relationship of the Porcupine Hills formation to the underlying Willow Creek have previously been discussed.

CHAPTER IV

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The region encompassed by Callum Creek, Langford Creek, and Gap map-areas may be divided, structurally, into two parts, the Alberta syncline and the Disturbed belt, corresponding respectively with the physiographic subdivisions of the Porcupine Hills and Foothills (*See* page 4). The Disturbed belt itself may be further subdivided into eastern, central, and western parts. Within the boundaries of the map-areas covered by this report, the limits of these divisions may be defined as follows (*See* Figure 4).

The *Alberta syncline* includes those parts of Callum Creek and Langford Creek map-areas that lie east of the contact between the Willow Creek and St. Mary River formations. The strata dip predominantly at low angles to the east, but gentle west dips are present in the northeast marking the axis of the syncline.

The *eastern part of the Disturbed belt* extends westward from the western edge of the Alberta syncline to the easternmost traces of the Livingstone and Todd Creek faults. For the most part, it is characterized by steeply west-dipping strata, repeated by closely spaced, high-angle thrust faults and minor folds. In its eastern part, adjacent to the Alberta syncline, the deformation was less intense, resulting in steep east dips, open folds, and west- and east-dipping faults[1].

The *central part of the Disturbed belt* lies between the easternmost traces of the Livingstone and Todd Creek faults and the western margin of the Palæozoic strata of the Livingstone Range. The Livingstone thrust plane underlies the greater part of the belt. The area between the Todd Creek and Livingstone faults in the southeastern part of Gap map-area is presumed to have been overlain at one time by the Livingstone thrust slice.

The *western part of the Disturbed belt* embraces the remainder of Gap map-area, but may also be considered to extend as far west as the High Rock Range of the Rocky Mountains, some 6 miles beyond the west border of the area. It is characterized by widely spaced thrust faults, with the strata between them exhibiting a varying intensity of folding.

THE ALBERTA SYNCLINE

The west flank of the Alberta syncline underlies the eastern and greater part of Langford Creek map-area and the eastern half of Callum Creek map-area. The western limit is considered to lie along the contact between the St. Mary River and Willow Creek formations, which lies close to the physiographic boundary between the Porcupine Hills and the Foothills.

[1] The term 'fault' will commonly be used throughout this report without qualification. As no 'normal' faults were observed, the term refers only to 'reverse' or 'thrust' faults. The fault plane may be inclined either to the east or to the west.

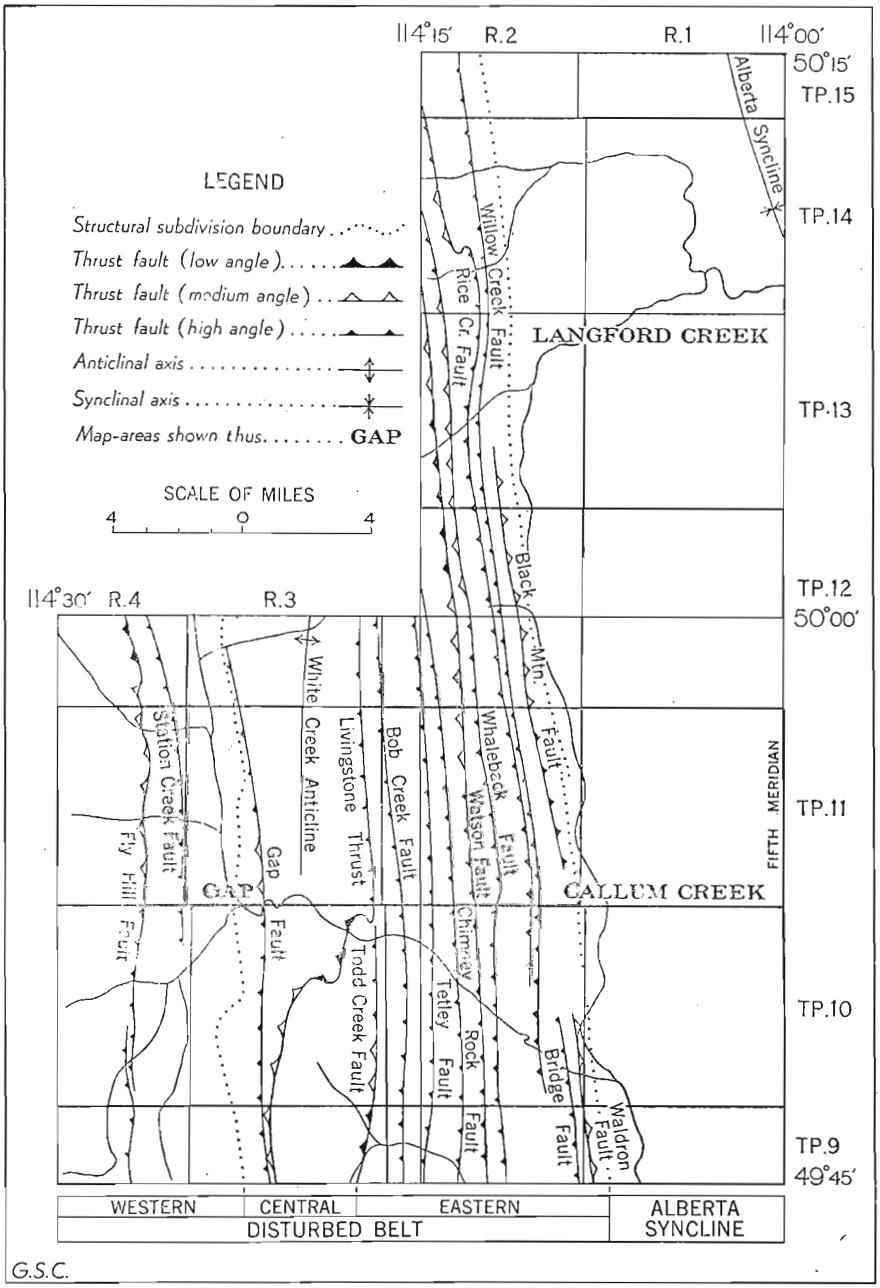


Figure 4. Tectonic map showing principal faults of Callum Creek, Langford Creek, and Gap map-areas.

Willow Creek and Porcupine Hills strata directly underlie the Alberta syncline, the former occupying a belt along its west flank. Small folds and minor east-dipping thrust faults were observed in the area underlain by the Willow Creek formation. Low west dips in the northeastern part of Langford Creek map-area demark the axis of the broad Alberta syncline. The west flank dips gently eastward over much of its width, but in the northwest is sharply upturned.

THE EASTERN PART OF THE DISTURBED BELT

GENERAL STATEMENT

The eastern part of the Disturbed belt includes the region from the western margin of the Alberta syncline to the easternmost trace of the Livingstone thrust in the northern part of Gap map-area and to the Todd Creek fault in the south.

Strata of the Belly River formation and Alberta group underlie the greater area. They dip steeply, chiefly towards the west, and are repeated by several closely spaced, high-angle thrust faults. Folds are not common nor persistent along the strike.

The narrow area underlain principally by the St. Mary River formation, and herein considered to lie within the Distrubed belt, is in some ways structurally a part of the Alberta syncline. In the northern part of Callum Creek and Langford Creek map-areas the strata of the St. Mary River formation dip eastward and are inseparable, structurally, from the western flank of the Alberta syncline. However, in the southern part of Callum Creek map-area, the strata are folded and broken by east- and west-dipping thrust faults, the degree of disruption approaching in intensity that of much of the Disturbed belt farther west. Physiographically, the ridges underlain by the St. Mary River formation are also similar to the ridges of the Foothills.

Five wells have been drilled in the eastern part of the Disturbed belt: Socony Vacuum, Stimson No. 1 well, in l.s. 12, sec. 5, tp. 15, rge. 2; Northwest Company, Willow Creek well, in l.s. 16, sec. 29, tp. 14, rge. 2; Northwest Company, Rice Creek well, in l.s. 1, sec. 20, tp. 9, rge. 2; Marjon Lundbreck No. 1 well, in l.s. 3, sec. 4, tp. 10, rge. 2; and Maxmont No. 1 well, in l.s. 10, sec. 20, tp. 9, rge. 2. The last well is still drilling. Oilfield Development No. 1 well, in l.s. 7, sec. 7, tp. 13, rge. 2, lies a short distance west of Langford Creek map-area, but furnishes information on some of the faults within the map-areas under consideration.

BRIDGE, WALDRON, AND BLACK MOUNTAIN STRUCTURES

The Bridge, Waldron, and Black Mountain structures lie within the area underlain principally by the St. Mary River formation between the Willow Creek fault on the west and the eastern margin of the Disturbed belt on the east. In Langford Creek map-area, the strata are steeply east-dipping, but to the south, in Callum Creek map-area, they are folded and broken by faults. These structures are excellently exposed along Oldman River, in secs. 23 and 24, tp. 10, rge. 2.

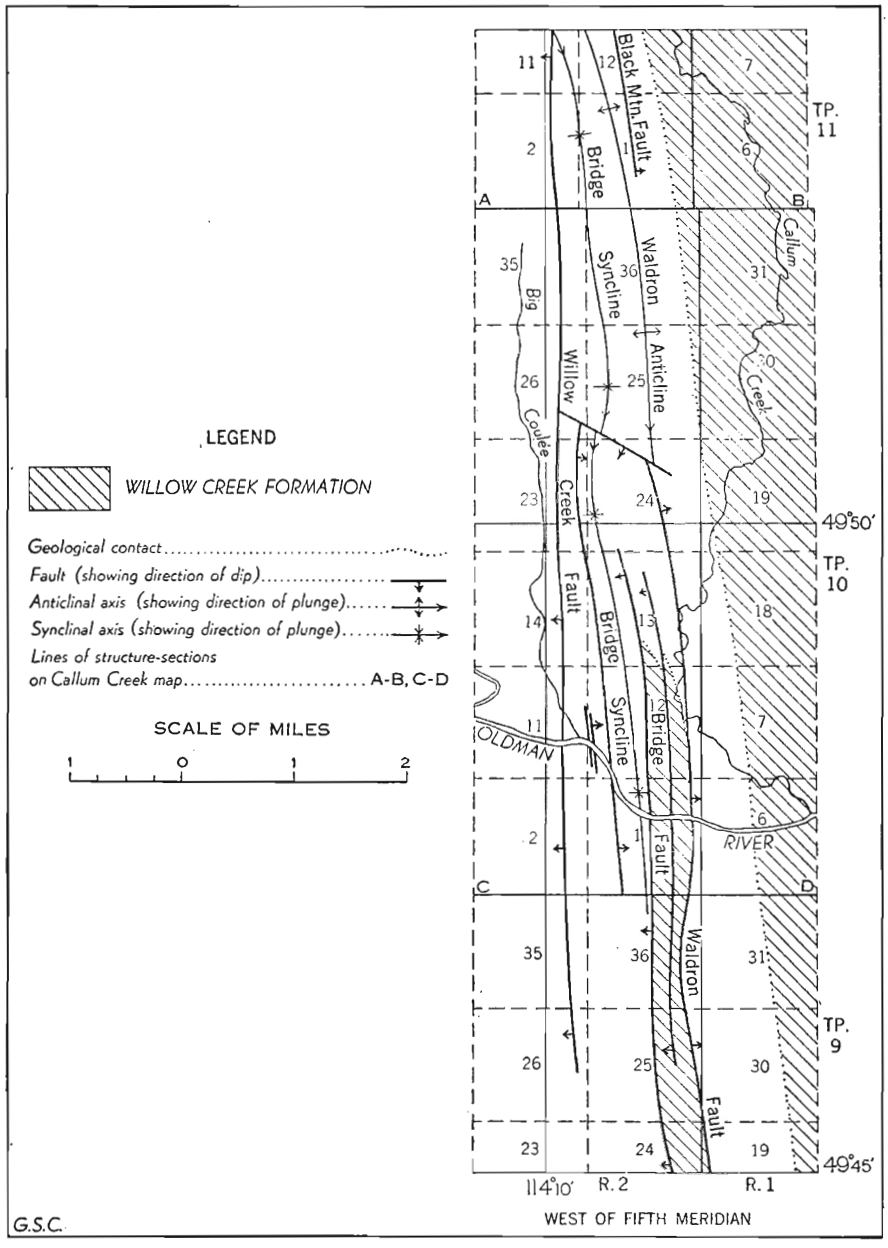


Figure 5. Sketch map of Bridge and Waldron structures, Callum Creek map-area.

The Bridge fault (*See* Figure 5 and Structure-section C-D, Map 982A), steeply west dipping, thrusts west-dipping St. Mary River strata over west-dipping Willow Creek beds. A tight syncline above the fault (Bridge syncline), plunging south, extends about 1 mile south of the river, but becomes broader north of it as displacement on the Bridge fault decreases. To the west, three minor faults, all east-dipping, repeat an unknown amount of St. Mary River strata. As has been pointed out by Hume (1931), the presence of these east-dipping faults above a steeply west-dipping fault indicates a decrease in the dip of the west-dipping fault (in this case, the Bridge fault) in the vicinity of their convergence at depth.

East of the Bridge fault, the steeply (70 degrees) west-dipping Willow Creek strata are repeated by a west-dipping fault. Near the east-dipping Waldron fault, the Willow Creek beds are overturned beneath the mass of St. Mary River strata overthrust from the east. Minor east-dipping faults, with anticlinal drag indicating movement to the west, and also west-dipping faults lie above the Waldron fault. The west-dipping minor thrust faults lying above the east-dipping Waldron fault indicate a decrease in dip of the Waldron fault plane at depth (*See* Structure-section C-D, Map 982A). This relationship is the same as that observed in the case of the Bridge fault discussed above, differing only in that the Waldron fault plane is inclined eastward, whereas the Bridge fault dips west.

In summary, along Oldman River, St. Mary River strata are thrust over Willow Creek from the west along a west-dipping thrust fault (Bridge fault), and from the east along an east-dipping thrust fault (Waldron fault).

The Bridge and Waldron faults, with Willow Creek strata between them, are believed to extend southward into the adjoining Cowley map-area (Hage, 1943) to connect with the syncline of Willow Creek beds along Todd Creek. There, according to observations made by the writer, the Willow Creek beds appear to form a continuous section, in part overturned to the west, bordered by east- and west-dipping faults that end in the flanks of the syncline a short distance north of Crowsnest River.

North of Oldman River, the Bridge fault and the minor fault within the Willow Creek to the east pass into the east flank of the steeply south-plunging Bridge syncline (*See* Figure 5). The Waldron fault passes northward into the axis of an anticline (Waldron anticline). Basal St. Mary River strata are exposed at the north end of the Bridge syncline where it bears west against the Willow Creek fault. The Waldron anticline may extend northward to join with the anticline beneath the Willow Creek fault (*See* page 60).

A tear fault is inferred to lie across the structure in secs. 24 and 25, tp. 10, rge. 2. The zone of 'blocky' sandstones in the upper part of the St. Mary River formation on Oldman River forms the flanks of the Bridge syncline and extends north to NW. section 13, where it forms the nose of the south-plunging (20 degrees) syncline. Northward, along the axis, older beds are exposed beneath it as the southward plunge of the syncline continues. Still farther north, however, the same 'blocky' sandstones reappear in the same south-plunging syncline (5 to 10 degrees), indicating the presence of an intervening fault. The offset of the axis of the syncline

and the accentuated southward plunge in section 24 suggest that this is a south-dipping tear fault along which the south side has been displaced upwards and northwestwards with respect to the north side.

The Black Mountain fault (*See* Figure 5) is an east-dipping thrust that repeats part of the St. Mary River formation of the east flank of the Waldron anticline. The position of this fault at the surface is indicated in secs. 13 and 24, tp. 11, rge. 2, by a wide shear zone. On Black Mountain, the zone of 'blocky' sandstones in the upper part of the St. Mary River formation is repeated. Contortions, with anticlinal drag indicating westward movement of the eastern slice, were observed on Callum Creek in the southern part of Langford Creek map-area. No evidence of the surface position of this fault was found farther north.

WILLOW CREEK AND RICE CREEK STRUCTURES

In Stimson Creek (Hume, 1943a) and Pekisko Creek (Hume, 1940b) map-areas, which lie respectively north and northwest of Langford Creek area, upper Blairmore beds are exposed along a rather tight anticline, whose east flank has been thrust over east-dipping Wapiabi strata. These structures extend southerly into Langford Creek map-area, where they are termed the Willow Creek anticline and the Meinsinger fault (Figure 6). The plunge of the anticline is close to 0 degrees in Stimson Creek map-area, but changes to 3 degrees south in the northern part of Langford Creek map-area, successively higher beds being exposed along the axis. Displacement on the Meinsinger fault decreases rapidly southward, dying out completely south of Willow Creek, where Belly River strata are unfaulted and form a south-plunging anticlinal nose (secs. 20 and 21, tp. 14, rge. 2). A west-dipping fault (Willow Creek fault) separates the Belly River strata of the east flank of the Willow Creek anticline from the east-dipping St. Mary River strata to the east. This fault is believed to be continuous with the major fault in the western part of Stimson Creek map-area, which in the north thrusts Belly River and Bearpaw strata over Edmonton beds.

The Northwest Company, Willow Creek well lies a short distance west of the Meinsinger fault on the axis of the Willow Creek anticline. Drilling commenced in Blackstone strata near the top of the formation. A summary of the log follows (*See* Structure-section A-B, Map 981A):

Depth	Formation
Feet	
0–570	Blackstone
570–1,950	Blairmore
1,950–2,320	Kootenay (repeated by folding below 2,145)
2,320–2,930	Blairmore (minor fault 2,490; repeated by folding below 2,700)
2,930–2,950	Kootenay
2,950–	(fault)
2,950–3,050	Blairmore
3,050–3,200	Kootenay
3,200–3,330	Fernie (in part repeated by folding)
3,330–3,500	Kootenay (overturned)
3,500–3,600	Blairmore (possibly in fault contact with Kootenay)

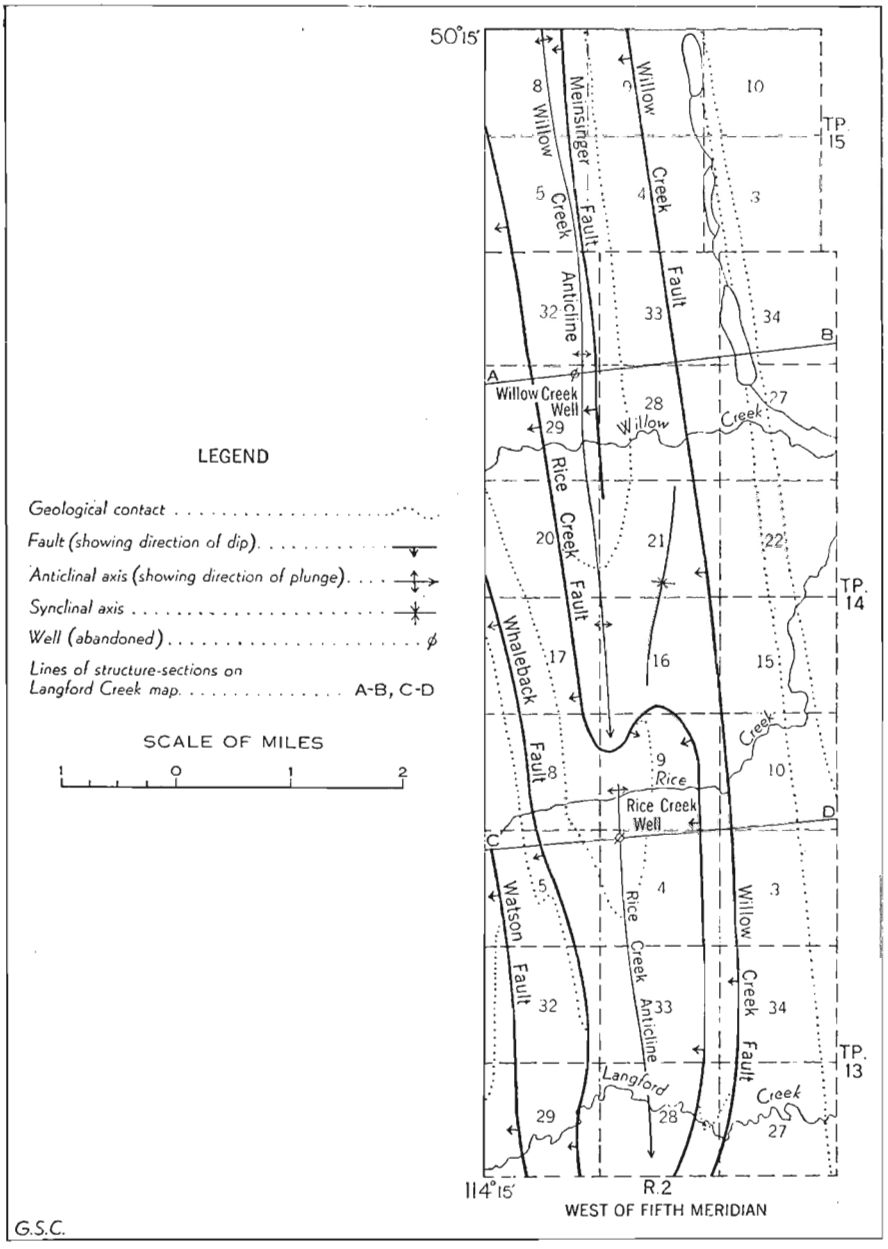


Figure 6. Sketch map of Rice Creek and Willow Creek structures, Langford Creek map-area.

As interpreted in Structure-section A-B, this well shows that the Meinsinger fault dies out at depth into an overturned syncline of Blairmore strata. The repetition of Blairmore at 2,950 feet depth may be due to shearing in the east flank of the overturned syncline. The lower overturned anticline, in which Fernie strata were encountered, probably lies only a short distance above the Willow Creek fault. From a consideration of the structure and thickness of the beds between the base of the Blairmore at 1,950 and the bottom of the well at 3,600 feet depth, Rundle strata may be reasonably inferred to lie above the Willow Creek fault a short distance to the west at about 1,200 feet elevation.

The Socony Vacuum, Stimson No. 1 well, in l.s. 12, sec. 5, tp. 15, rge. 2, close to the west border of Langford Creek map-area, reached the Rundle formation at a depth of 3,490 feet. The Rundle formation forms the core of the Willow Creek anticline, the crest of which lies a short distance to the east at about 2,000 feet elevation. The Willow Creek and Meinsinger faults were encountered at a depth of 5,140 feet; the drill passing from Banff into Blairmore strata. No petroleum or natural gas was encountered, and the well was abandoned at 5,430 feet depth, still in the Blairmore group.

In Pekisko Creek map-area (Hume, 1940b), to the northwest of Langford Creek map-area, the continuation of the Willow Creek anticline and Meinsinger form the eastern flank of the Highwood uplift, beneath which Rundle strata have been encountered in drilling, although commercial quantities of petroleum were not obtained. The top of the Rundle formation was reached by Pekisko Hills No. 1 well, close to the crest of the structure, at a drilling depth of 1,065 feet or an elevation of approximately 2,385 feet. Between the Pekisko Hills No. 1 well and the Stimson Creek No. 1 well the elevation of the top of the Rundle in the Willow Creek anticline decreases from 2,385 to 2,000 feet. The south plunge continues to the Willow Creek well, where the crest of the anticline in Rundle strata is inferred to lie at 1,200 feet elevation.

The west flank of the Willow Creek anticline is bounded by the Rice Creek thrust fault, which repeats Alberta and Blairmore strata. The latter appear only near the northwest corner of Langford Creek map-area in a tight, overturned, south-plunging, anticlinal drag-fold. The westward dipping basal Belly River strata of this fault slice form a ridge that may be followed southward (*See* Figure 6) to where the strata curve eastward to form a south-plunging anticlinal nose (Rice Creek anticline). It is remarkable that the surface trace of the axial plane of the Rice Creek anticline lies in direct continuation of that of the Willow Creek anticline, with both structures plunging southward. The basal Belly River strata of the east flank of the Rice Creek anticline extend northward only as far as sec. 9, tp. 14, rge. 2, where they overlie contorted upper Belly River strata of the east flank of the Willow Creek anticline, separated from them by the Rice Creek fault.

Additional information on the structure is furnished by the Northwest Company, Rice Creek well, which was located on the crest of the Rice Creek anticline in Wapiabi strata. A summary of the log follows (*See* Structure-section C-D, Map 981A):

Depth	Formation
Feet	
0–340	Wapiabi
340–490	Bighorn
490–700	Blackstone
700–	(fault)
700–2,020	Belly River
2,020–3,100	Wapiabi
3,100–3,360	Bighorn
3,360–4,080	Blackstone
4,080–5,210	Blairmore
5,210–	(fault)
5,210–5,320	Bighorn (overturned)
5,320–5,740	Wapiabi
5,740–5,747	Bighorn

As interpreted on Structure-section C-D and Map 981A, the fault encountered at 700 feet drilling depth is the southward continuation of the Rice Creek fault, and the sequence of Belly River, Alberta, and Blairmore below the fault is the southward continuation of the south-plunging Willow Creek anticline. Thus, the Rice Creek fault is folded anticlinally, separating the upper Belly River beds of the Willow Creek anticline from the overlying Wapiabi of the Rice Creek anticline. Farther east, the fault is folded synclinally, and separates, as previously mentioned, the east-dipping basal Belly River strata of the east flank of the Rice Creek anticline from the contorted and synclinally folded east flank of the Willow Creek anticline.[1]

The drilling depth of the Alberta group in the Rice Creek well was only 2,060 feet, which is comparable to the thickness of 2,000 to 2,700 feet recorded for the Stimson Creek map-area (Hume, 1943a) to the north and the 2,000 feet for the Cowley map-area (Hage, 1943) to the south. Accordingly, the Alberta strata encountered in the well are presumed to dip at a low angle. This assumption is supported by the fact that the Rice Creek well, which is located on the crest of the Rice Creek anticline, also lies near the crest of the Willow Creek anticline.

In SW. sec. 16, tp. 14, rge. 2, the numerous small anticlines, underlain by a minor, low-angle thrust, are separated from the east-dipping strata of the east flank of the Willow Creek anticline by a minor tear fault. The tear fault strikes east, and ends where a small anticline and syncline bulge sharply eastward. These minor structures underlie the Rice Creek thrust fault, and are presumed to have been produced by the overriding of the Rice Creek thrust slice. The basal Belly River beds above the thrust plane, which dip 45 to 50 degrees east on the crest of the ridge, may be

[1] In this interpretation of the Rice Creek fault, the writer has benefited from T. A. Link's discussion and cross-section through the Rice Creek well (Link, 1935), though led to somewhat different interpretations at certain points.

traced down the east slope to where their dip changes to 20 degrees. Higher beds, still farther east, are overturned, dipping westward adjacent to the Rice Creek fault. The fault dips east at a low angle beneath the basal Belly River beds and changes to a westward dip near where the higher strata are overturned.

The Willow Creek fault was encountered in the Rice Creek well at a depth of 5,210 feet, where the drill passed from Blairmore into Bighorn strata. Although it lies here at a greater depth than that at which it is assumed to lie in the Willow Creek well, a little below 3,600 feet, the fault cuts beds of the upper (Willow Creek) anticline. The lower syncline and anticline of the Willow Creek well were not encountered in the Rice Creek well, perhaps having been removed by the Willow Creek fault. Rundle strata in the Willow Creek anticline consequently lie at a still greater depth than at the Willow Creek well.

As noted above, after passing through the Willow Creek fault, the drill encountered Bighorn strata, then drilled a thickness of shale before encountering the Bighorn pebble zone again at 5,740 feet. These two occurrences are interpreted as a minor overturned syncline, probably produced by drag beneath the Willow Creek fault (*See* Structure-section C-D, Map 981A). If the strata beneath the fault were all east dipping, as is indicated at the surface, and were considered to maintain the dip of the St. Mary River formation, a lower stratigraphic horizon would have been reached in this well. Accordingly, an anticlinal structure, with moderate closure, after the fashion described by Hume (1940a), is inferred to lie to the east of the syncline beneath the Willow Creek fault. Surface indications of what may be the crest of this structure were observed within basal St. Mary River strata on South Willow Creek, in sec. 22, tp. 13, rge. 2, and in sec. 34, tp. 12, rge. 2. It may continue south to join with the northern extension of the Waldron anticline (*See* page 55).

The Willow Creek and Rice Creek faults lying close together swing westward before continuing southward between dominantly west-dipping Belly River and east-dipping St. Mary River strata. The structure in the Bearpaw formation between the two faults is anticlinal where observed.

The Rice Creek fault probably ends along the contact between the Belly River and Bearpaw formations a short distance north of Oldman River. On this river the Willow Creek fault thrusts the Bearpaw over the St. Mary River formation with a small stratigraphic throw; the fault probably ends before reaching the northern boundary of Cowley map-area, where the contact between the St. Mary River and Bearpaw formations is believed to be unfaulted.

WHALEBACK STRUCTURES

The Whaleback fault reaches its maximum development in Callum Creek and Langford Creek map-areas, dying out northward and southward in Pekisko Creek and Cowley map-areas respectively. Belly River strata underlie the thrust thoughout its length, with upper Wapiabi and basal Belly River immediately overlying it. Most of the strata above and below the fault dip westward at angles varying between 80 and 30 degrees.

Between the Whaleback fault and the Watson fault, south of Oldman River, the Belly River strata are broken by two high-angle faults of minor displacement. Northward, the dip of the western fault decreases to a low angle, with highly contorted Belly River strata lying above it.

In the southern part of Langford Creek map-area, Wapiabi strata lie above the Whaleback fault as a narrow slice, which broadens northward into an anticline and syncline (Figure 7). A fault breaks the west flank

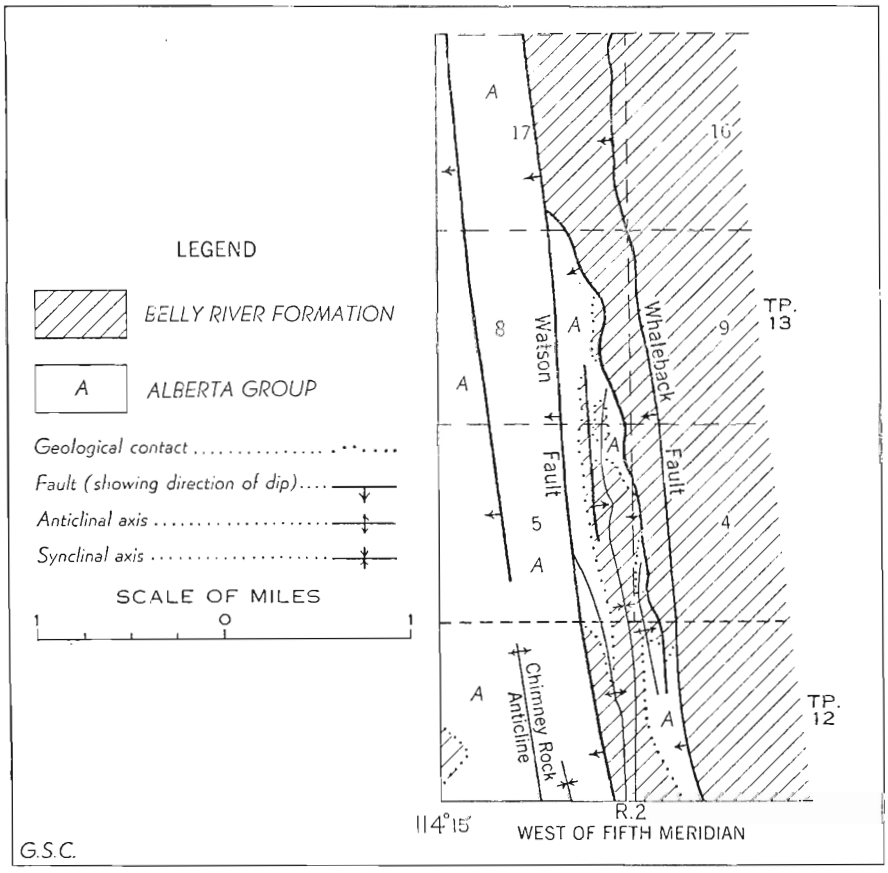


Figure 7. Sketch map of minor structures between the Watson and Whaleback faults, southwest Langford Creek map-area.

of the syncline, and northward, with increased displacement, thrusts Wapiabi strata of the core of the anticline over Belly River strata of the east flank of the syncline. The dip of the fault plane is low, and the surface trace of the fault gradually diverges from the Whaleback fault and merges with that of the Watson fault. Basal Belly River strata between this low-angle fault and the Watson fault are folded into an anticline and syncline. The syncline is cut out, in the north, against the low-angle fault with an east-dipping fault of minor displacement repeating the strata of its west flank.

Belly River strata, mostly of the upper part of the formation, are exposed between the Whaleback fault and the southern extension of the Rice Creek fault. They are closely folded, and are cut by many minor faults. Most of the folds do not persist for more than 4 or 5 miles, and seem to be due mainly to drag produced during displacement on the faults, as only small thicknesses of east-dipping, or overturned west-dipping, strata were observed.

Most of the Belly River strata beneath the Whaleback fault dip westward in contrast with the east-dipping St. Mary River beds to the east. As displacement on the Rice Creek and Willow Creek faults is small or negligible in the southern part of Callum Creek map-area, this area between the Whaleback and Rice Creek faults represents the surface expression of a compound anticlinal structure within the Belly River strata. It will be referred to as the Whaleback anticline.

Belly River strata form a long west flank to the Whaleback anticline, as is indicated by the log of the Marjon Lundbreck No. 1 well (*See* page 64 and Structure-section C-D, Map 982A). Belly River strata were encountered beneath the Whaleback fault below a depth of 5,920 feet. The east flank of the structure contains contorted Bearpaw strata and east-dipping St. Mary River beds, as far east as the Bridge fault.

The Whaleback anticline plunges south into the northern part of Cowley map-area (Hage, 1943), where the Bearpaw and St. Mary River formations swing westward on south-plunging minor folds. A north plunge is indicated by the narrowing of the belt of Belly River strata between the Whaleback and Rice Creek faults in the northern part of Callum Creek and southern part of Langford Creek map-areas, and by the north plunge of the minor structures within it, as in tp. 11, rge. 2, Callum Creek map-area.

The Whaleback anticline, like the Rice Creek anticline, lies between the Rice Creek fault on its east flank and the Whaleback fault on its west flank. Although occupying similar structural positions, these two anticlines are separated by a syncline and fault in the area between Langford and South Willow Creeks, and whereas the Rice Creek anticline is a shallow structure underlain by the folded Rice Creek fault, the Whaleback anticline is believed to persist at depth.

WATSON STRUCTURES

The Watson fault extends through the Callum Creek and Langford Creek map-areas, thrusting Wapiabi strata over Belly River beds. It continues southward within the Belly River formation to south of Crowsnest River, in the adjoining Cowley map-area, and northward, west of the northwest corner of the Langford Creek area into the Pekisko Creek map-area (Hume, 1940b), where it bifurcates twice, the eastern branches dying out.

Near the southern border of Callum Creek map-area (*See* Figure 8 and Plate III B), the structures in the Belly River strata above the thrust plane are those of a shallow syncline (Watson syncline) bordering the Watson fault, and an anticline (Watson anticline) faulted along its crest.

Both structures plunge south. The anticline extends southward into the adjoining Cowley map-area, with a narrow belt of Wapiabi marking its crest, where it is termed the Lundbreck anticline (Hage, 1943).

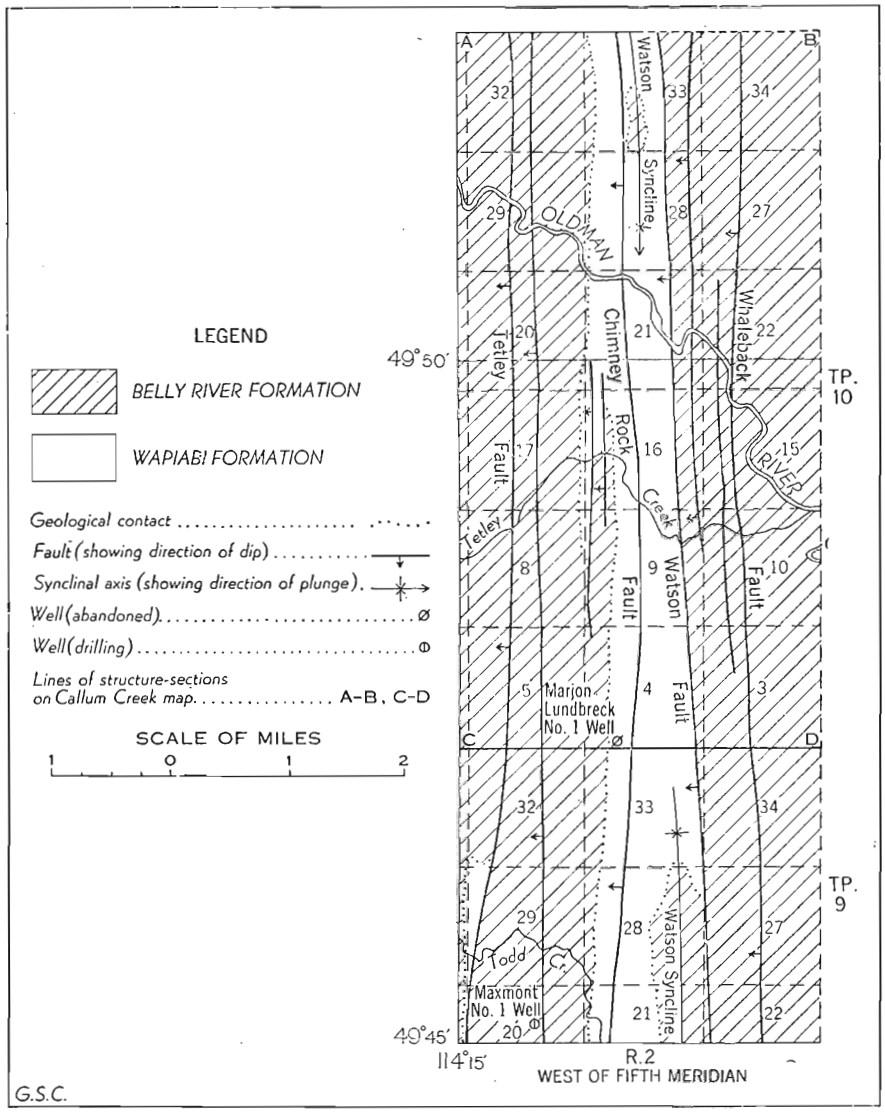


Figure 8. Sketch map of structures of southwest Callum Creek map-area.

North of Oldman River, in sec. 33, tp. 10, rge. 2, basal Belly River beds of the Watson syncline are tightly folded and plunge south. The Belly River beds of the west flank of the Watson anticline swing west, where they are cut out against the Tetley and associated faults.

In southwest Langford Creek map-area (Figure 9), west of the Watson fault, basal Belly River strata form a syncline (Chimney Rock syncline) and an anticline (Chimney Rock anticline). The west limb of the anticline is dragged into a syncline beneath a fault (Chimney Rock fault) that thrusts Blairmore strata (west of the map-area) over Belly River and Wapiabi beds. This fault cuts through the extreme southwest corner into Callum Creek map-area, where Blackstone and Bighorn beds are thrust over Wapiabi, passing into the crestal region of the Watson anticline, indicating that the crest of this anticline diverges westward from the Watson thrust. The Watson syncline plunges north to connect with the syncline below the Chimney Rock fault west of the Chimney Rock anticline.

A similar divergence of structures above the Watson thrust is shown by the Chimney Rock anticline and syncline (*See* Figure 9). The syncline plunges north to connect with the Belly River beds of a thrust slice in sec. 29, tp. 13, rge. 2, along the west border of Langford Creek map-area. The Belly River beds are in part folded into a syncline, and are bounded on the west by a fault that rises out of the Chimney Rock anticline.

This divergence of structures above the Watson fault is in marked contrast with the parallelism of the fault with the structures beneath it. It may signify that the Watson fault is a major thrust, with increasing displacement at depth.

The log of the Marjon Lundbreck No. 1 well in southern Callum Creek map-area (*See* Structure-section C-D, Map 982A) furnishes additional information on the Chimney Rock, Watson, and Whaleback faults:

Depth	Formation
Feet	
0–510	Wapiabi
510–820	Bighorn
820–	(fault)
820–1,920	Wapiabi
1,920–2,360	Bighorn (minor fault 2,110)
2,360–2,840	Blackstone
2,840–2,870	Blairmore
2,870–	(fault)
2,870–2,990	Blackstone
2,990–5,080	Blairmore
5,080–	(fault)
5,080–5,230	Blackstone
5,230–5,490	Blairmore
5,490–	(fault)
5,490–5,920	Alberta (Blackstone?)
5,920–	(fault)
5,920–6,204	Belly River

The Bighorn formation was encountered twice, at widely separated intervals, indicating a fault. This may be the Chimney Rock fault, which would then extend south through the contorted and faulted Wapiabi strata exposed on Oldman River, in sec. 21, tp. 10, rge. 2, coinciding with the axial region of the Watson anticline as previously mentioned. Other minor faults occur within the Alberta and Blairmore groups as shown on the accompanying structure-section.

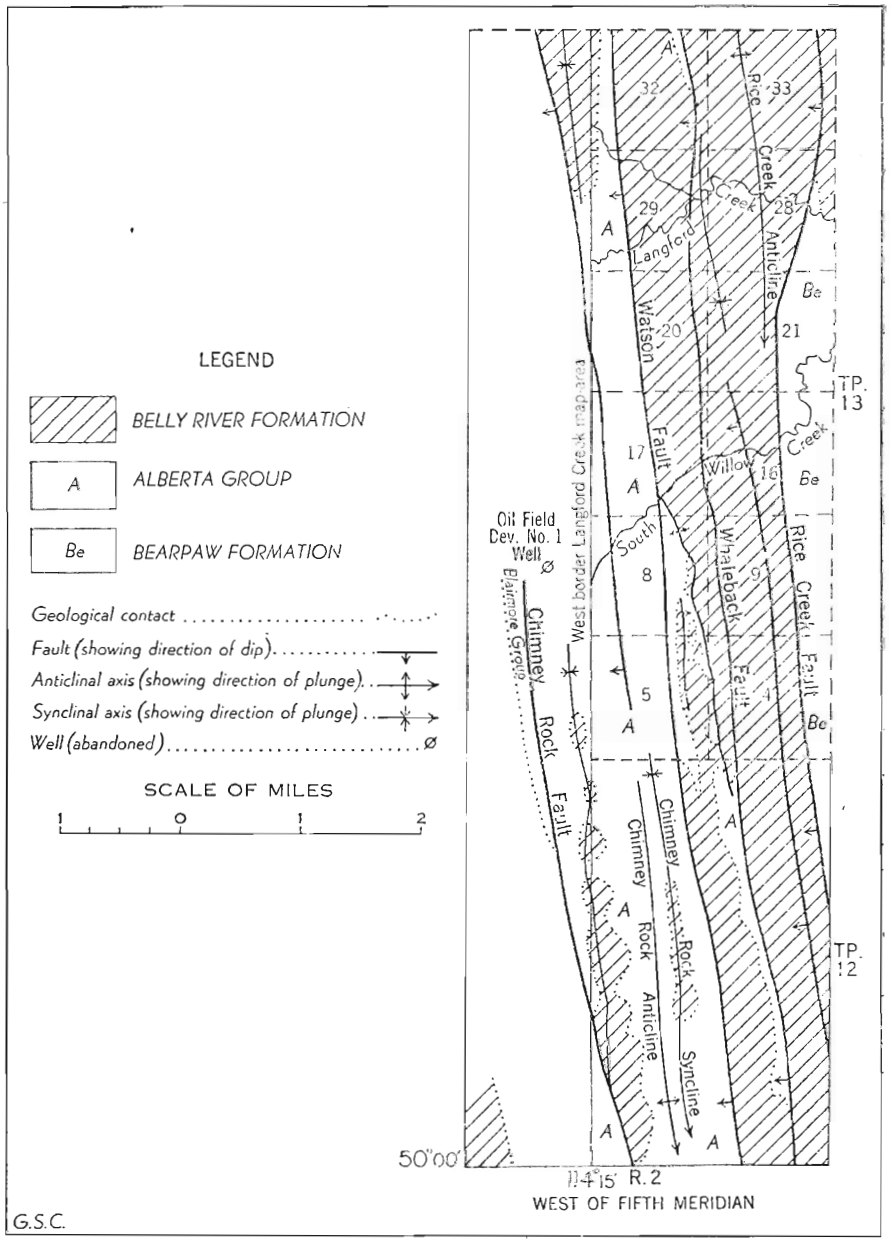


Figure 9. Sketch map of structures of southwest Langford Creek map-area and adjacent area.

At a depth of 5,080 feet, after drilling 2,090 feet of Blairmore strata, a fault was encountered that is believed to be the Watson fault. A fault at a depth of 5,490 feet repeating Blairmore and Alberta (Blackstone?) strata was next encountered, and may be a continuation at depth of one of the minor faults between the Watson and Whaleback faults. At 5,920 feet, the drill passed from Blackstone (?) strata into Belly River beds, indicating the presence of a second major fault, the Whaleback fault.

If the faults encountered at depths of 5,080 and 5,920 feet in the Marjon Lundbreck No. 1 well are the Watson and Whaleback faults, a relatively low angle of dip of their surfaces is indicated, about 55 degrees and 45 degrees, respectively, assuming a plane fault surface, or less at depth, as the faults steepen towards the surface (*See* Structure-section C-D, Map 982A). The Whaleback and Watson faults converge, and probably join at greater depth.

A decrease northward in the dip of the Watson fault is suggested by the divergence of the structures above it; by the change of dip of the subsidiary fault to the east; and by the change to low dips in the Belly River strata of the Whaleback thrust slice. One is scarcely prepared, however, for the amount of decrease in dip that is indicated by the Oilfield Development No. 1 well, in l.s. 7, sec. 7, tp. 13, rge. 2, about one-third mile west of the point where South Willow Creek leaves the west border of Langford Creek map-area. In this well, a fault, encountered at a depth of 2,480 feet, thrust Bighorn (Cardium) beds over Belly River strata. In the southwestern part of Langford Creek map-area it appears that these Belly River strata can only belong to the Whaleback thrust slice or to the slice to the east of it (*See* Figure 9 and Map 981A). If the former is the case, then the fault at 2,480 feet is the Watson fault, and its dip would be about 26 degrees, assuming a plane fault surface. At the surface, however, the Watson fault appears to have a dip in excess of 40 degrees, so that at depth the fault plane would be inclined at less than 26 degrees and may even be warped into gentle folds beneath the Chimney Rock anticline and syncline. If the Belly River strata encountered in the well belong to the thrust slice east of the Whaleback fault, then the Whaleback and Watson faults merge before passing through the Oilfield Development No. 1 well.

STRUCTURE OF THE TETLEY AND BOB CREEK FAULT SLICES

The Tetley fault extends along the western margin of Callum Creek map-area, crossing into the northeast corner of Gap map-area. Its northern extension is unknown, but it has been mapped to the south along the western margin of Cowley map-area (Hage, 1943).

Steeply west-dipping Belly River strata lie above the fault for most of its length. A tightly folded syncline lies below for part of its length, separated from the west flank of the Watson anticline by a minor fault (Figure 10). The east limb of this syncline was observed to be overturned to the west, in secs. 17 and 20, tp. 11, rge. 2. This westward overturning of the east limb of the syncline adjacent to the fault to the east is believed to have been produced by rotation along the fault, and indicates that this fault and the Tetley fault on the west flank of the syncline are very steeply inclined, and may even dip eastward in the vicinity of the beds that are overturned (*See* cross-sections, Figure 10).

The Bob Creek fault extends along the eastern margin of Gap map-area, parallel with the Tetley fault. Wapiabi strata appear above the fault only in the extreme south and in the north. The central region, entirely within the Belly River formation, is, therefore, structurally low. Steeply dipping strata lie above and below the fault, indicating a high angle of dip of the fault plane, at least near the surface.

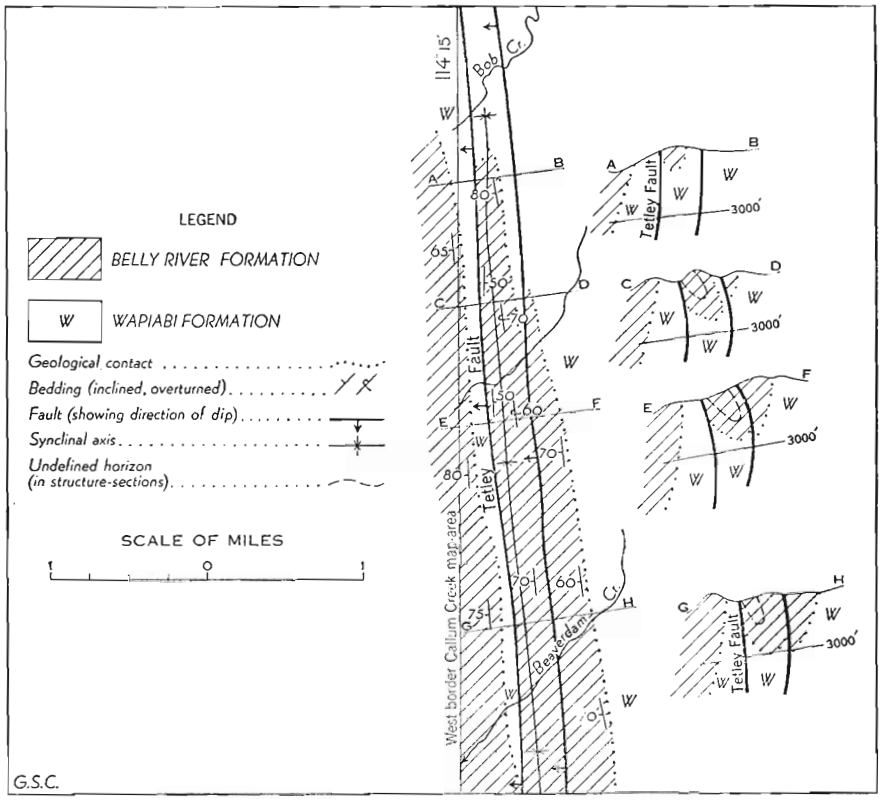


Figure 10. Sketch map and cross-sections of Tetley fault, Callum Creek map-area.

In the northern part of Gap map-area, Belly River strata between the Bob Creek fault and Livingstone thrust form a thick, steeply west-dipping thrust slice. In the southern part (*See* Figure 14) this thrust slice is bounded on the west by the Todd Creek fault. There, the Belly River strata are folded and broken by two small low-angle faults, the westernmost of which is the more continuous. Between the latter and the Todd Creek fault, the strata are folded into two anticlines and a syncline, the axes of which trend obliquely to the surface traces of the faults. A tight, overturned anticline lies between the western and eastern faults, and broadens southward. It is a major feature in the unmapped eastern part of Blairmore map-area to the south. The eastern fault ends in a syncline that borders this anticline on the east.

THE CENTRAL PART OF THE DISTURBED BELT

GENERAL STATEMENT

The Livingstone thrust plane underlies much of the central part of the Disturbed belt in Gap map-area (*See* Figure 4). The region between the Todd Creek fault and the Livingstone thrust in the southeastern part of the area is presumed to have been overlain by the Livingstone thrust slice and will be discussed in that connection. The eastern limit of the belt is bounded, accordingly, by the easternmost traces of the Livingstone and Todd Creek faults. The western boundary is marked by the western margin of the Palæozoic strata of the Livingstone Range.

The Livingstone thrust is a major fault of more than 4 miles lateral displacement, and has a stratigraphic throw of some 7,000 feet. Palæozoic strata are exposed above the thrust along Livingstone Range and in a small anticlinal inlier along Oldman River, a mile east of The Gap. Fernie, Kootenay, and Blairmore strata overlie the central part of the thrust, which outcrops as a bedding plane thrust between the Kootenay, or Fernie, and Belly River strata. This part of the thrust plane has been folded and now exhibits a sinuous surface trace.

The northward continuation of the Livingstone thrust may be represented by the Barwell Mountain and Dyson Mountain thrusts of Bragg Creek and Dyson Creek map-areas (Hage, 1946), which lie some 35 miles north of Gap map-area, or it may lie to the west of these thrusts.

Few wells have been drilled in the central part of the Disturbed belt. Quaich Globe No. 1 well, in l.s. 12, sec. 35, tp. 9, rge. 3, was temporarily suspended in August 1948. A new well, Quaich Globe No. 2, is being drilled at present in l.s. 4, sec. 35, tp. 9, rge. 3. Royal Sun No. 1 well, in l.s. 2, sec. 17, tp. 13, rge. 3, lies about 4 miles north of Gap map-area along the trend of the Livingstone Range.

STRUCTURE OF THE LIVINGSTONE RANGE

The structure of the part of the Livingstone Range within the limits of Gap map-area (*See* Figure 11) is simplest in the north, increasing in complexity southward. Where shown on White Creek, in sec. 8, tp. 12, rge. 3, the structure is that of a north-plunging, sharp, asymmetric anticline (Livingstone anticline), the west flank of which dips west at 75 degrees and the east flank at 60 degrees east (Figure 11, cross-section 1). Just south of White Creek, a steeply dipping thrust fault (Gap fault) first appears on the west flank of the Livingstone anticline (Figure 11, cross-section 2).

These structures remain essentially unchanged south to sec. 21, tp. 11, rge. 3, where a tear fault of small displacement offsets the strata of the east flank of the Livingstone anticline (Figure 11, between cross-sections 6 and 7) and ends eastward in Kootenay and Fernie beds. The north side is displaced westward relative to the south side. South of the tear fault the dip of the west flank of the Livingstone anticline decreases rapidly from 80 degrees near the crest to 35 degrees down the flank. This rapid change is coincident with several minor thrusts, which vary rapidly in dip from high to low angle as the dips of the beds change in a like manner (Figure 11, cross-sections 8 and 9). The tear fault and the minor thrusts

on the west flank of the Livingstone anticline are due essentially to adjustments of pressure as the main anticline changes from one with a steeper western flank to one with a steeper eastern flank.

The crest of the Livingstone anticline and the Gap fault cross to the east side of the crest of the Livingstone Range about 1 mile north of The Gap (*See* Figure 11, cross-section 10). The strata of the west flank of the anticline and above the fault decrease in dip, so that the whole west flank of the range dips evenly west. The dip of the fault plane accordingly is decreased, and the minor faults to the west disappear.

In The Gap, where the deep gorge of Oldman River crosses the Livingstone Range, relatively lower structural and stratigraphic levels are reached (Figure 11, cross-sections 12 to 14, and Plate IV). Banff strata, in part overturned to the east, are present in the core of the Livingstone anticline. They are also exposed above the Gap fault and in the core of an anticline (Gap anticline) below it. Between the Gap and Livingstone anticlines, lie a syncline (Gap syncline) and a fault (Thunder Mountain fault). This fault has formed on the east flank of the Gap syncline, or on the west flank of the Livingstone anticline.

The displacement along the Gap fault decreases southward, due partly to the formation of the structures between it and the Livingstone anticline, and partly because, with increased elevation, it merges with the crest of the Gap anticline. The Gap fault and anticline continue south as an unbroken anticline where strata of sufficiently high elevation are preserved, and as a faulted anticline where erosion has cut to lower levels. The Gap syncline to the east is asymmetric, with a steeper west flank. It extends through the peak of Thunder Mountain, but is cut off by the Thunder Mountain fault a short distance south (Figure 11, cross-sections 18 to 21). The Thunder Mountain fault rapidly increases displacement southward.

Beneath the Thunder Mountain fault the Livingstone anticline becomes increasingly overturned, approaching recumbency (20 degrees west) in sec. 21, tp. 10, rge. 2 (Figure 11, cross-sections 14 and 16). Farther south, the east flank is rapidly cut off by a fault that rises along the contact between the Rocky Mountain and Fernie (Figure 11, cross-sections 24 to 26) and continues southward at a low angle, gradually cutting across the strata of the west limb until it merges with the underlying main Livingstone thrust about 1½ miles above the south border of the area (Figure 11, cross-sections 27 to 30).

The Thunder Mountain and Gap faults almost merge in places, but continue southward independently, separated by a tightly folded syncline that is probably the continuation of the Gap syncline (Figure 11, cross-sections 24 to 26). Still farther south, the syncline gives way to an overturned anticline, probably the continuation of the Gap anticline. Few exposures are present between these two faults, but the anticline apparently plunges south with only the overturned east limb separating the Gap and Thunder Mountain faults in the extreme south of the range (Figure 11, cross-sections 27 to 31).

Above the Gap fault the main ridges of the Livingstone Range are underlain by west-dipping strata of the Banff, Rundle, and Rocky Mountain formations. The dips are steep adjacent to the Gap fault, but decrease somewhat toward the west where minor folds and thrusts appear.

On the east flank of the Livingstone Range, immediately north of the south boundary of Gap map-area, a tear fault is present (Figure 11, cross-section 32). Along the crest, Member C of the Rundle formation north of the tear fault lies in contact with Member A on the south side. Down the east flank, Members A and D on the north side are in contact with faulted members of the upper Rundle and Kootenay and Blairmore strata. The sequence of strata on the south side of the tear fault suggests a continuation of the thrusts that are present to the north, although the evidence is not conclusive.

LIVINGSTONE THRUST SHEET AND ASSOCIATED STRUCTURES

In the southern part of Gap map-area, Palæozoic strata lie directly in contact with and above the Livingstone thrust plane or are separated from it by a tightly folded syncline of Blairmore and Kootenay beds. The Kootenay strata of the east flank of this syncline do not outcrop, but from information gained in the central part of the Livingstone thrust this southern part, of which the eastern extension is now removed by erosion, was probably also overlain by the Kootenay formation. The fault plane dips west, probably at a moderate angle (*See* Structure section E-F, Map 978A).

Between the Livingstone anticline and thrust, in sec. 9, tp. 10, rge. 3, Blairmore, Kootenay, and Fernie strata are folded into tight, overturned anticlines and synclines. The Livingstone thrust dips west at a low angle beneath these structures, but steepens in the west beneath the Livingstone Range, as the strata of its west flank dip westward at about 60 degrees. In sec. 22, tp. 10, rge. 3, Kootenay and Fernie are thrust over Belly River of the west flank of the Ernst Creek syncline along the Livingstone thrust. The thrust plane dips west, but changes to an east dip to extend under the Kootenay and Fernie of the Camp Creek syncline, thereby separating it from the underlying Ernst Creek syncline of Belly River strata (Figure 12). On Oldman River, in sec. 26, tp. 10, rge. 3, the Livingstone thrust dips again westward between Kootenay and Belly River beds.

Blairmore and Kootenay strata continue to overlie Belly River beds as far east as sec. 36, tp. 10, rge. 3, forming the Camp Creek asymmetric anticline and the highly contorted Jacknife syncline (*See* Figure 12). The thrust rises above an elevation of 4,800 feet in the core of the Camp Creek anticline, as Belly River is exposed to that elevation. The thrust then changes to an east dip, underlying the basal Blairmore conglomerate of the axis of the Jacknife syncline, which is exposed at an elevation of 4,600 feet. Exposures of Belly River occur along a north-trending ridge a short distance to the east, dipping steeply westward. The Livingstone thrust consequently changes to a high-angle thrust, trending northward, and separates Blairmore strata from the west-dipping Belly River beds.

The surface trace of the eastern margin of the Livingstone thrust mass is remarkably straight as it is followed northward up the valley of Camp Creek. The Jacknife syncline diverges westward from the thrust trace. It is an asymmetric syncline, with a steep or overturned west flank, and plunges north, as indicated by the appearance of Blackstone strata overlying Blairmore beds along Jacknife Coulée, in sec. 35, tp. 11, rge. 2,

whereas Kootenay strata lie along the axis at its southernmost extremity. The Jacknife anticline (*See* Figure 12) lies between the Livingstone thrust and the Jacknife syncline. In the south, it is merely a drag adjacent to the thrust, but n ;hward it becomes much larger and involves a considerable thickness of strata. Steeply dipping Alberta strata, in places with a synclinal structure, form the east flank of the Jacknife anticline adjacent to the Livingstone thrust in the north.

Almost no evidence of faulting was observed in the Blairmore above the Livingstone thrust east of the Livingstone Range. The folds are small, tightly compressed, and overturned close to the Palæozoic formations, but are broader and more persistent farther east. Along the northeastern margin of the thrust, they are again more compressed.

On Oldman River, in secs. 2 and 3, tp. 11, rge. 3, a small anticlinal inlier projects above the surrounding Fernie black shales, and exposes Spray River, Rocky Mountain, and upper Rundle strata (*See* Figure 11, cross-section 12). Minor faults occur, but can scarcely be shown on the scale of the map. A *décollement*[1] at the top of the massive black limestones of Member C of the Rundle formation occurs at and slightly above river level. The strata of Member D have been folded into an overturned anticline, the east flank of which dips 80 degrees west whereas the underlying strata of Member C are not folded but dip only to the west at low angles. The fault underlies Oldman River for most of its length, but is exposed on the north and east banks. Just east of the anticline thin-bedded sandstones near the base of the Fernie group have been thrown into several complex and recumbent folds, too small to be shown on the map.

Along the southern trace of the Livingstone thrust, the Palæozoic strata of the above-mentioned anticline are missing. The Palæozoic strata probably do not extend above the thrust farther south than where the east flank of the Livingstone anticline is strongly overturned (*See* Figure 11, cross-sections 12 to 16). Farther south along the Livingstone Range, the Livingstone anticline is the easternmost structure in the Palæozoic rocks above the Livingstone thrust.

Northward, above the thrust, no strata older than Fernie are exposed. However, the eastern limit of the Palæozoic strata above the Livingstone thrust and beneath the overlying Mesozoic cover can be reasonably inferred. Within the overthrust mass of the Livingstone thrust slice, the degree to which the anticlinal structures within the Fernie, Kootenay, and basal Blairmore beds have been compressed depends on the presence or absence of relatively competent formations in their cores. The anticlines are open where they contain a core of Palæozoic rocks above the thrust plane, or where, as a result of folding of the thrust plane, competent Belly River strata are introduced below the thrust plane into the core. On the other hand, where the above conditions are not encountered, the Fernie, Kootenay, and basal Blairmore strata are thrown into tightly squeezed anticlines. It should be noted that where the beds above the thrust have been folded synclinally, the thickness and competency of the Blairmore strata produce broad, open synclines even where no Palæozoic strata are involved, as for example in the southern part of the Camp Creek syncline.

[1] *Décollement* is a French word meaning literally, "unglueing". In a geological sense, the term is applied to the independent disruption by folding or faulting of sedimentary beds by sliding over the underlying rocks.

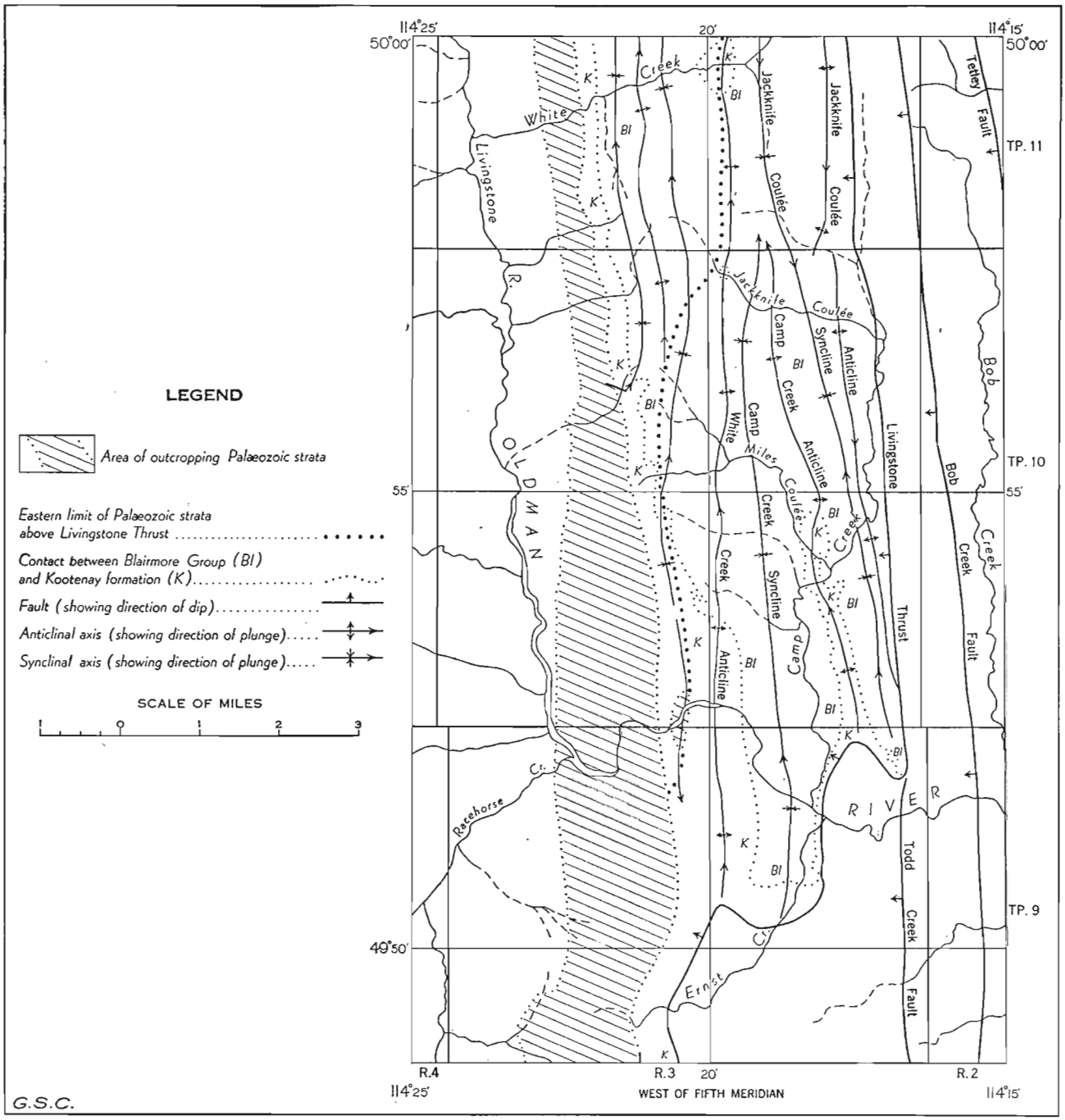


Figure 12. Sketch map of structures of northeast Gap map-area.

Applying this principle to the White Creek anticline, along which Palæozoic rocks are exposed some 4 miles north of Gap map-area (*See* Figure 1, and Calgary sheet, Map 204A, Geological Survey of Canada), we find that in its southern part, in sec. 34, tp. 11, rge. 3, where basal Blairmore and Kootenay beds form the crest, the fold is so tight that both limbs dip 60 degrees west. Here, Palæozoic rocks may be assumed to be missing above the Livingstone thrust plane. Farther north, on White Creek, in sec. 15, tp. 12, rge. 3, where Fernie strata form the core, the anticline is more open. It is asymmetric, sharply crested, and has a vertical eastern limb. Neither the Fernie beds in the core nor the higher strata of the east limb are contorted: the inference is justified, therefore, that resistant Palæozoic beds are present below the surface, above the Livingstone thrust plane. Less than 5 miles still farther north the Palæozoic rocks reach the surface.

An examination of Map No. 978A and Figure 12 will show that the surface trace of the axial plane of the White Creek anticline is very linear along that part of the anticline presumed to contain Palæozoic strata in its core, but is irregular and variable where they are believed to be absent.

This eastward extension of Palæozoic formations above the Livingstone thrust is also coincident, in the Livingstone Range, with a tear fault and with a change in the Livingstone anticline from a steeper east flank, south of the tear fault, to a steeper west flank north of it. The north side of the tear fault is displaced westward relative to the south side (*See* page 68). These features seem to have resulted from the greater resistance to eastward movement offered by the larger mass of Palæozoic strata lying east of the Livingstone anticline north of the tear fault than that to the south of it (compare Structure-sections A-B and C-D, Map No. 978A). This relative westward-directed stress is also reflected in the east-dipping thrust fault along the axis of the syncline that borders the Livingstone anticline at the junction of White Creek and Livingstone River (*See* page 78).

In summary, the eastern limit of the Palæozoic strata above the Livingstone thrust beneath the overlying Mesozoic cover (*See* Figure 12) extends from the east flank of the Livingstone anticline, in sec. 21, tp. 10, rge. 2, north to the east flank of the Palæozoic inlier on Oldman River, in sec. 2, tp. 11, rge. 3. From there it extends north beneath highly contorted Blairmore, Kootenay, and Fernie strata adjacent to the east flank of the Livingstone Range, which form, in essence, a major syncline and anticline. It crosses the syncline to the east into the core of the White Creek anticline north of the tear fault in the Livingstone anticline and north of the squeezed anticlinal core in sec. 34, tp. 11, rge. 3.

The Camp Creek anticline illustrates the difference between the simple, open type of fold that is found where folding of the thrust plane has incorporated Belly River strata into the core of an anticline, and the tight folds that appear where the thrust plane is not folded. The former condition is in evidence in the southern part of the Camp Creek anticline, in sec. 36, tp. 10, rge. 3, and in Structure-section C-D of Map No. 978A (*See* also Figure 13, cross-section C-D). The structures of sec. 11, tp. 11, rge. 3, where Camp Creek crosses the anticline 3 miles farther north, present a striking contrast. There, some of the strata of the east flank of the Camp Creek anticline have been overturned twice so that they again dip

eastward (Figure 13, cross-section A-B). It is apparent that the fault plane and the underlying strata cannot be incorporated into the core of the Camp Creek anticline in the overlying strata to the degree observed in its southern part. About 4 miles still farther north the Camp Creek

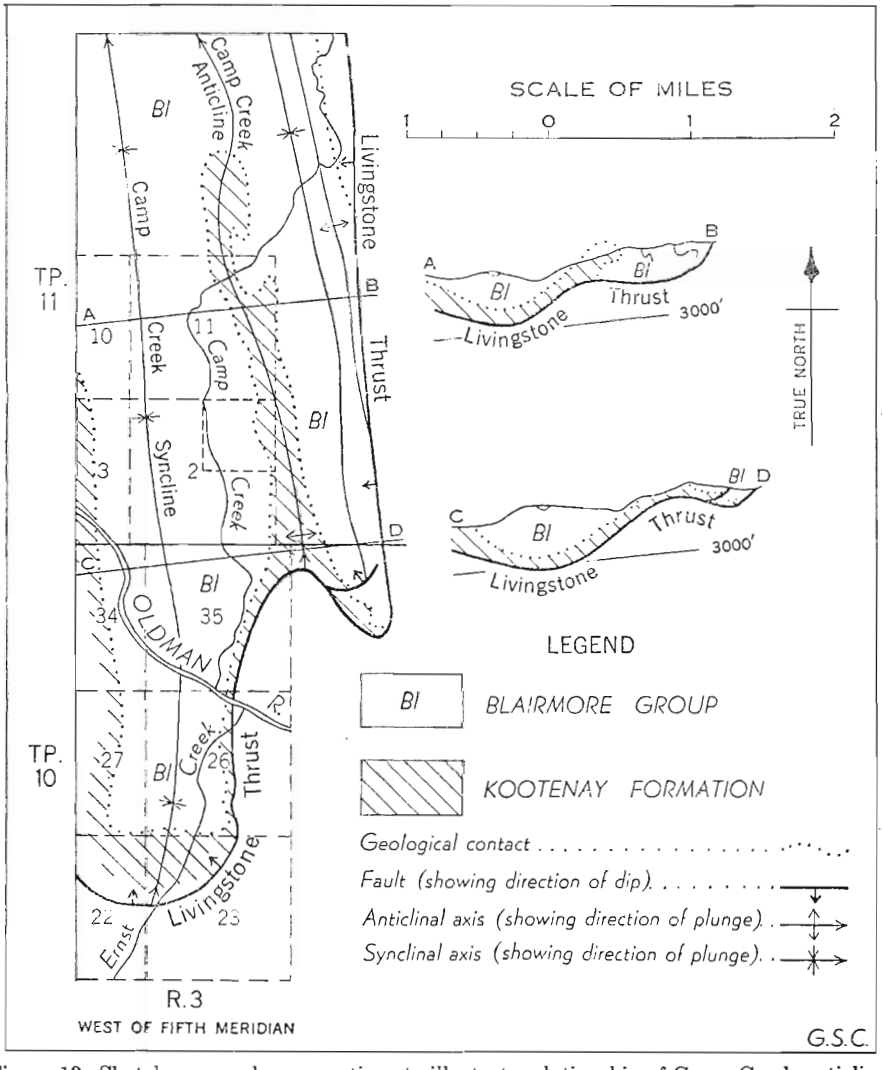


Figure 13. Sketch map and cross-sections to illustrate relationship of Camp Creek anticline to Livingstone thrust, Gap map-area.

anticline ends and, accordingly, the anticlinal fold in the Livingstone thrust plane and that in the underlying strata also die out. Other folds, the Jacknife syncline and anticline to the east of the Camp Creek structures and the White Creek anticline to the west of them, increase in magnitude

as the amount of folding in the Camp Creek structures decreases. The Livingstone thrust is presumed to be folded beneath them (*See* Structure-section A-B, Map 978A).

It appears to the writer that the folds in the Livingstone thrust plane and in the overlying strata are initiated by folding of the underlying beds. Where these beds are markedly folded, the thrust plane and overlying strata are also folded; where folding in the underlying beds decreases in intensity, it is accompanied by a flattening of the fold in the thrust plane and by crumpling of the core of the overlying anticline.

STRUCTURES BELOW THE LIVINGSTONE THRUST

The structures of the Belly River strata that directly underlie the central part of the Livingstone thrust in Gap map-area may be observed less than 1 mile south of it along Oldman River and in the hills still farther south. These observed structures have been projected beneath the overlying thrust in Structure-section C-D of Map 978A. The Belly River strata have been more intensely folded in the east and have also been intersected by faults that do not cut the Livingstone thrust or the strata above it (*See* Structure-section C-D, Map 978A). The Livingstone thrust plane has been folded to about the same degree as the strata above it, but only the central, synclinal part of the underlying beds (Ernst Creek syncline) has undergone a similar degree of deformation. The Belly River to the east of the Ernst Creek syncline and the Alberta strata to the west of it have been strongly deformed.

The major structures of the Belly River strata beneath the Livingstone thrust may be revealed by observing the surface distribution of the Wapiabi formation and the attitude of the exposed basal Belly River beds (*See* Map 978A and Figure 14). The Ernst Creek syncline is a broad, open structure, plunging north. To the east lie a faulted anticline and a highly faulted syncline, the east flank of the latter adjoining the Todd Creek fault. The anticline and syncline coincide, in a general way, with the axes of the Camp Creek anticline and Jacknife syncline above the Livingstone thrust plane. The relationship is less apparent close to the thrust due to the contortion and convergence of the structures. Basal Belly River beds of the west flank of the syncline are repeated by two east-dipping faults of small displacement. The anticline and syncline plunge northward, so that Wapiabi strata appear in the south.

The southward continuation of the Ernst Creek syncline within Wapiabi strata cannot be defined owing to lack of exposures. An anticline in Blairmore strata, in sec. 25, tp. 9, rge. 3, Gap map-area (*See* Figure 14) plunges northward and is faulted along its east flank. This anticline probably lies structurally west of the Ernst Creek syncline. A sharply folded syncline in the Bighorn formation outcrops a short distance west of the anticline. West-dipping Bighorn strata are also exposed directly below the Livingstone thrust at the south border of Gap map-area and 1½ miles north of it. Only highly contorted and sheared Blackstone strata outcrop between these exposures of the Bighorn formation. The structure is probably that of a major anticline such as shown on Map 978A and Structure-section E-F, but as the Blackstone formation is very

thin (about 450 feet) in this area, the strata must be closely folded and possibly broken by faults of small displacement in order to underlie such a wide area.

These structures between the Todd Creek fault and the Livingstone thrust form together a north-plunging, compound anticline, which will be referred to as the Quaich structure, the name being taken from that of the company at present engaged in drilling operations in the area. Strata of the Alberta group, in part with low dips, underlie much of the area across a width of about 3 miles. If no faults underlie the Quaich structure, the top of the Rundle formation would be expected at the shallow depth of about 3,000 feet in the vicinity of the Quaich Globe wells. There are, however, at least two low-angle thrust faults, the Todd Creek fault and the faulted anticline west of it, which lie along the eastern part of the structure and which are expected to have considerable stratigraphic throw at depth. The Todd Creek fault, at the surface, dips westward at about 28 degrees; the fault to the west probably dips at about the same or a lower angle (*See* Structure-section E-F, Map 978A). The total stratigraphic repetition on both these faults is probably about 5,000 feet, so that the top of the Rundle formation, in the vicinity of the Quaich Globe wells, lies at about 8,000 ± feet drilling depth. Other faults, lying east of the Todd Creek fault, are believed to dip west at high angles and are not expected to underlie the Quaich structure directly.

The structure of the strata beneath the Livingstone thrust plane in the northern part of Gap map-area cannot be determined except in a general way by assuming that the structures below the thrust coincide to some extent with those observed above it. Some information is available on the distribution of the formations below the thrust. In Gap map-area, Alberta strata underlie the southern part of the thrust, and Belly River beds lie beneath the central and northern parts; the contact between them passes beneath the thrust plane in sec. 22, tp. 10, rge. 2. Some 36 miles to the north, in Pekisko Creek map-area (*See* Figure 1), the contact reappears beneath what is probably the northern extension of the Livingstone thrust. The Royal Sun No. 1 well, in l.s. 2, sec. 17, tp. 13, rge. 3, about 5 miles north of Gap map-area in the northern extension of the Livingstone Range (*See* well 2, Figure 1), encountered the Livingstone thrust at a depth of 2,431 feet, the drill passing from Rundle? limestones and dolomites into green shales and sandstones, probably of the Belly River formation. In the Anglo Canadian, Savanna Creek No. 1 well (*See* well 1, Figure 1), Wapiabi (Upper Alberta) strata were encountered beneath the Livingstone thrust.

THE WESTERN PART OF THE DISTURBED BELT

GENERAL STATEMENT

The western part of the Disturbed belt is herein considered to include the region between the Palæozoic rocks of the Livingstone Range, to the east, and the High Rock Range of the Rocky Mountains to the west (*See* Figure 1). Although the western border of Gap map-area lies about midway within this belt, all but one of the major structural features fall within it. The exception is a thrust fault that extends for more than 70 miles along the strike of the belt and lies only a short distance west

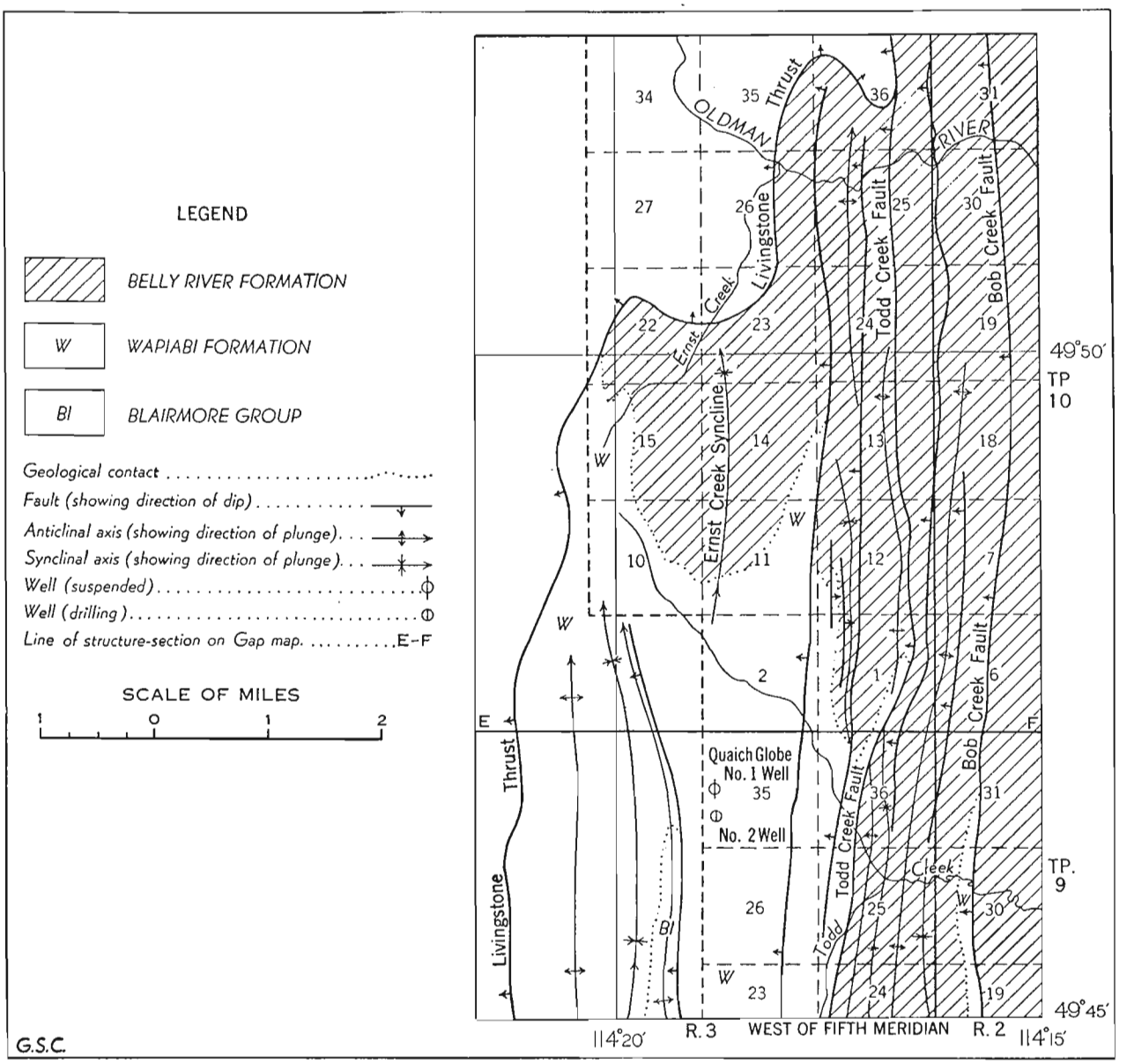


Figure 14. Sketch map of structures of southeast Gap map-area.

of the Gap area. This thrust passes through the town of Coleman on Crowsnest River (*See* Figure 1) and will be referred to as the Coleman fault.

The intensity of deformation decreases generally from east to west across the belt. Between Livingstone Range and the Fly Hill fault (*See* Map 978A and Structure-section C-D) the strata are closely folded and repeated by a few faults. Between the Fly Hill and Coleman faults, Kootenay, Blairmore, Alberta, and Belly River strata form a west-dipping slice, in part slightly folded and faulted. Above the Coleman fault, a second, similar succession of strata dips west at low angles. The Belly River beds of this slice are overlain by Palæozoic strata of the High Rock Range of the Rocky Mountains thrust eastward along the northern extension of the Lewis thrust.

No wells have been drilled in the western part of the Disturbed belt in Gap map-area. However, the Anglo Canadian, Savanna Creek No. 1 well, which lies some 13 miles north and 1 mile west of the northwest corner of the area in l.s. 5, sec. 20, tp. 14, rge. 5, furnishes valuable information on the general structure and extent of the Livingstone thrust.

MAJOR STRUCTURES

The major structural features of the western part of the Disturbed belt cannot be easily determined from Gap map-area alone, but are best observed in adjoining regions (*See* Figure 1; also Calgary sheet, Map 204A, Geological Survey of Canada).

Within the western part of the Disturbed belt, that is between the Livingstone and High Rock Ranges, Palæozoic strata are exposed in two uplifted areas, the Blairmore Range south of Gap map-area and the southern part of the Highwood Range to the north of it. The structure of the Blairmore Range is that of a sharply folded anticline, faulted along its east flank (Rose, 1920). The southern part of the Highwood Range is a broad, flat-topped anticline in Palæozoic rocks, which is separated from the Livingstone Range by a broad synclinal structure underlain mainly by Mesozoic strata (*See* Upper Elk and Upper Highwood Rivers, Geol. Surv., Canada, Map 1980, 1924).

The Blairmore and Highwood Ranges are joined by an anticlinal structure within Palæozoic rocks beneath the Fly Hill fault in Gap map-area (*See* Figure 1 for surface trace of this fault and the structure-sections of Map 978A for relationship of Palæozoic strata to it). The anticline within Palæozoic strata will be referred to as the Fly Hill anticline. Within the overlying strata this anticline is not everywhere marked by a single crest. In the southern part of Gap map-area, the crest lies between the Fly Hill fault and the syncline of Crowsnest and Blackstone strata (*See* Structure-section E-F, Map 978A). In the central and northern parts of the area, the crest lies between the Fly Hill fault on the west and the Station Creek fault on the east (*See* Structure-sections A-B and C-D, Map 978A). Displacement on both the Fly Hill and Station Creek faults is greatest in the northern part of the area.

The strata beneath the Fly Hill fault dip westward, forming the west flank of the Fly Hill anticline within Blairmore strata. On Oldman River, in sec. 35, tp. 11, rge. 4, Kootenay strata above the fault and Blairmore

below it dip west at 45 degrees, indicating a west dip for the fault plane of not less than 45 degrees. At higher elevations on the ridge to the north of Oldman River, the strata above and below the fault are found to have decreased in dip to about 20 degrees. As the thrust plane lies essentially parallel with bedding planes in the Kootenay formation, its dip must, accordingly, have decreased from 45 degrees in the valley to 20 degrees at 2,000 feet higher elevation. The dips of the Blairmore strata beneath the fault plane decrease as the crest of the Fly Hill anticline is approached. These observations suggest that displacement had occurred along the Fly Hill fault prior to the completion of folding of the strata of the Fly Hill anticline, so that the continued folding of the strata of the west flank of the anticline was accompanied by the warping of the thrust plane and the strata above it.

A similar relationship was observed on the south end of Fly Hill in sec. 23, tp. 9, rge. 4, but here, and still farther south, the dip of the thrust plane cannot be determined as closely as on Oldman River.

The Anglo Canadian, Savanna Creek No. 1 well penetrated what may be the western extension of the Livingstone thrust. This well lies 13 miles north and 1 mile west of Gap map-area, about on the crest of the broad anticline that underlies the southern extension of the Highwood Range (*See* Figure 1). As mentioned above, this uplifted area lies in the continuation of the Fly Hill anticline.

The Savanna Creek well was commenced in Devonian rocks (Hume, 1941), and penetrated a fault at a depth of 110 feet, below which Wapiabi strata were encountered. The top of the Blairmore was reached at 1,210 feet and the well continued in this group to a depth of 3,370 feet where it was abandoned. Hume (1941) correlates the fault at 110 feet depth with the one underlying Sentinel Mountain in the southwest corner of Pekisko Creek map-area (Hume, 1940b). This latter fault thrusts Rundle strata over Blairmore and Kootenay beds. If this is the same thrust that was encountered in the Savanna Creek well, it has cut into higher stratigraphic levels between its surface trace beneath Sentinel Mountain and the Savanna Creek well. Although this is possible, it is more probable that the surface trace of the thrust encountered in the well is the northern extension of the Livingstone thrust, which lies about 4 miles east of Sentinel Mountain and thrusts Blairmore and Alberta strata over Belly River (*See* Hume, 1940b). The thrust would then cut into lower stratigraphic levels, that is, from the Belly River formation into the Wapiabi formation on passing from the surface trace to the Savanna Creek well. The thrust that underlies Sentinel Mountain would, in that case, be a subsidiary thrust above the main, underlying, Livingstone thrust.

In Gap map-area, a horizontal displacement of only 3 to 4 miles is seen along the Livingstone thrust, but if the fault encountered in the Savanna Creek well is the Livingstone thrust, then lateral displacement along it is perhaps 6 to 8 miles or greater, and the fault plane may be inferred to extend westward at a shallow depth beneath the structures west of the Livingstone Range in Gap map-area, at least as far west as the Fly Hill anticline.

MINOR STRUCTURES

An east-dipping thrust fault is exposed along Livingstone River near its junction with White Creek. This fault lies in Blairmore strata, close to the axis of the syncline that borders the Livingstone anticline of Palæozoic rocks. Where the east-dipping thrust is present, the axial plane of the Livingstone anticline is inclined to the west.

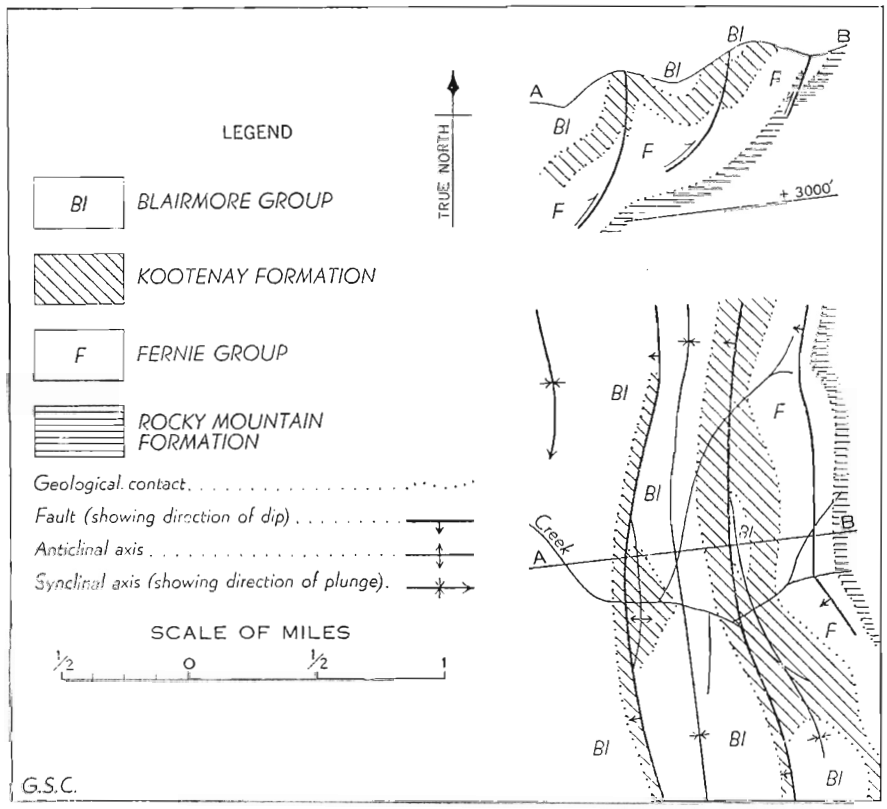


Figure 15. Sketch map and cross-section of some minor structures in NW. ¼, tp. 9, rge. 3, Gap map-area.

An interesting relationship between faulting and associated folding is clearly shown in the northwest part of tp. 9, rge. 3, along a creek flowing west from the Livingstone Range into Daisy Creek about 1½ miles north of the south border of Gap map-area (Figure 15). High-angle thrust faults repeat the strata of the west flank of the anticline and east flank of the syncline, whereas the east flank of the anticline is unbroken. These structures illustrate on a small scale a general characteristic of faulting in this region; that many of the thrust faults originate on the western limbs of anticlines or eastern limbs of synclines rather than on the 'middle' limb between them.

CHAPTER V

MECHANICS AND REGIONAL RELATIONS

ZONES OF BEDDING-PLANE SLIPPAGE

Many contrasts in lithology feature the stratigraphic succession of Mississippian to Tertiary rocks in Callum Creek, Langford Creek, and Gap map-areas. The most important of these, from the structural point of view, are the zones of weak rocks lying between stronger strata. The weak rocks show a tendency, under deformation, to localize faults parallel with their bedding planes, so that the overlying rocks are moved over those beneath for great horizontal distances. The stronger strata, on the other hand, are commonly intersected diagonally by the faults. Once the initial fault plane is formed, the zones of weak rocks serve as lubricants to decrease the frictional resistance to movement along the fault plane.

Of the weak rocks, coal seams and fissile, marine black shales are the most effective. Coal seams are found abundantly in the Kootenay formation, and the fissile black shales of the Fernie group lie in close association below. These strata, about 1,000 feet thick, constitute what is probably the most important zone of bedding-plane slippage in the region. Coal seams are also present in the upper part of the Belly River formation, overlain by the marine shales of the Bearpaw formation. Apparently more bedding-plane slippage took place along the coal seams of the Belly River formation than along the shales of the Bearpaw formation, as rocks of the latter and younger formations are found only along the eastern margin of the Disturbed belt. The black shales of the basal Banff and Exshaw formations, although not exposed in this region, are thin, but probably form a zone of bedding-plane slippage within the thick succession of massive limestones and dolomites of Devonian and Mississippian age. Within the map-areas under consideration, the thick marine shales of the Alberta group show little evidence of major thrusts paralleling their bedding planes, although the group as a whole is commonly broken by many minor slippages.

The remaining formations are relatively strong. Strata of the Bearpaw and younger formations outcrop only in the little disturbed eastern parts of Langford Creek and Callum Creek map-areas, so that their structural behaviour in the more intensely deformed region to the west could not be studied. Although the Rundle formation is composed mainly of competent strata, it includes two zones that are relatively weaker. These are Member D, with green and red shales, and Member B, which consists of thin-bedded platy dolomites. Many of the faults that cut the overlying formations end at depth in these two members of the Rundle.

As the oldest Palæozoic rocks exposed in the three map-areas are those of the Banff formation, it is necessary to refer to the information available in adjoining or nearby areas to learn what zones within older Palæozoic strata may have facilitated fault movements. As herein interpreted the log of the Anglo Canadian, Savanna Creek No. 1 well indicates

that the Livingstone thrust may have followed close to the Exshaw shales for a considerable distance. The Lewis thrust beneath the High Rock Range of the Rocky Mountains follows close to the base of the Banff formation for part of its length, but has not been studied in detail. In Moose Mountain (Beach, 1940) and Dyson Creek (Hage, 1946) map-areas, a major thrust lies within the upper part of the Palliser formation of Devonian age, close to the overlying Exshaw formation. Evidence available at this time indicates a tendency to localization of large-scale bedding plane thrusts within the zone of weak rocks comprising the uppermost Devonian strata, the Exshaw formation, and the basal part of the Banff formation. For simplicity, this zone will be referred to as the Exshaw zone of bedding-plane slippage, but it should be borne in mind that additional information is needed on the structural relationship of major thrust faults to these strata.

Still less information is available on lower zones of bedding-plane slippage owing to the scarcity of outcrop of strata older than Devonian in the Foothills of Alberta. Hake, Willis, and Addison (1942) believe there is a regional *décollement* at the base of the Devonian system in the central Foothills, as rocks older than Devonian are unknown in the numerous Palæozoic ranges of that region. However, in the southern Foothills, in Moose Mountain map-area (Beach, 1940) Cambrian strata lie beneath Devonian formation above a major thrust. In the Clark Range of southwestern Alberta, a great thickness of Late Precambrian (Beltian) rocks overlies the low-angle Lewis thrust. There, in Beaver Mines map-area (Hage, 1940), the Lewis thrust lies between the argillites of the Siyeh formation of Precambrian age and the Upper Cretaceous Belly River formation.

Three major zones of bedding-plane slippage have, therefore, played important parts in the deformation of the rocks in Callum Creek, Langford Creek, and Gap map-areas. Examples of slippage along the upper, Belly River zone are found in the Livingstone and Lewis thrusts; slippage along the Kootenay-Fernie zone is well exemplified by the Livingstone, Fly Hill, and Coleman thrusts; and, although not strictly within these map-areas, the Livingstone thrust, as shown by the Savanna Creek well, and the Lewis thrust in the vicinity of Dutch Creek, may be used as illustrations of slippage along the Exshaw zone.

MECHANICS OF BEDDING-PLANE THRUSTS

The nature of large bedding-plane thrust sheets, such as the Livingstone thrust sheet, can best be judged by a comparison with one that has undergone little subsequent deformation. The Cumberland thrust block, on the outer edge of the southern Appalachian Mountains in the eastern United States, furnishes a carefully studied and analysed example.

The Cumberland thrust block consists of a rectangular mass 125 miles long and 25 to 30 miles wide (Rich, 1934; *See* his bibliography for references not here repeated). The thrust sheet is bounded on the northeast and southwest by tear faults. It has been moved northwestward along a fault plane that is believed to follow the stratigraphic horizon of, first the Cambrian Conasauga shale, then that of the Chattanooga black shale (Upper Devonian and Lower Mississippian age) for much of its length.

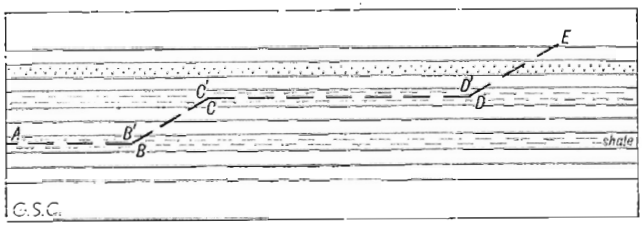


Figure 16. Diagram representing course of incipient thrust plane (A-E) in a series of sedimentary rocks. After Rich.

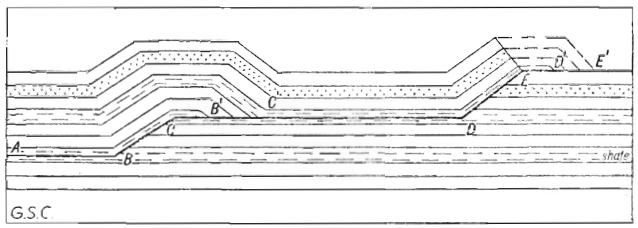


Figure 17. Result of small displacement on fault plane such as shown in Figure 16. After Rich.

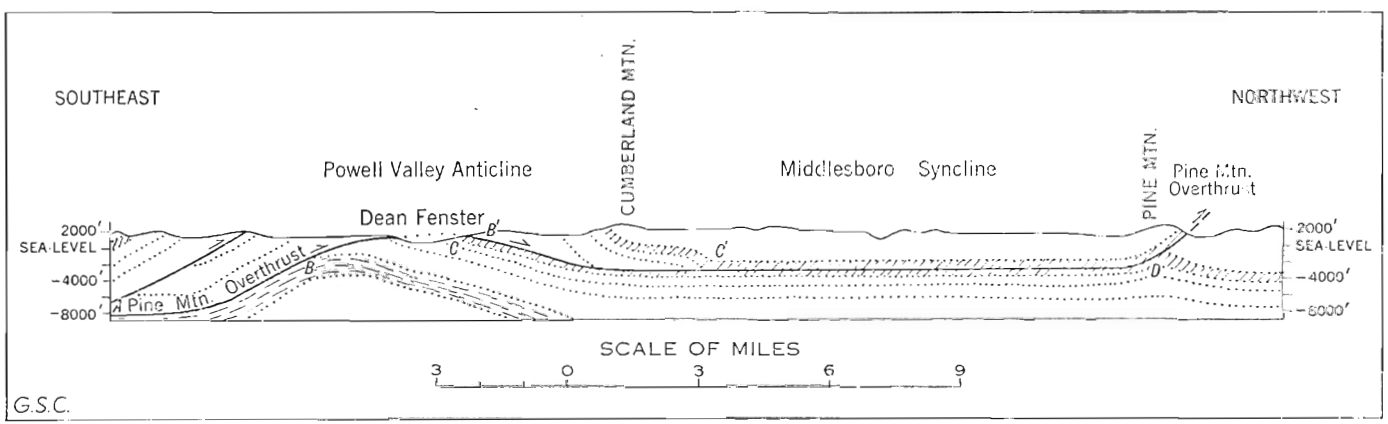


Figure 18. Structure-section through Cumberland thrust sheet of southern Appalachian Mountains. The Chattanooga shale is shown hachured; the Conasauga shale is dashed. After Miller and Fuller.

The rocks above the thrust form a broad, flat-bottomed syncline (Middlesboro syncline), which to the southeast is bordered by a broad anticline (Powell Valley anticline). Windows in the core of the anticline expose Silurian beneath Ordovician strata and indicate a displacement of some 6 miles (*See* Figure 18 taken from Miller and Fuller (1944), who give a more recent detailed structure-section). At the northwestern front, this thrust plane emerges as the 'Pine Mountain overthrust', along which much mangled Chattanooga shale has been thrust over the Pottsville series of Pennsylvanian age (geological maps of Kentucky, Tennessee, and West Virginia).

Figure 16 illustrates Rich's interpretation of the Pine Mountain thrust. According to him, it originated from a fracture (A-E) that followed close to the bedding-planes in a shale zone until frictional resistance became too great; it then sheared diagonally upwards (B-C) across more resistant beds to where another shale zone was reached; after following this zone of bedding-plane slippage for some distance (C-D), the fracture finally cut across the overlying rocks to the surface (D-E).

Movement along such a fracture would produce a structure such as is shown in Figure 17. Along the flat parts, displacement is the result of bedding-plane slippage. Where the stronger strata are sheared across diagonally (B′-C′ and D′-E′), the overlying beds are bent into an anticline. A flat-bottomed syncline is formed between. This result is essentially identical, as has been pointed out by Rich, with the structures actually observed in the case of the Cumberland thrust block shown in cross-section, Figure 18.

A thrust sheet formed in this manner is distinguished by two features: (1) along a line drawn at right angles to the strike, intervals along which the overlying strata lie parallel with the thrust plane (C′-D, Figures 17 and 18) alternate with others along which the overlying beds meet the thrust plane at sharp angles (B′-C′); (2) the former intervals coincide with synclinal surface structures; the latter, with structures that are anticlinal. These structures may be expected to become intensified upon subsequent folding.

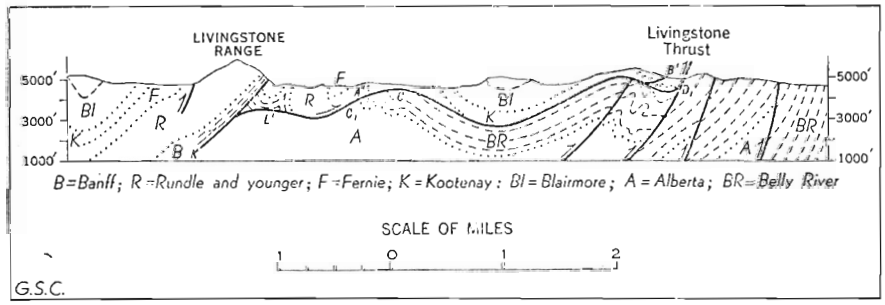


Figure 19. Structure-section through Livingstone thrust sheet, Gap map-area (cf. Structure-section C-D, Gap map).

A comparison of Figures 18 and 19 shows at once the similarity between the Livingstone and Cumberland thrust sheets (comparable parts bear similar letters). Lateral displacement is about the same for both thrusts.

In the part C′-D of the Cumberland thrust sheet the stratigraphic displacement is zero; the thrust parallels the bedding within the Chattanooga shale. On the other hand, displacement along the Livingstone thrust has brought the lower zone of slippage (A′-B′, or, specifically, the Kootenay-Fernie zone) into contact with the upper one (C-D_1, or upper Belly River zone) with a resulting stratigraphic displacement of about 7,000 feet.

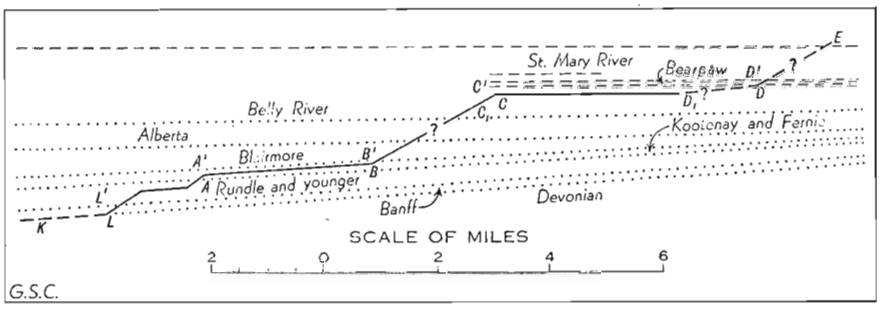


Figure 20. Path (K-E) followed by Livingstone thrust through Upper Palæozoic and Mesozoic strata, as inferred from Figure 19.

The part K-L′ (or Exshaw zone) of the Livingstone thrust sheet corresponds with a zone of bedding-plane slippage still lower than the Conasauga horizon of the Cumberland thrust sheet. The part L′-A′ is similar to B′-C′ of the Cumberland thrust sheet, but now lies at a higher structural level. The part B′-C′ of the Livingstone thrust is now removed by erosion.

The greater complexity of the part L′-A′ (Figure 19) of the Livingstone thrust sheet compared with the simple anticline of the Cumberland overthrust mass is not surprising. Although lateral displacement on the two thrusts is about the same, the Palæozoic strata (L′-A′) of the Livingstone thrust sheet must have met with much greater frictional resistance in passing over two anticlinal warps in the thrust plane (A and C, Figure 20) and one synclinal warp (B), whereas the comparable strata of the Cumberland thrust sheet (B′-C′, Figure 18) have only passed over one anticlinal warp. In the southern part of the Livingstone Range of Gap map-area the Banff and Rundle formations were cut through at a rather high angle, and have been thrust upwards along steeply inclined subsidiary faults (*See* Structure-section E-F, Map 978A). In the northern part of the Gap area, the diagonal fracture has cut through them at a lower angle, probably decreased by following bedding planes within the Rundle formation, so that Palæozoic strata now overlie the central part of the thrust, and are also probably, in part, deformed by later folding of the thrust slice (*See* Structure-section A-B, Map 978A).

From this comparison the writer concludes that:

(1) The Livingstone thrust plane originated, without initial folding, from a fracture that cut diagonally through the upper Palæozoic strata, proceeded parallel with the bedding in the Kootenay and Fernie for a considerable distance, and then cut diagonally upward through the overlying Blairmore group (*See* Figure 20).

(2) As the central part of the Livingstone thrust slice lies on what is approximately a bedding plane in the upper part of the Belly River formation, the upper part of the Livingstone thrust plane, now removed by erosion, must have decreased in dip and followed the upper Belly River zone of bedding-plane slippage before finally steepening and breaking through the overlying strata to the surface (*See* Figure 20).

(3) The lower, diagonal part of the Livingstone thrust plane in the upper Palæozoic rocks may change to a bedding-plane thrust within or close to the Exshaw formation, which it would then probably follow for a considerable distance before cutting into the underlying Devonian formations.

(4) The structures in the Palæozoic strata of the Livingstone Range and those that, in the north, have been inferred to lie beneath Mesozoic strata, are thought to be the result of secondary folding, induced by frictional resistance to the forward movement along the fault plane. As a result, the thin, wedge-like, eastern termination of the Palæozoic rocks, created by the initial diagonal fracture, as shown in Figure 20, was crumpled and faulted as the main mass moved upwards along the thrust plane.

In summary, the Livingstone thrust is presumed to have the following characteristic features:

(1) It originated from a series of primary fractures without appreciable preliminary folding.

(2) The initial fracture formed essentially parallel with the bedding planes in the three zones of bedding-plane slippage of this region, and cut diagonally through the intervening strata.

(3) The initial fault plane thereby consists of a series of 'flats' and 'steeps' or bedding-plane and diagonal parts.

(4) Displacement on an initial fault plane of this character produces anticlinal and synclinal bends in the displaced mass, purely as a result of such displacement.

(5) Frictional resistance to the forward movement of the overthrust mass has modified the initial simple anticlinal fold in the eastern wedge-like mass of Palæozoic strata.

The deformation the Livingstone thrust has undergone subsequent to its formation will be outlined in detail in the following discussion of folding of bedding-plane thrusts. The characteristics of the Livingstone thrust, as set forth above, are not unique, but are fundamental features of the major thrusts, whether folded or not, of the southern Alberta Disturbed belt.

FOLDING OF BEDDING-PLANE THRUSTS

Many of the major thrust faults of the Disturbed belt have themselves been subjected to folding after displacement has occurred along them. Folding of these thrust planes has taken place only where considerable bedding-plane thrusting is involved, and especially where bedding and thrust planes are essentially parallel.

The subsequent folding of the fault planes of major thrusts is consistent with, and indeed an integral part of, the mode of origin of major thrusts, such as the Livingstone, described in the preceding section. Folding of the

fault plane is, in part, only the result of the accentuation of its initial anticlinal and synclinal bends. An initial anticlinal bend is present in the thrust plane where it changes from a diagonal, crosscutting shear to a bedding-plane thrust (*See* Figures 16 and 17, point C), and an initial synclinal bend where it changes again to a diagonal shear (point D). These warps are produced as a direct result of the character of the initial thrust plane. If the deforming stresses are not entirely released by displacement of the overthrust mass, but are transmitted horizontally into the mass beneath, folding will take place, accentuating the initial warps of the thrust plane into definite anticlinal and synclinal folds. Furthermore, if the folding of the thrust plane and the strata above and below it does not completely alleviate the deforming stresses, faulting and folding will take place beyond the mass involved with the folded thrust.

The folding of the Livingstone thrust is believed to have originated in the above manner. Displacement along the thrust plane has brought the Kootenay-Fernie zone of bedding-plane slippage into contact with the upper Belly River zone, so that the two now lie in contact for a horizontal distance of about 3 miles (*See* Figure 19). The initial anticlinal and synclinal bends at the west and east extremities of the bedding-plane part of the thrust plane were accentuated; in the line of section of Figure 19 (Structure-section C-D, Map 978A), these bends lie at points C and D_1, respectively. Between them a secondary fold developed, the axes of which, in the strata above the Livingstone thrust, in the thrust plane itself, and in the strata below the thrust, coincide. This can only mean that the folds were formed simultaneously, initiated by folding of the strata below the thrust, probably as a result of the pressure of the overthrust mass against the truncated western margins of the strata below the thrust. The part of the Livingstone thrust sheet directly overlain by Kootenay and Fernie strata must have ridden out as an almost undeformed mass, for if the strata above the thrust plane had folded without affecting the thrust plane or the strata below it, the anticlines would not now carry cores of the strata that lie below the thrust, but would show a true *décollement* structure above an undeformed thrust plane. Where two zones of bedding-plane slippage are superimposed one upon another along a bedding-plane thrust, such as in the Livingstone thrust where Kootenay and Fernie strata lie above Belly River beds, the resulting superposition of strata is comparable to that of an unfaulted succession, and the whole may be folded in the same manner as an unfaulted section, with or without *décollement* above a zone of slippage.

The Livingstone thrust may also be folded to some extent beneath the overlying Palæozoic strata (*See* Structure-sections A-B and C-D, Map 978A, and Figure 19). The degree of folding of the fault plane is, however, not as great as that observed in the Palæozoic strata overlying it, as these structures, for example the Livingstone anticline (*See* Structure-sections A-B and C-D, Map 978A), are believed to have formed with *décollement* at or near the base of the Banff formation. The westward extension of the Livingstone thrust is folded synclinally beneath the structures west of the Livingstone Range, and anticlinally beneath the Fly Hill anticline where the fault is believed to pass from the base of the Banff formation into the underlying Devonian strata (*See* page 87).

A second example of a folded major fault plane is found in the Lewis thrust, which underlies the High Rock Range of the Rocky Mountains west of Gap map-area. A small part of the thrust, in the vicinity of the

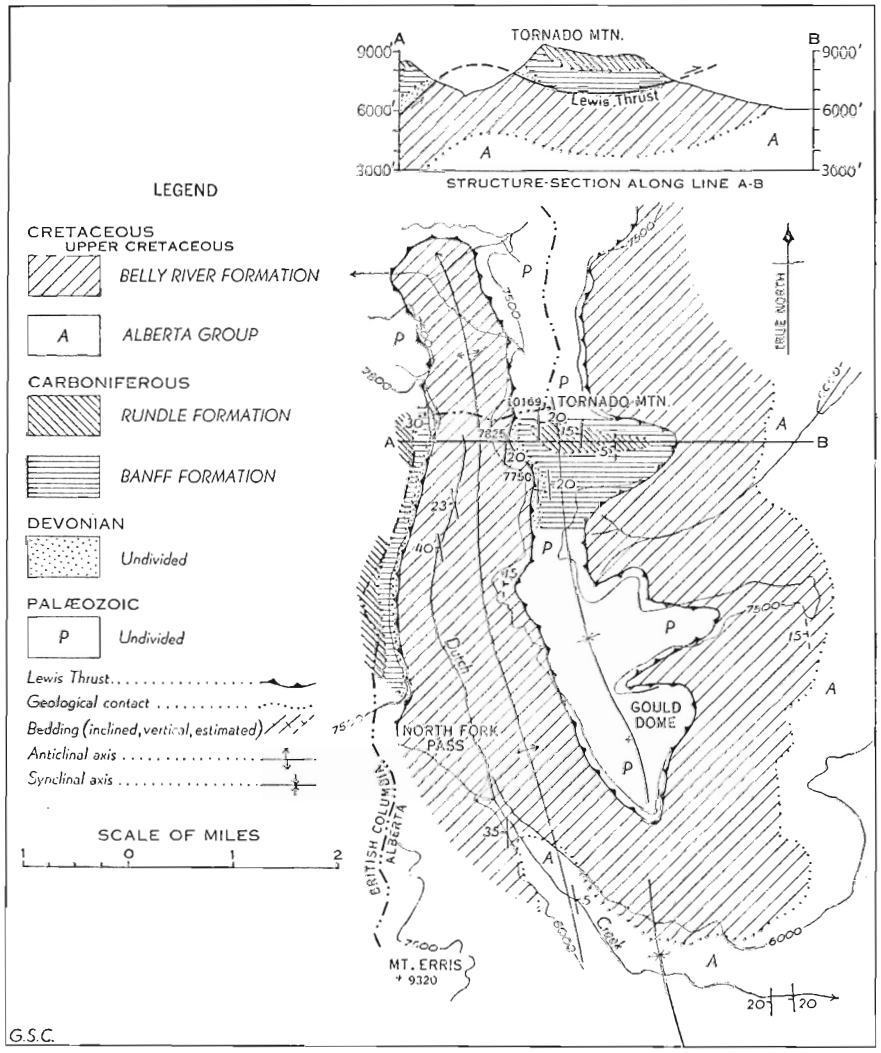


Figure 21. Sketch map of the Lewis thrust near the headwaters of Dutch Creek, Alberta.

headwaters of Dutch Creek, was studied by the writer and Professor B. Rose of Queen's University in 1947. The structure is excellently exposed (*See* Plate V B), and the similarity to the Cumberland overthrust of the southern Appalachian region is striking.

Figure 21 shows the essential details in plan and section that were observed at close hand and through binoculars. The north-trending headwaters of Dutch Creek have produced a deep re-entrant in the surface trace of the Lewis thrust. Palæozoic strata underlying the spur to the east of it have been bent into an asymmetric syncline, the east flank of which dips west from 5 to 15 degrees, and the west flank from vertical to 20 degrees east. The re-entrant itself lies along the crest of an anticline in Palæozoic rocks; the strata of the main range to the west form the west flank, dipping at about 30 degrees west. These two major structures are reflected in the Belly River strata beneath the Lewis thrust. West-dipping Belly River strata were observed along the east front of the Palæozoic spur and along the north-trending headwaters of Dutch Creek. East dips occur within Belly River beds along the west front of the spur and within Wapiabi strata along the lower part of Dutch Creek.

The structure-section of Figure 21 shows the relationship of the Lewis thrust to the strata and structures above and below it. On the east front of the spur, the Lewis thrust dips west at a low angle between basal Banff and upper Belly River strata. It is folded into a shallow syncline beneath the syncline in Palæozoic rocks and dips eastward along the west front of the spur. Two elevations were obtained on the fault plane (*See* Figure 21), indicating an east dip of 75 feet in about 750 feet, or about 12 degrees. Along the west front of the spur, thin, and in places contorted, Devonian and Exshaw strata lie directly above the fault, and highly sheared coal was observed at two places immediately below it. The Lewis thrust is folded anticlinally over the re-entrant and dips west at about 30 degrees beneath Devonian rocks along the main range west of Dutch Creek.

Where the Lewis thrust passes from the base of the Banff formation into Devonian strata, an anticline has formed, with a syncline lying to the east of it. Comparing the cross-section of Figure 21 through the Lewis thrust with that of the Cumberland thrust in Figure 18, it is apparent that the anticline in Devonian rocks of the Lewis thrust sheet occupies a structural position similar to that of the pre-Chattanooga rocks of the Powell Valley anticline above the Cumberland thrust. The east limb of the syncline, with the Lewis thrust lying at the base of the Banff formation, corresponds with the flat bedding-plane part of the Cumberland thrust. The initial bends in the Lewis thrust plane have been accentuated into definite anticlinal and synclinal folds. These similarities between the Lewis and Cumberland thrust sheets suggest that the mechanics of their origin is the same.

The nature of that part of the Lewis thrust where the fault plane passes from the base of the Banff into Devonian strata may be applied to the interpretation of the westward extension of the Livingstone thrust at these lower stratigraphic levels. The Anglo Canadian, Savanna Creek No. 1 well was drilled close to the crest of a broad, flat-topped, anticlinal structure forming the southward continuation of the Highwood Range, and is separated from the northern part of the Livingstone Range by a broad syncline with Mesozoic rocks exposed at the surface (*See* Figure 1). The Livingstone thrust is believed to lie close to the base of the Banff formation, folded anticlinally beneath the northern part of the Livingstone

Range (*See* comparable structure-section through the northern part of Gap map-area) where Royal Sun No. 1 well penetrated it at a depth of 2,432 feet. The thrust is folded synclinally beneath the broad syncline west of the Livingstone Range, and anticlinally beneath the southern continuation of the Highwood Range where it was encountered by the Savanna Creek well; the drill passing from Devonian strata into the Wapiabi formation at a depth of 110 feet. The eastern limit of Devonian strata, then, would be expected to lie along the eastern limb of the anticlinal structure of the Highwood Range, and would extend southward into Gap map-area along the east flank of the Fly Hill anticline. In the Blairmore Range, south of Gap map-area, believed to be the southward continuation of the Fly Hill anticline, Devonian strata outcrop. Within Gap map-area, the Livingstone thrust lies beneath Banff strata as far west as the east flank of the Fly Hill anticline, where it would then steepen and cut into the underlying Devonian formations.

MECHANICS OF BACK-LIMB THRUST FAULTS

It is common expectancy to find a syncline beneath a fault and an anticlinal structure above it. This is due to the conception that the fault rose from an asymmetric or overturned fold by shearing through the steeper limb. It is remarkable, then, that in the map-areas covered by this report, many faults repeat the strata of the gentler limb, with the result that the major anticlinal structure lies beneath it.

In a series of simple, parallel folds that have developed some degree of asymmetry, the steeper limb is commonly called the 'middle limb'. This limb may also be called the 'front limb' of the anticline, and the other, or gentle limb, may be called the 'back limb' (Figure 22). Back-limb thrust faults are, accordingly, thrust faults that repeat the strata of the back limb of the anticlinal structures, as contrasted with those that break the front limb (Figure 23, a and b).

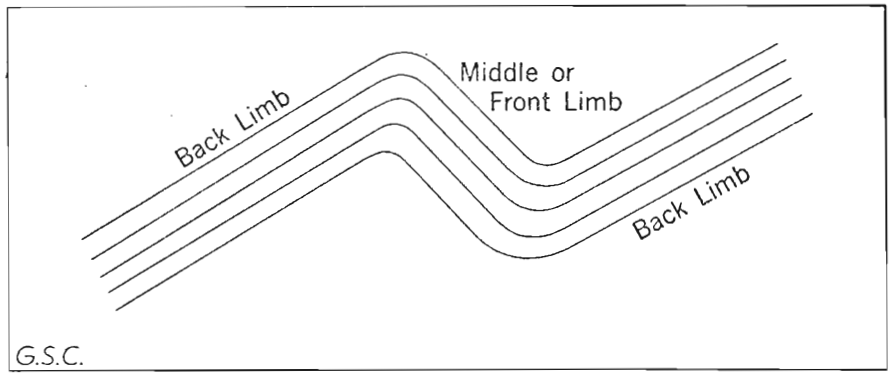


Figure 22. Illustrating nomenclature of folds as used in report.

In the areas under present consideration, the deforming stresses were directed from the west, so that the back-limb thrusts lie on the west flank of the underlying anticlines. The following examples serve as illustrations of this relationship of the faults to the underlying anticlines: the Fly Hill

fault; the Rice Creek fault; the unnamed fault illustrated in Figure 15; the Gap, Thunder Mountain, and minor faults on the west flank of the Livingstone anticline (*See* Figure 11); and the Whaleback and associated faults. The Black Mountain and Waldron faults, although dipping east, and lying on the east flank of the underlying Waldron anticline, have originated on its back-limb. The Watson, Tetley, Bob Creek, and Chimney Rock faults are also back-limb thrusts, but their relationship to an underlying anticlinal structure may not be as apparent. These faults are believed to lie above a major thrust that follows the Kootenay-Fernie zone of bedding-plane slippage and, as will be shown in the following paragraphs, have formed within the east flank of a major synclinal structure above the underlying thrust.

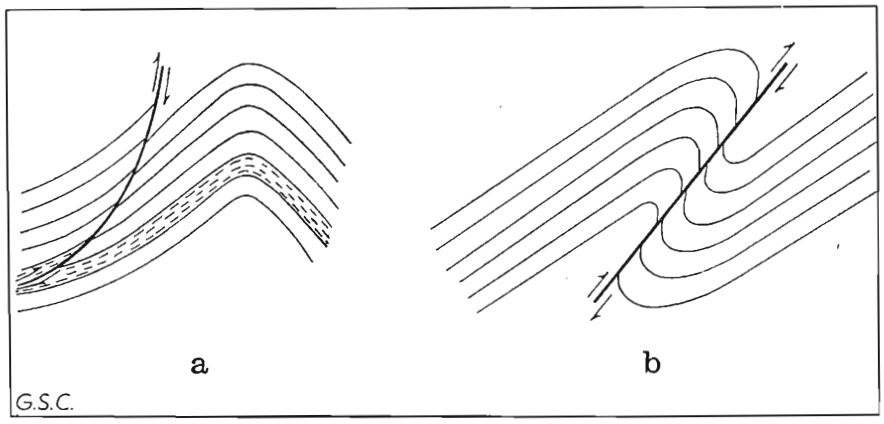


Figure 23. Illustrating nomenclature of faults: (a) back-limb thrust fault; (b) front-limb thrust fault.

The reason for this type of faulting is believed to lie in the different behaviour of the weak and strong rocks under deformation, and in the manner in which they were initially deformed. In this region, the strata below and between major thrusts, such as the Livingstone and Lewis thrusts, were, by nature of the alternating parallel and crosscutting character of the fault plane (*See* Figures 17 and 20), subjected to differential pressures that bore against the truncated western margins of the strong members and developed bedding-plane slippage along the weak ones (*See* Figure 24a, points T). If folding develops within the thrust slices during thrusting, the stronger strata of the back limb of the anticlines, which in this region is the western flank, will tend to be shoved eastward differentially with respect to one another (Figure 24a, point U). The strata of the middle limb, or eastern limb of the anticline, do not exhibit as much differential movement, as the limbs of the associated syncline tend to 'ride out' away from the axis, producing differential movement that in the western flank of the syncline shoves higher strata westward and thereby creates a stress that is opposed to the effect of the differential deforming stress (Figure 24 a and b, points V). On the other hand, within the back-limb region, that is the west flank of the anticline and east flank of the syncline (points U and W, respectively), these two stresses are both directed

eastward and complement one another. The back-limb thrusts (Figure 24c), formed to relieve the cumulative stress of the differential deforming pressure and the differential movement between the strong and weak rocks, are concave westward, cutting through the strong members at an angle and paralleling the bedding in the weaker rocks. A clear illustration of

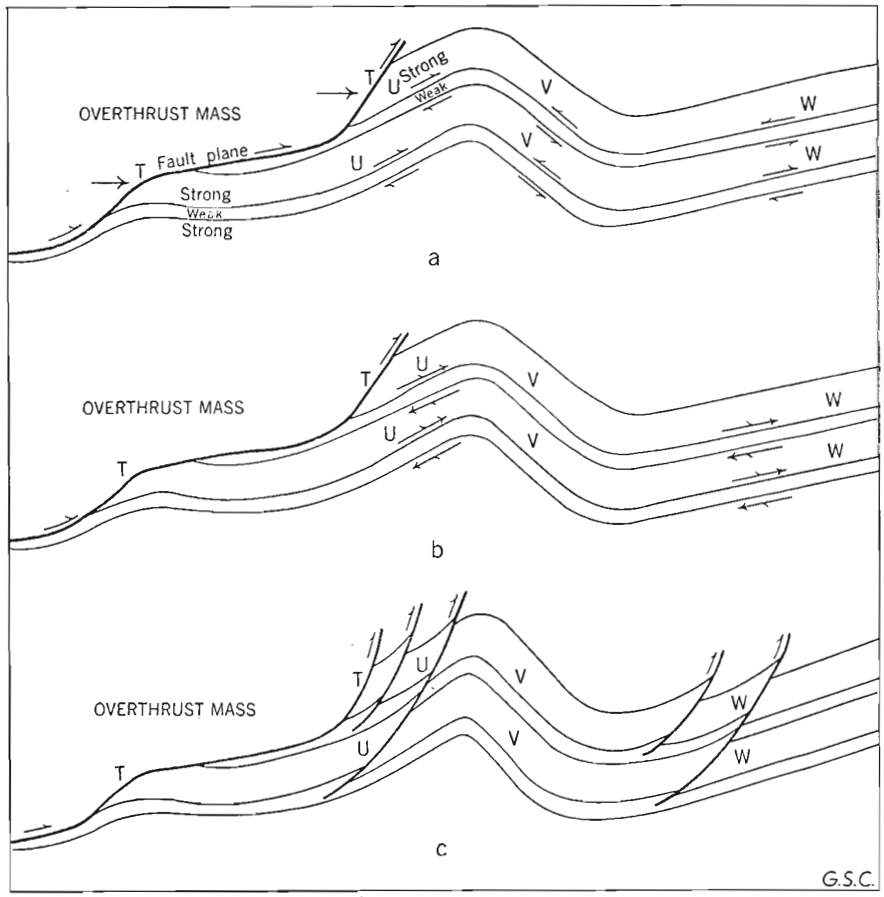


Figure 24. Diagrammatic illustration of formation of back-limb thrust faults during folding of a series of strong and weak strata under differential stress (T, points where overthrust mass bears against strong members; U, W, back-limb region; V, front-limb region).
a. Illustrating relationship of overthrust mass to fold in underlying strata, showing vector of stress → arising from overthrust mass bearing against truncated strong strata beneath thrust plane, and vector of stress ⇄ arising through bedding-plane slippage between strong and weak strata as a result of folding.
b. Illustrating cumulative effect of stresses.
c. Illustrating resulting back-limb thrust faults formed to relieve cumulative stresses.

back-limb thrusts are those illustrated in Figure 15. The west limb of the anticline and the east limb of the syncline, that is, the 'back-limb' region, are broken by faults, but none was observed in the 'middle-limb' or 'front-limb' region. It should be noted here that the west limb of the anticline is steeper than the east limb; the result of rotation by displacement along the curved back-limb faults.

Field evidence also shows that the formation of the back-limb thrust and the folding of the underlying strata into an anticline, take place simultaneously and in some instances result in the folding of the back-limb fault plane. One instance is the Fly Hill fault, described on pages 76 and 77 and illustrated in Figure 25 a and b (*See also* Structure-section A-B, Map 978A). Folding of the strata of the underlying Fly Hill anticline continued even after the Fly Hill fault had formed on its back limb, so that part of the fault plane is bent, concave eastward, conforming in dip with the strata of the west limb of the anticline. The continued folding in the

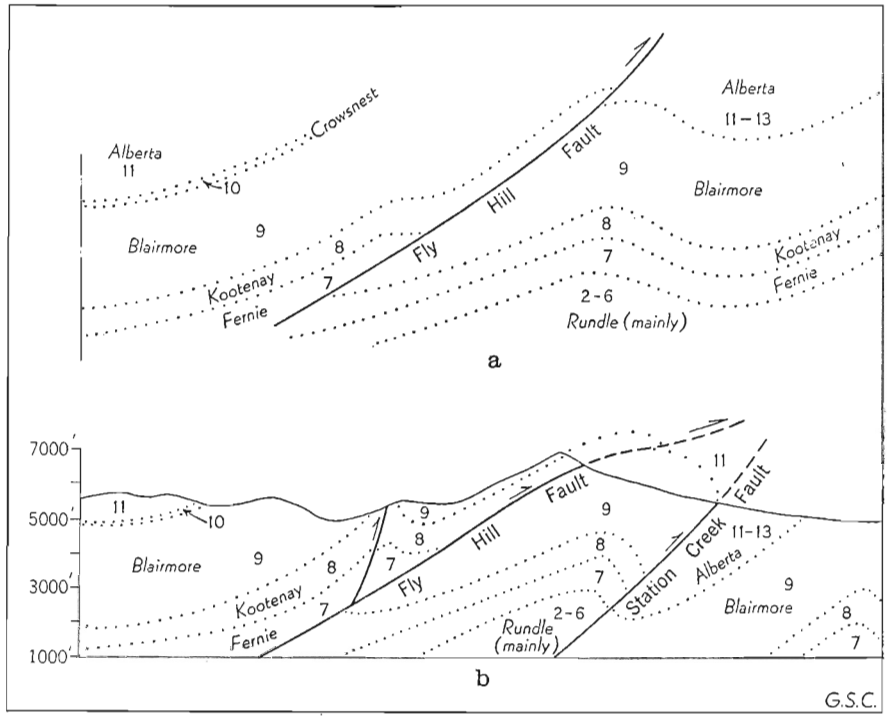


Figure 25. Structure-sections illustrating stages in the formation of the Fly Hill back-limb thrust: (a) prior to completion of folding of underlying anticline and formation of Station Creek front-limb fault; (b) final stage, as interpreted in Structure-section A-B, Gap map.

anticline may have been brought about as a result of drag on the 'front-limb' fault that formed along its eastern flank (Station Creek fault). This fault extends only as far south as there is actual evidence of warping of the Fly Hill fault, and has its maximum displacement in the north where the Fly Hill anticline is best developed, and where the Fly Hill fault is folded most. South of the south end of the Station Creek fault, the Fly Hill fault is concave westward (*See* Structure-section E-F, Map 978A). The Fly Hill fault and underlying anticline within Blairmore strata overlie a major anticlinal structure within Palæozoic rocks. This anticline may have been formed as a result of the displacement of Devonian rocks over an anticlinal bend in the Livingstone thrust.

The Rice Creek fault provides a second illustration of a folded back-limb thrust (cf. Structure-section C-D, Map 981A, with Figure 25b). The Rice Creek fault has formed on the west flank or back limb of the underlying Willow Creek anticline, which carries Rundle strata in its core. Like the Fly Hill fault, considerable displacement had taken place along it before folding of the underlying anticline was completed, so that the Rice Creek fault was folded into a shallow anticline and syncline. When the Rice Creek fault was folded to such a degree that displacement could no longer take place along it final pressure was released by the formation of the Willow Creek front-limb fault.

It is perhaps of economic significance that in these two instances of folded back-limb thrusts, the Rice Creek and Fly Hill faults, the underlying anticlines involve the Rundle formation. The anticline in the Rundle lies to the west of and above the front-limb fault, if present.

The Gap fault, which lies on the west flank of the Livingstone anticline in the northern part of the Livingstone Range, repeats steeply west-dipping beds, but south of sec. 9, tp. 11, rge. 3, about 5 miles north of The Gap, the Livingstone anticline becomes overturned to the east and the dip of the strata of its west flank decreases. The dip of the Gap fault plane and of the strata above it also decrease, so that the Gap fault plane is bent, concave eastward, above the Livingstone anticline (*See* Figure 11, cross-sections 11 and 12). It appears that the Gap fault plane was partly folded as a result of the tighter folding and eastward overturning of the Livingstone anticline after the Gap fault had formed on its back limb.

Thus the development of secondary folds within the thrust sheets produces associated back-limb thrusts on their west flanks, due to the cumulative effect of the stresses arising from the overlying overthrust mass and the differential movements between the strong and weak strata. Some of these back-limb thrusts may be folded as a result of the continuation of folding in the underlying anticline after the thrust had formed. Further studies may show whether or not all folded back-limb thrusts are associated only with anticlines that involve Rundle strata at depth.

A study of the eastern part of the Disturbed belt within Callum Creek, Langford Creek, and the eastern part of Gap map-areas, as well as other mapped areas in the southern Foothills of Alberta, shows many closely spaced thrust faults, commonly less than a mile apart yet extending for 30 to 50 miles or more along their strike. Where the faults reach high stratigraphic levels, especially within Belly River strata, they tend to lie remarkably parallel with one another and to end gradually by decrease of stratigraphic displacement. Within the lower levels of the Alberta and Blairmore groups, however, the faults lose, to some extent, their parallel character and bifurcate and anastamose to form thin, irregular thrust slices. Although these variations may be due in part to lateral change in the physical character of the beds, they are also probably the result of changes in behaviour varying with depth. The strata lying between the closely spaced faults are commonly steeply inclined, especially those of the Belly River formation, and are rarely marred by folds or tear faults. The thrust faults that break the strata into such thin, but long, thrust slices are believed to have originated in the same manner as the back-limb faults previously described, and their mechanics of origin will be further discussed in following paragraphs.

Referring once again to Figure 17, it is seen that as a result of displacement on the initial fault plane, the overthrust mass is bent into two anticlinal structures with an intervening syncline. Figure 26a shows the same features, but instead of an assumed series of strata, the actual stratigraphic succession and thickness observed in the Gap map-area are used.

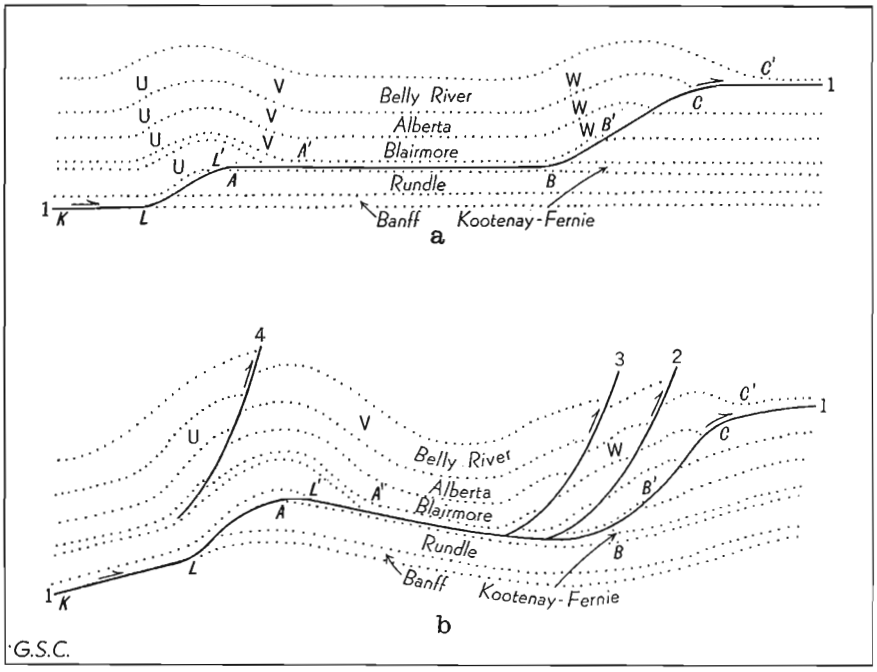


Figure 26. Diagrams illustrating stages (a, b) in the formation of back-limb thrust faults (2, 3, 4) above initial thrust. (U, W, back-limb region; V, front-limb region): a, showing initial thrust (1-1) with small displacement; b, showing relationship of back-limb thrust faults (2, 3, 4) to initial thrust (1-1) after additional displacement.

In the back-limb region of the major anticlines (Figure 26a, points U and W; cf. Figure 24, same points), the differential movement between the strong and weak formations within the thrust sheet tend to be accentuated. In the part V-W, where the fault plane is directly overlain by the Kootenay-Fernie zone of bedding-plane slippage, greatest differential movement between the strata occurs where the major fault plane passes upwards from a bedding-plane thrust to a diagonal shear, that is at point B. A back-limb thrust forming there will pass downward into the Kootenay-Fernie zone of bedding-plane slippage merging with the initial thrust plane and will cut upwards through the overlying beds at an angle (Figure 26b, fault 2). The fault plane, thus formed, is curved, concave towards the origin of pressure, as in the corresponding part of the initial thrust, so that, with displacement, a rotating movement is imparted to the strata above the newly formed thrust, which steepens their dips. In effect, a new front has formed, similar to the initial front of the major thrust, but lying to the west of it. By the same process, other similar back-limb thrusts may form, each progressively farther west within the overthrust mass

(Figure 26b, fault 3). Each of these faults takes up a part of the displacement that occurs farther west along the major thrust (compare the total amount of displacement of the contact between Blairmore and Kootenay strata on the back-limb thrusts with that at the Rundle and Fernie contact). The initial, or easternmost, fault need not necessarily exhibit the greatest stratigraphic throw, or actual displacement, nor does the fault exhibiting these characteristics necessarily retain them along its strike.

To the writer, the structural features of the thin thrust slices of the eastern part of the Disturbed belt seem explicable best by the above process. The thin thrust slices at one time formed the front of a larger thrust mass, the whole of which was displaced along an initial major fault plane, but became detached from it through the formation of successive back-limb thrusts, developing from east to west within the overthrust mass. The strata being displaced along a curved fault plane are rotated, and their dips correspondingly steepened, whereas the beds below the newly formed fault plane no longer undergo much upward movement. It is difficult to see how the thin thrust slices could by themselves be thrust over the underlying strata without being crumpled or broken by tear faults, as would be the case if they formed progressively from west to east.

The rotating effect imparted to the strata overlying the back-limb thrusts is believed to be illustrated, in an extreme case, in secs. 17 and 20, tp. 11, rge. 2, Callum Creek map-area (*See* page 66 and Figure 10). There, between the Tetley fault and the minor fault to the east, lies a tightly folded syncline within Belly River strata. This syncline was probably formed on the west flank of the Watson anticline by drag beneath the overriding Tetley fault slice, but became detached from it by later faulting of its east flank. Rotation on the minor fault has overturned the east flank of the syncline westward to as much as 60 degrees. This fault plane must dip eastward also, at 60 degrees or less, and the Tetley fault plane to the west probably has about the same attitude. This is an extreme case, and only of local extent, but illustrates the effects of such rotating movements.

It is apparent that the splitting of the major thrust sheet into a number of smaller thrust slices by a series of back-limb thrusts, in the manner outlined above, is dependent on an underlying zone of bedding-plane slippage, which the initial fault followed. If, as is commonly true in the Disturbed belt of southwestern Alberta, this zone is that of the Kootenay and Fernie formations, then an important economic consideration follows: Palæozoic strata do not overlie any of these back-limb thrusts. The extent to which the initial thrust followed the Kootenay-Fernie zone of bedding-plane slippage must be determined in order to locate the Palæozoic strata above the thrust. Where the initial thrust passes from the Kootenay and Fernie into the underlying Palæozoic strata, an anticlinal fold will form in the Palæozoic rocks as a result of displacement (*See* Figure 26a). This structure may be reflected by a region underlain by older strata than that to the east. Each back-limb thrust that repeats the strata of the back limb of the anticline will have the effect of widening the structurally high area, but the high within the Palæozoic rocks will tend to remain beneath the eastern part of it. Each back-limb thrust above the bedding plane part of the major thrust within the Kootenay and Fernie to the east of

the Palæozoic high will limit the high to the west of it. The subsurface high in the Palæozoic strata, then, lies immediately east of the back-limb thrust (Figure 26c, fault 4) of the anticline involving the Palæozoic rocks, and west of the back-limb thrusts that arise from the Kootenay-Fernie zone (Figure 26c, faults 2 and 3). It should be noted that, for simplicity of presentation, only a small amount of displacement is shown on the initial fault. With greater displacement, as for example if the Kootenay-Fernie zone of bedding-plane slippage (A′-B′) were thrust over the Belly River zone (C-1), the overthrust mass may be broken by additional back-limb thrusts lying between point A′ and fault 3, and may even be broken by a front-limb fault forming between point A′ and fault 4.

An examination of the maps of the region between the Whaleback fault in Callum Creek map-area and the Livingstone thrust to the west, reveals many minor and three major high-angle faults repeating Belly River and Wapiabi strata; the Watson, Tetley, and Bob Creek faults. These faults are believed to be back-limb thrusts lying above a major bedding-plane thrust, the eastern limit of which is probably the Whaleback fault. Stratigraphic displacement is greater at the surface along the Watson fault, but the Marjon Lundbreck No. 1 well indicates that the Whaleback and Watson faults merge at depth, and that displacement is as great or greater along the Whaleback fault. The Tetley and Bob Creek faults lie parallel farther west, dipping steeply and repeating highly inclined Belly River strata. West of the Bob Creek fault lower stratigraphic levels within the Belly River are brought to the surface, eventually forming a much faulted syncline, beyond which lies a major, compound anticline within the Wapiabi formation, the Quaich structure.

As interpreted by the writer, this region, from west to east, shows low-angle, back-limb thrusts as far east as the Todd Creek fault. These thrusts have formed on the west flank of a structural high within Palæozoic strata, to the east of which lie the Bob Creek, Tetley, Watson, and Whaleback back-limb thrusts, which merge at depth into an underlying major thrust within the Kootenay and Fernie. The structural high within the Palæozoic strata above this thrust is believed to lie between the Todd Creek and Bob Creek faults. Its surface projection, however, lies a short distance west of the surface trace of the Todd Creek fault.

EAST-DIPPING THRUST FAULTS

East-dipping thrust faults are known to occur within Callum Creek, Langford Creek, and Gap map-areas along the axis of a syncline, above west-dipping faults, and associated with an anticline along the western border of the Alberta syncline.

The presence of an east-dipping fault in the axis of a syncline has already been discussed in sufficient detail (*See* pages 72 and 78). East-dipping faults of the second type, which lie to the west or above a west-dipping fault, have been taken to be indications of a change at depth to a low dip in the underlying west-dipping fault plane (Hume, 1931). Two such faults, one above the Todd Creek fault and one above the minor fault that extends from the Whaleback to the Watson thrust, are associated with a low-angle thrust plane, and repeat strata of the west flank of a syncline lying above it. In a third instance, where east-dipping faults

lie above the steeply west-dipping Bridge fault, their presence has been assumed to indicate a decrease in dip of the Bridge fault plane where the east-dipping faults merge with it.

Major, east-dipping faults bordering the easternmost limit of the Disturbed belt are common features throughout the length of the Foothills. Two such faults are represented in the areas covered by this report: the Waldron fault, which lies near the crest of the Waldron anticline (*See* Structure-section C-D, Map 982A), and the Black Mountain fault, which extends along its eastern flank farther to the north.

This association with an underlying anticline suggests that the mechanics of their origin is comparable with that of back-limb thrusts, which was discussed in preceding pages. These faults lie within sharply upturned St. Mary River strata adjacent to the western limb of the strongly asymmetric Alberta syncline. Apparently the differential stresses that developed during the upturning of the western limb of this syncline were released more easily by the formation of east-dipping thrusts in the west limb than by displacement of the whole synclinal mass along west-dipping faults in its eastern limb.

GENERAL SUMMARY

An application of the mechanics of bedding-plane thrusting to the structures of Callum Creek, Langford Creek, and Gap map-areas reveals several fundamental conclusions concerning the deformation of the strata, which are, perhaps, applicable to the whole of the southern Disturbed belt of Alberta. They may be stated briefly as follows:

(1) The stresses were directed from the west, producing, without initial folding, successive, major thrusts.

(2) These major thrusts, as typified by the Livingstone thrust, originated from a primary fracture that paralleled the bedding planes in the upper Belly River, Kootenay-Fernie, and Exshaw zones of bedding-plane slippage, and that cut diagonally across the intervening stronger strata.

(3) Displacement along these initial fault planes produced anticlinal and synclinal bends in the overthrust mass, purely as a result of such displacement.

(4) Frictional resistance to the forward movement of the overthrust mass may modify the initial simple folds that form where the thrust cuts diagonally through the stronger strata.

(5) The initial anticlinal and synclinal bends in the strata of the overthrust mass, and corresponding bends in the thrust plane itself, may be accentuated by folding in the strata underlying the thrust plane. This folding is produced by the compressive stresses from the west, transmitted by the overthrust mass pressing against the truncated western margins of the more resistant formations beneath the thrust plane.

(6) Folding within the overthrust mass is commonly accompanied by the development of back-limb thrust faults, which lie on the back limb, or west flank, of the anticlines. These thrusts are the result of differential

movements between the strong and weak strata, produced by the initial parallel and crosscutting character of the fault plane. In some instances, considerable displacement has taken place on the back-limb fault before the folding of the anticline has been completed, so that the fault plane is also folded to some degree.

(7) Other back-limb faults may form above the Kootenay-Fernie bedding-plane part of the major thrust plane. These thrusts lie parallel or subparallel with one another within the Belly River strata, but merge somewhat at depth before passing into the Kootenay-Fernie zone of bedding-plane slippage. The concave nature of the fault plane causes rotation of the overthrust mass and a steepening of the dips of the strata. These faults form in succession from east to west within the overthrust mass.

(8) East-dipping thrusts lying above a west-dipping fault indicate a decrease in dip of the west-dipping fault along the line where the east-dipping thrust merges with it.

The importance of this discussion and its conclusions may be, perhaps, best judged by their economic value. The important oil and natural gas producing horizons of the southern Foothills of Alberta have been found to lie within the Rundle formation of Mississippian age, underlying the Kootenay-Fernie zone of bedding-plane slippage. Because the Kootenay-Fernie zone plays such an important rôle in the development of the structures of the southern Foothills, the question as to whether it has functioned as a slippage zone in a given locality becomes of real economic importance. Depending on whether it has or has not been active in that manner, Rundle strata may or may not be present beneath a given anticline, or close to the surface above a given thrust.

It has become increasingly apparent, through drilling, that the Rundle formation is not always found at shallow depths above a fault along which low stratigraphic levels are exposed at the surface. Even though there may be indications that the fault plane is steeply inclined at the surface, so that Rundle strata could be inferred to lie above the thrust if its dip were projected to depth, the possibility is very great that the fault plane decreases in dip at depth and follows close to the bedding in the Kootenay formation. Because the initial major fault plane follows the Kootenay-Fernie zone of bedding-plane slippage for great horizontal distances, the faults and folds that develop above this part of the thrust plane are not underlain by Rundle strata. The latter are displaced only as a large mass above a major fault, folded by drag in its eastern part, and broken perhaps by secondary, subsidiary faults. Only a study of the whole of the thrust sheet and the relationship of the folds and faults to one another can enable one to outline the structural high within the part of the thrust sheet overlain by the Rundle formation. In an area where only beds considerably younger than the Rundle outcrop, this is admittedly difficult, but it is hoped that the present analysis will prove to be of some value in such attempts.

CHAPTER VI

ECONOMIC GEOLOGY

PETROLEUM AND NATURAL GAS

GENERAL STATEMENT

The economic possibilities of Callum Creek, Langford Creek, and Gap map-areas as potential oil and gas fields are dependent not only on the presence of suitable reservoir or source rocks, but on the occurrence of structures suitable for collecting and maintaining commercial quantities of petroleum and natural gas. Preceding chapters have dealt at some length with the various structures of these map-areas, and brief lithological accounts have been given of the formations that compose them. The following sections deal more specifically with the known reservoir rocks and with the favourable and unfavourable features of those structures that may be assumed to have some prospective possibilities.

RESERVOIR ROCKS

Commercial quantities of petroleum and natural gas have been obtained in the Foothills belt from the Blairmore group, the Rundle formation, and Devonian formations. As Devonian strata do not outcrop within the map-areas under consideration, their porosity conditions there are unknown; nor is it probable that Devonian beds underlie any favourable structures in this region.

The Maxmont No. 1 well, in l.s. 10, sec. 20, tp. 9, rge. 2, Callum Creek map-area, has reported many occurrences of oil and natural gas within the Alberta and Blairmore groups. The oil is not in sufficient quantity to be recovered commercially, but some of the shows of natural gas are reported to be of considerable volume. The sandstones from which oil was reported in this well do not appear very porous. Drilling is being continued on the prospect of reaching the Rundle formation, as the shows may indicate a migration from that formation.

The basal member (A) of the Rundle formation, where exposed in the Livingstone Range of Gap map-area, has well-developed porosity in some of the limestones of its upper 300 feet, although mostly in the form of disconnected vugs ½ to 1 inch in diameter. Some of these limestone beds are composed almost entirely of crinoidal and bryozoan remains, and possess high porosity and permeability. They are known to be continuous for long distances along the strike. The dolomites of Member A are commonly fine-grained, and show no porosity. The top of this member lies about 930 feet below the top of the Rundle formation at The Gap.

Member B of the Rundle formation contains some beds of porous limestone, vuggy limestone, and limestone breccias interbedded with thin-bedded argillaceous dolomites. The porous beds lie between 660 and 805 feet below the top of the formation.

The uppermost member (D) of the Rundle formation contains many thin, porous limestones, and some slightly porous, buff, finely crystalline dolomites, but none appears to be thick enough to afford a satisfactory reservoir for a large volume of petroleum. These beds were observed to carry pyrobitumen in their pore spaces on the crest of the Livingstone anticline north of White Creek in Gap map-area. In the Livingstone Range, Member D is overlain by thin deposits, ascribed to the Rocky Mountain and Spray River formations, which converge rapidly eastward, and may be absent to the east of the surface trace of the Livingstone thrust. If so, additional porosity may have been developed in Member D during the pre-Fernie interval of erosion and non-deposition. Further, the porous zones of Member D would lie in direct contact with the black marine shales of the Fernie group, which are commonly regarded as a source of petroleum.

PROSPECTIVE STRUCTURES

Waldron Anticline

The Waldron anticline lies within St. Mary River strata along the eastern limit of the Disturbed belt. Its crest lies close to the surface trace of the Willow Creek fault in the Langford Creek and northern part of Callum Creek map-areas, but diverges eastward from it in the south. It is highest structurally in the southern part of Langford Creek map-area, where basal St. Mary River strata form the crest. The west flank is broken by the west-dipping Willow Creek and Bridge faults, and the east-dipping Waldron and Black Mountain faults are found on its east flank.

The stratigraphic depth to the top of the Rundle formation from the base of the St. Mary River formation is about 7,150 feet. The drilling depth would be greater, depending on the amount of higher strata to be drilled and the dip of the strata, both of which would vary with surface position. A small increase in drilling depth would be met if the well were located east of the east-dipping Waldron and Black Mountain faults.

Favourable conditions that warrant testing of this anticlinal structure are the lack of west-dipping faults on its east flank, which would cause excessive increase in drilling depth, and good closure across the strike. Unfavourable conditions are lack of pronounced closure northward along the axis, and the possibility that the Waldron anticline involves only part of the exposed stratigraphic succession and is not affected by a closed anticlinal structure within the Rundle formation at depth.

Whaleback Anticline

The Whaleback anticline is a compound structure within Belly River strata east of the Whaleback fault in Callum Creek map-area. Favourable considerations are a large east-west closure, good evidence of both north and south closures, and lack of evidence of thrust faults with large displacements on its east flank. The structural high lies in the region where the anticline is crossed by Oldman River.

The crestal part of the Whaleback anticline is broken by several small faults, none of which is believed to have great displacement. Drilling depth to the top of the Rundle formation is dependent on the amount of

stratigraphic displacement on these faults and on the dip of the beds. Data on the probable dip of the west flank of this structure are furnished by the Marjon Lundbreck No. 1 well. The Belly River strata encountered below the Whaleback fault at 5,930 feet depth appear to represent a lower part of the formation. As shown on Structure-section C-D, Map 982A, the Belly River strata are assumed to dip westward at about 35 degrees. The stratigraphic thickness from the base of the Belly River to the top of the Rundle formation is about 3,500 feet assuming the Wapiabi to be 1,200 feet, Bighorn 100, Blackstone 450, Blairmore 1,300, Kootenay 100, and Fernie 400 feet thick. On a 35-degree dip, the drilling thickness would be 4,400 feet. To this figure must be added the amount of Belly River strata to be drilled, which would vary with surface position, and an allowance made for the amount of repetition on the minor faults in the crestal region. A well located along Oldman River near the surface trace of the Whaleback fault (*See* Structure-section C-D, Map 982A) would lie on the west flank of the anticline and would be expected to drill about 3,000 feet of Belly River strata, 2,250 feet of Alberta, and reach the top of the Rundle formation at a depth of about 8,000 feet. The crest of the anticline, where the Rundle formation would be reached at about 7,500 feet, lies a short distance to the east of this location.

It is apparent that the interpretation of the structure of the Whaleback anticline is dependent upon the assumption that the Willow Creek and Rice Creek faults have little displacement or have died out completely in the southern part of Callum Creek map-area. This assumption is based on observations along Oldman River, sec. 11, tp. 10, rge. 2, of the contacts between the Bearpaw formation and the underlying and overlying formations. The strata close to the contact with the Belly River formation are contorted and partly sheared, but no displacement appears to have taken place; this contact is offset by the Rice Creek fault to the north of the river. The contact between the Bearpaw and St. Mary River formations is offset by the Willow Creek fault; the stratigraphic throw is small, and perhaps the inference is justified that actual displacement is also small. The Rice Creek and Willow Creek faults are believed to be absent in Cowley map-area (Hage, 1943) south of Callum Creek map-area, but in Beaver Mines map-area (Hage, 1944), south of Cowley map-area, both contacts of the Bearpaw formations are faulted. The stratigraphic displacement there is small, as observed at the surface, but as shown by the Anglo Canadian, Castle River No. 1 well increases at depth. The anticlinal structure on which this well was drilled is comparable in structural position to the Whaleback anticline, but no strata older than those of the Blairmore group were encountered in the Castle River No. 1 well, which reached a total depth of 7,189 feet.

However, both in southern Callum Creek and northern Cowley map-areas, considerable deformation has occurred east of the Willow Creek fault. The decrease in displacement along the Rice Creek and Willow Creek faults may be taken up by displacement along the Bridge and associated faults, so that all may have little displacement at depth (*See* Structure-section C-D, Map 982A).

The shallow depth to the Rundle formation and the favourable closures are features that warrant testing of the Whaleback anticline.

Willow Creek Anticline

The Willow Creek anticline lies in the northern part of Langford Creek map-area. In it, the Rundle formation was encountered by the Socony Vacuum, Stimson Creek No. 1 well (l.s. 12, sec. 5, tp. 15, rge. 2) at a depth of 3,490 feet or an elevation of 1,160 feet in the continuation of the Willow Creek anticline at depth. Commercial quantities of petroleum and natural gas were not obtained. The Willow Creek anticline forms a south-plunging part of a broad, structurally high area in the eastern part of Pekisko Creek map-area, which adjoins Langford Creek map-area on the northwest. No production was obtained in that area.

The Stimson Creek well served as a valuable test of the possibility of local closure within the Rundle formation along the Willow Creek anticline or of lateral variations in permeability conditions that could result in effective closure to the north along the south-plunging anticline. As the Stimson Creek well proved unsuccessful and there seems little possibility of other structural or stratigraphic conditions favourable to the accumulation of petroleum, further testing of the Willow Creek anticline is unwarranted.

Watson Anticline

The Watson anticline lies a short distance west of the Watson fault in Callum Creek map-area. The possibility of finding Rundle strata in the core of the Watson anticline above the Watson fault is not great. Marjon Lundbreck No. 1 well, l.s. 3, sec. 4, tp. 10, rge. 2, encountered the Watson fault at 5,080 feet depth, and no strata older than those of the Blairmore group were encountered above it. North of this well, the dip of the Watson fault plane decreases markedly, but south of it, as indicated by the Maxmont No. 1 well (still drilling), the dip of the fault plane is believed to have steepened. Whether Rundle strata lie above this steeper part of the Watson fault plane is not yet known. The many shows of oil and gas encountered in the Maxmont No. 1 well are perhaps indicative of migration from deeper seated reservoir beds, presumably in the Rundle formation.

The writer is inclined to believe, at this time, that the Watson fault passes into the Kootenay-Fernie zone of bedding-plane slippage beneath the Watson anticline, and that no Rundle strata will be encountered above the Watson fault in the vicinity of the Maxmont No. 1 well. The Watson fault may be expected to be overlain by the Rundle formation only considerably west of its surface trace, west of the Todd Creek fault.

Quaich Structure

The Quaich structure includes the structural high indicated by the pre-Belly River strata west of the Todd Creek fault and below the Livingstone thrust. If no faults were present in this region the depth to the top of the Rundle formation would be about 3,000 feet. However, low-angle thrusts, the Todd Creek and the faults to the west of it, cause repetitions in the stratigraphic succession (*See* Structure-section E-F, Map 978A). The major faults to the east, the Bob Creek and Tetley faults, are steeply

west-dipping at the surface, whereas the Todd Creek and associated faults dip at low angles to the west. This results in a divergence of these faults at depth, which is presumed to be caused by an anticlinal structure of Palæozoic rocks lying above a major thrust formed by the merging at depth of the Bob Creek, Tetley, Watson, and Whaleback faults into the Kootenay-Fernie zone of bedding-plane slippage. This major fault is believed to cut down section from the Kootenay-Fernie zone into Palæozoic rocks a short distance west of the Bob Creek fault, thereby developing an anticlinal structure within the Palæozoic strata. The Todd Creek and faults to the west of it are believed to have formed on the west flank or 'back limb' of this Palæozoic anticline, the highest part of which, accordingly, lies between the Todd Creek and Bob Creek faults. Its surface projection, however, lies a short distance west of the surface trace of the Todd Creek fault.

The Quaich Globe No. 1 and No. 2 wells, in l.s. 12, sec. 35, and l.s. 4, sec. 35, respectively, tp. 9, rge. 3, Gap map-area, the former, at this date, temporarily suspended, are expected to reach the top of the Rundle formation at about 8,000 feet drilling depth, encountering stratigraphic repetitions on the Todd Creek and associated faults of a total of about 5,000 feet.

Porosity conditions of the Rundle formation where exposed in the Livingstone Range a short distance west of the Quaich Globe wells have been discussed. These conditions are expected to be encountered in the Quaich Globe wells. Failing good porosity in the uppermost porous zones (Member D) of the Rundle formation, deeper drilling is recommended to test those of Members A and B.

Structures Above the Livingstone Thrust

The Rundle formation is everywhere deeply eroded in the Livingstone Range, but lower prospective producing zones within Devonian strata are not exposed. From data available at the present time it does not appear probable that Devonian strata are present beneath any of the structures of the Livingstone Range above the Livingstone thrust. Rundle strata are inferred to underlie some of the structures east of the Livingstone Range, above the Livingstone thrust plane, but these structures are apparently structurally highest north of Gap map-area where the Rundle formation is exposed at the surface. Consequently, whatever accumulations may have been present have now probably been dissipated.

Fly Hill Anticline

The Palæozoic rocks of the Fly Hill anticline probably represent a link between the Palæozoic strata of the Blairmore Range south of Gap map-area and the southern extension of the Highwood Range north of it. The top of the Rundle formation in the Fly Hill anticline is structurally very low with respect to these two regions where the formation outcrops, and no indications of local closures were found.

COAL

GENERAL STATEMENT

Coal seams of varying thickness have been observed in the Kootenay, Belly River, and St. Mary River formations. Some of these seams have been trenched, or opened by means of small adits for local use, but none is utilized commercially at present.

KOOTENAY COAL

The Kootenay formation outcrops only in Gap map-area, and for the most part west of the Livingstone Range. Two seams, 3 and 9 feet thick, are exposed along the west flank of that range. This belt of strata is the least disrupted in the region, but dips westward at high angles. Elsewhere west of the Livingstone Range, the formation is underlain by thrust faults, and may be badly contorted. Adjacent to the range on the east, the Kootenay formation is highly contorted, and the coal seams of this region would be expected to thicken and thin from place to place. A short adit from which coal was extracted for local use is in sec. 23, tp. 10, rge. 3, Gap map-area. The seam lies closely below the basal conglomerate of the Blairmore group. Another adit, on the south bank of Oldman River, in sec. 25, tp. 10, rge. 3, has been driven into a coal seam that lies about 45 feet below the base of the Blairmore.

BELLY RIVER COAL

Coal seams, neither very thick nor of great lateral extent, occur in the upper part of the Belly River formation, close below its contact with overlying Bearpaw shales. These seams were opened in sec. 31, tp. 10, rge. 2, on the north bank of Oldman River. Equivalent strata in sec. 11, tp. 10, rge. 2, show only carbonaceous shale.

ST. MARY RIVER COAL

Four seams, one of which is 8 feet thick, occur in the basal beds of the St. Mary River formation along Oldman River, in sec. 11, tp. 10, rge. 2. The coal of this 8-foot bed has a high lustre, good cleat, and is free from shaly interbeds. It is not slickensided, and does not appear to have been thickened. Other seams occupying the same stratigraphic position are exposed on South Willow Creek, in sec. 21, tp. 13, rge. 2, in small trenches and adits. The coal has a high lustre, but is slickensided and contains some shale lenses.

APPENDIX

DESCRIPTION OF WELLS

Log of Northwest Company, Rice Creek Well

Location: l.s. 1, sec. 4, tp. 14, rge. 2, W. 5th. mer.

Elevation: 4,625± feet.

Geological log prepared by the writer after examination of the samples stored at the Geological Survey, Ottawa.

—	Thickness	Depth
	Feet	Feet
Missing	30	30
Wapiabi Formation		
Shale, dark grey, silty, with minor brown ironstone and fine-grained, grey sandstone, 30 to 80 and 150 to 220 feet; bentonite at 240, 330, and 340 feet	310	340
Bighorn Formation		
Sandstone, coarse-grained, grey, with small chert pebbles	10	350
Shale, dark grey, silty, micaceous; bentonite at 390 feet	80	430
Sandstone, medium-grained, grey, with small chert pebbles at 450 feet	60	490
Blackstone Formation		
Shale, dark grey, silty; fine-grained, grey sandstone at 610 feet; bentonite at 550 feet	140	630
Shale, highly slickensided	70	700
Rice Creek fault	.....	700
Belly River Formation		
Shale and sandstone: pale green, silty shale with medium-grained, green sandstone at 720 and 750 feet	50	750
Shale, light grey	30	780
Sandstone, medium-grained, green	10	790
Missing	10	800
Shale, light grey, splintery	40	840
Sandstone, medium- to coarse-grained, green	20	860
Shale, green, silty, and grey, splintery	30	890
Sandstone, coarse-grained, arkosic, green	20	910
Shale, as above, with medium-grained, green sandstone at 1,000 to 1,010, 1,060 to 1,080, 1,170 to 1,180, and 1,200 to 1,230 feet	320	1,230
Shale, brown	10	1,240
Sandstone, medium- to coarse-grained, arkosic, green	50	1,290
Shale and sandstone: green, silty, and grey shale, with medium-grained, green sandstone at 1,320 feet	30	1,320
Shale, brown, with coal streaks	10	1,330
Shale, green, silty, and grey	70	1,400
'Basal beds' of Belly River formation		
Sandstone, medium-grained, pale green to white	20	1,420
Shale, grey and brown; coal streaks at 1,460 feet	50	1,470
Sandstone, fine-grained, white	10	1,480
Shale, grey, silty; shell fragments at 1,500 feet	100	1,580
Sandstone, fine-grained, white; coarse at 1,620 feet and minor pale green, silty shale at 1,600 feet	40	1,620

—	Thickness	Depth
	Feet	Feet
Belly River Formation—Continued		
Shale, green and grey	30	1,650
Sandstone, medium-grained, white	30	1,680
Shale, green and grey	20	1,700
Sandstone, coarse-grained, white	110	1,810
Shale, grey	50	1,860
Sandstone, medium-grained, grey	20	1,880
Shale, brown; with coal streaks	30	1,910
Sandstone, fine- to medium-grained, light grey to green	30	1,940
'Transition beds' of Belly River formation		
Shale and sandstone: dark grey shale and fine-grained, grey sandstone	40	1,980
Shale, pale green, silty, and dark grey shale, with minor fine white sandstone	40	2,020
Wapiabi Formation		
Missing	10	2,030
Shale, dark grey, silty, with fine-grained, grey sandstone at 2,180 feet	190	2,220
Sandstone, medium-grained, grey	20	2,240
Shale, dark grey, silty; minor sandstone	80	2,320
Sandstone, fine-grained, grey	10	2,330
Shale, dark grey, silty; pyrite at 2,470 feet	170	2,500
Shale, dark grey, silty, with brown ironstone; bentonite at 2,680 feet; fibrous calcite at 2,640 feet	200	2,700
Shale, dark grey, silty; fibrous calcite at 2,710, 2,780, 2,800, and 2,970 to 3,080 feet; brown ironstone at 2,810 to 2,860 feet; bentonite at 3,040 feet	300	3,100
Bighorn Formation		
Conglomerate: small chert pebbles with minor medium-grained sandstone	20	3,120
Sandstone and shale: fine-grained, grey sandstone and dark grey, silty shale; bentonite at 3,190 feet	70	3,190
Shale, dark grey, silty	90	3,280
Sandstone, medium-grained, grey	40	3,320
Shale, dark grey, silty	20	3,340
Conglomerate: chert pebbles in medium-grained, grey sandstone	20	3,360
Blackstone Formation		
Shale, dark grey, silty	30	3,390
Shale and sandstone: shale as above, with fine-grained, grey sandstone	30	3,420
Shale, dark grey	260	3,680
Shale and sandstone: dark grey, silty shale, with medium-grained, grey sandstone	70	3,750
Shale, dark grey; blue bentonite at 3,780 to 3,820 feet; micaceous, blue bentonite at 3,890 and 4,000 to 4,020 feet; minor sandstone in basal 90 feet	270	4,020
Missing	90	4,110
Blairmore Group		
(Upper contact probably at 4,080 feet)		
Shale, green and brown, bentonitic at 4,140 feet	30	4,140
Sandstone, fine-grained, pale green, and green shale	30	4,170
Shale, brown, bentonitic	10	4,180
Sandstone, fine- to medium-grained, green	20	4,200
Shale, grey and green	20	4,220
Sandstone, fine-grained, grey	20	4,240

——	Thickness	Depth
	Feet	Feet
Blairmore Group—Continued		
Shale, pale green and grey	30	4,270
Shale, brown, bentonitic	10	4,280
Shale and sandstone: green shale and fine-grained, green sandstone	20	4,300
Shale, pale green, silty; missing at 4,310 feet	20	4,320
Sandstone, fine-grained, green; missing at 4,340 feet	20	4,340
Tuff, friable, waxy, light brown	10	4,350
Missing	50	4,400
Shale, grey	10	4,410
Tuff, friable, waxy, light brown	10	4,420
Shale, pale green	20	4,440
Shale, grey and green	30	4,470
Sandstone, medium-grained, speckled grey	20	4,490
Shale, green and grey	10	4,500
Sandstone, medium- to coarse-grained, green; coaly streaks at 4,500 feet; McDougall-Segur sand	90	4,590
Missing	10	4,600
Shale, green, silty, with maroon at 4,610 to 4,630 and 4,670 feet	70	4,670
Sandstone, medium-grained, green; coaly streaks at 4,710 feet	50	4,720
Shale, grey, silty	30	4,750
Sandstone, medium-grained, green	240	4,990
Shale, dark grey	10	5,000
Sandstone, fine- to medium-grained, green	150	5,150
Shale, grey, silty	20	5,170
Sandstone, fine- to coarse-grained, white	40	5,210
Willow Creek fault	.....	5,210
Bighorn Formation		
(Overturned)		
Sandstone and shale: dark grey, slickensided shale and green sandstone	10	5,220
Shale, dark grey, silty, slickensided	80	5,300
Sandstone, medium-grained, grey, with chert pebbles	20	5,320
Wapiabi Formation		
(Overturned synclinal structure)		
Shale, dark grey, silty; brown ironstone	30	5,350
Shale, dark grey, silty	150	5,500
Shale and sandstone: dark grey, silty shale, with brown ironstone and fine-grained, grey sandstone	30	5,530
Shale, dark grey, silty, slickensided; brown ironstone	60	5,590
Shale, dark grey, silty	150	5,740
Bighorn Formation		
Conglomerate; green chert pebbles	7	5,747

Log of Northwest Company, Willow Creek Well

Location: l.s. 16, sec. 29, tp. 14, rge. 2, W. 5th. mer.

Elevation: 4,400 ± feet.

Geological log prepared by the writer after examination of the samples stored at the Geological Survey, Ottawa.

——	Thickness	Depth
	Feet	Feet
Drift	80	80
Blackstone Formation		
Shale, dark grey, silty	120	200
Shale and sandstone: shale as above, with fine-grained, grey sandstone abundant at 240 feet	80	280
Missing	290	570
Blairmore Group		
Sandstone, coarse-grained, angular, black and white	10	580
Shale, grey	20	600
Shale, green and brown, bentonitic	20	620
Sandstone, fine-grained, green	50	670
Shale, pale green and grey	20	690
Shale, grey, green, and brown, bentonitic	20	710
Sandstone, fine- to medium-grained, green	10	720
Shale, grey	10	730
Tuff, spotted, fine-grained, and pale green and brown, bentonitic shale	10	740
Sandstone, medium-grained, green	10	750
Shale, pale green, silty	10	760
Tuff, bentonitic, spotted	10	770
Sandstone, medium-grained, green	20	790
Shale, pale green; tuffaceous at 810 feet	20	810
Sandstone, medium-grained, green	50	860
Shale, pale green, silty; brown bentonitic at 860 to 880 feet	40	900
Shale, grey	10	910
Shale, pale green and brown, bentonitic	50	960
Sandstone, medium-grained, speckled grey	10	970
Shale, greenish grey, silty	10	980
Sandstone, medium- to coarse-grained, greenish grey, arkosic; McDougall-Segur sand	50	1,030
Shale, green, silty	30	1,060
Sandstone, fine-grained, green	10	1,070
Shale, green, silty, and brown; coaly streaks at 1,120 feet	60	1,130
Sandstone, medium-grained, green	20	1,150
Shale, green and maroon	20	1,170
Shale, green; missing at 1,210 feet	40	1,210
Sandstone, medium-grained, green, arkosic	40	1,250
Shale, green and minor grey	40	1,290
Shale, brown and grey, with coal at 1,300 and 1,310 feet	30	1,320
Sandstone, medium-grained, green, and green shale	60	1,380
Sandstone, medium- to coarse-grained, green, arkosic	10	1,390
Shale, green, silty; minor brown at 1,400 to 1,430 feet	120	1,510
Missing	10	1,520
Shale, grey and green	10	1,530
Sandstone, medium-grained, green, arkosic	40	1,570
Shale, green and grey; fragments of gastropod shells at 1,610 feet	40	1,610
Limestone and shale: brown, finely crystalline limestone and grey shale	60	1,670
Shale, grey and green	60	1,730
Sandstone, fine-grained, calcareous, white	100	1,830

—	Thickness	Depth
	Feet	Feet
Blairmore Group—Continued		
Shale, dark grey	10	1,840
Shale and sandstone: dark grey shale and fine-grained, white sandstone	30	1,870
Missing	10	1,880
Sandstone, fine- to medium-grained, grey, with siderite spherules at 1,930 to 1,950 feet; Dalhousie sand	70	1,950
Kootenay Formation		
(Overturned anticlinal structure)		
Shale, dark grey, silty	10	1,960
Missing	10	1,970
Shale, dark grey, carbonaceous; coal	20	1,990
Sandstone, medium-grained, dark grey	10	2,000
Shale, dark grey, carbonaceous; coal at 2,020 feet	20	2,020
Missing	10	2,030
Sandstone, medium-grained, grey to white	50	2,080
Shale, dark grey, carbonaceous; coal	10	2,090
Sandstone, medium-grained, dark grey; sheared coal at 2,130 feet	40	2,130
Missing; axis of anticline; section below is overturned	30	2,160
Sandstone; dark grey sandstone, carbonaceous shale, and coal	20	2,180
Sandstone, medium-grained, dark grey	20	2,200
Shale, dark grey, carbonaceous; coal	20	2,220
Sandstone, medium-grained, grey to white	10	2,230
Coal	10	2,240
Sandstone, medium-grained, grey	30	2,270
Shale, dark grey, carbonaceous; coal	30	2,300
Sandstone, fine-grained, white; grey shale	10	2,310
Shale, dark grey	10	2,320
Blairmore Formation		
(Overturned synclinal structure)		
Sandstone, coarse-grained; quartz and black chert; siderite spherules; Dalhousie sand	40	2,360
Shale, dark grey; ostracods at 2,400 feet	40	2,400
Sandstone, fine-grained, calcareous, light grey	50	2,450
Shale, dark grey; minor sandstone; sheared at 2,490 feet	40	2,490
Sandstone, fine-grained, calcareous, light grey; similar to that at 2,450 feet; may be repetition on fault at 2,490 feet	70	2,560
Shale, grey and green	80	2,640
Sandstone and shale: medium-grained, grey sandstone at 2,640 to 2,680 and 2,720 to 2,770 feet, and grey and green shale; synclinal axis about 2,700 feet	130	2,770
Shale, grey and green, sheared	20	2,790
Shale and sandstone: grey and green shale; medium-grained, green sandstone	20	2,810
Sandstone, fine-grained, calcareous, light grey	60	2,870
Shale, grey	30	2,900
Sandstone, medium- to coarse-grained, black and white, conglomeratic; Dalhousie sand	30	2,930
Kootenay Formation		
Shale, dark grey, carbonaceous	20	2,950
Fault	.....	2,950
Blairmore Group		
Sandstone, medium-grained, grey	50	3,000
Missing	10	3,010
Sandstone, medium-grained to conglomeratic, grey; siderite spherules; Dalhousie sand	40	3,050

—	Thickness	Depth
	Feet	Feet
Kootenay Formation		
Shale, dark grey, carbonaceous; coal	10	3,060
Sandstone, fine-grained, brown-stained	10	3,070
Shale, dark grey, carbonaceous	10	3,080
Sandstone, medium-grained, brown-stained	30	3,110
Sandstone, similar to Dalhousie sand; sample out of place	10	3,120
Sandstone and shale: medium-grained, dark grey sandstone and sheared brown shale	10	3,130
Shale, dark grey, carbonaceous, sheared; coal	40	3,170
Missing	10	3,180
Sandstone, fine-grained, grey	20	3,200
Fernie Group		
(Overturned anticlinal structure)		
Shale, black, fissile, sheared to 3,260 feet; belemnite fragments at 3,270 and 3,300 feet; glauconitic sandstone at 3,290 feet	110	3,310
Shale, black, fissile; fragments of brown, hematitic sandstone	20	3,330
Kootenay Formation		
(Overturned)		
Sandstone and shale: dark grey, fine-grained sandstone and grey shale	30	3,360
Shale, dark grey, carbonaceous; coal at 3,370 feet; minor sandstone	50	3,410
Sandstone, fine-grained, dark grey, brown-stained	40	3,450
Sandstone and shale: dark grey, carbonaceous shale and fine-grained, grey sandstone	30	3,480
Shale, dark grey, carbonaceous; coal	10	3,490
Shale, dark grey, sheared	10	3,500
Fault	.....	3,500
Blairmore Group		
Missing	10	3,510
Sandstone, fine-grained, white	40	3,550
Sandstone, coarse-grained to conglomeratic; fine-grained at 3,570 to 3,590 feet; Dalhousie sand	50	3,600

Log of Marjon Lundbreck No. 1 Well

Location: l.s. 3, sec. 4, tp. 10, rge. 2, W. 5th. mer.

Elevation: 4,570 ± feet.

Geological log prepared by the writer after examination of the samples stored at the Geological Survey, Ottawa.

—	Thickness	Depth
	Feet	Feet
Wapiabi Formation		
Shale, light grey, silty, with minor brown ironstone; minor sandstone at 70 and 110 feet	120	120
Sandstone, fine- to medium-grained, grey	20	140
Shale, dark grey, silty, with ironstone below 250 feet	140	280
Shale, dark grey, calcareous, minor sandstone at 310 feet; micaceous bentonite at 390 to 430 feet	230	510

—	Thickness	Depth
	Feet	Feet
Bighorn Formation		
Sandstone, medium-grained, grey, with chert pebbles	20	530
Sandstone and shale: fine-grained, grey sandstone and dark grey, silty shale; traces of ironstone	30	560
Shale, dark grey, silty; bentonite at 650 feet	90	650
Shale and sandstone: as above	70	720
Sandstone, medium-grained, grey	20	740
Missing	80	820
Fault	.....	820
Wapiabi Formation		
Shale, dark grey; minor ironstone; micaceous bentonite at 830 feet; slickensided	40	860
Shale, dark grey; minor ironstone; minor sandstone at 880 and 940 to 970 feet	220	1,080
Sandstone, medium-grained, grey	30	1,110
Shale, dark grey, silty; ironstone; bentonite at 1,240 feet	130	1,240
Shale, slickensided, dark grey	40	1,280
Fault	.....	1,280
Shale, dark grey, silty; minor sandstone	30	1,310
Missing	10	1,320
Shale, dark grey, silty; slickensided at 1,400 feet; micaceous bentonite at 1,400 and 1,480 feet, and abundant at 1,460 feet	160	1,480
Shale and sandstone: dark grey, silty shale and fine-grained, grey sandstone	70	1,550
Shale, dark grey, silty; sandstone at 1,710 and 1,790 to 1,810 feet; micaceous bentonite at 1,780 feet; ironstone below 1,810 feet	370	1,920
Bighorn Formation		
Sandstone, coarse-grained, grey, with chert pebbles	10	1,930
Shale, dark grey, silty; minor sandstone; minor ironstone; slickensided at 2,090 to 2,120 feet (fault at 2,110 feet)	190	2,120
Shale, dark grey, silty, with fine-grained, grey sandstone; chert pebbles at 2,160 feet; minor ironstone	150	2,270
Sandstone, medium-grained, grey	90	2,360
Blackstone Formation		
Shale, dark grey, silty; minor sandstone; minor ironstone at 2,470 to 2,480 feet	210	2,570
Shale, dark grey; bentonite, green, micaceous at 2,570 feet; blue at 2,650 feet; blue, micaceous at 2,700 feet; blue, pyritic at 2,720 feet; white, micaceous at 2,740 to 2,780 feet	240	2,810
Shale, dark grey, silty; minor grey sandstone	30	2,840
Blairmore Group		
Shale, pale green	20	2,860
Sandstone, coarse-grained, angular, black and white	10	2,870
Fault	.....	2,870
Blackstone Formation		
Shale, grey, slickensided, and minor grey sandstone	120	2,990
Blairmore Group		
Shale, pale green	20	3,010
Sandstone, coarse-grained, black and white	10	3,020
Shale, pale green, silty	10	3,030
Shale. brown, bentonitic	20	3,050

—	Thickness	Depth
	Feet	Feet
Blairmore Group—Continued		
Shale, maroon and green	30	3,080
Shale, green, silty, minor grey, and medium-grained, green sandstone at 3,090 feet	40	3,120
Sandstone, fine- to coarse-grained, green	20	3,140
Shale, green, silty, and brown, bentonitic	30	3,170
Shale, green, silty, and medium-grained, green sandstone at 3,180 feet	30	3,200
Tuff, brown, with angular fragments of feldspar; bentonitic shale	30	3,230
Shale, pale green and brown, bentonitic	10	3,240
Shale, maroon and green	20	3,260
Sandstone, fine-grained, green	20	3,280
Shale, green, silty, and brown, bentonitic	10	3,290
Tuff, as above; coarser fragments	20	3,310
Sandstone, medium-grained, green	20	3,330
Shale, pale green; maroon and brown at 3,350 feet	20	3,350
Tuff, brown; bentonitic shale and minor tuffaceous shale	40	3,390
Shale, pale green, silty; minor fine-grained sandstone	110	3,500
Sandstone, fine- to coarse-grained, green; conglomeratic at 3,550 to 3,600 feet; McDougall-Segur sand	150	3,650
Shale, pale green and maroon	20	3,670
Shale, green and brown	30	3,700
Sandstone, fine-grained, green	30	3,730
Shale, green and brown	70	3,800
Shale, green and maroon	30	3,830
Sandstone, medium-grained, green	10	3,840
Shale, green, silty, and brown; maroon at 3,880 feet	70	3,910
Sandstone, medium-grained, green	30	3,940
Shale, dark grey	30	3,970
Shale, green and brown; maroon at 4,020 to 4,060 feet	130	4,100
Shale, pale green; minor sandstone	40	4,140
Sandstone, fine- to medium-grained, green	30	4,170
Shale, pale green	10	4,180
Sandstone and shale: fine-grained, green sandstone and green shale	70	4,250
Shale, green and brown	140	4,390
Sandstone, medium- to coarse-grained, green	120	4,510
Shale, pale green and grey	10	4,520
Shale, dark grey, carbonaceous, slickensided	20	4,540
Missing	20	4,560
Shale, slickensided, dark grey, carbonaceous; plant fragments; some coarse-grained, grey sandstone	30	4,590
Shale, pale green and brown	70	4,660
Sandstone, fine-grained, green	40	4,700
Shale, pale green, silty	20	4,720
Sandstone, coarse-grained, green	20	4,740
Missing	40	4,780
Shale, pale green	10	4,790
Shale, dark grey, carbonaceous, slickensided	20	4,810
Shale, green, brown, and grey	30	4,840
Shale and sandstone: green, silty shale and medium-grained, green sandstone	70	4,910
Sandstone, medium-grained, green	90	5,000
Shale, grey; minor green	30	5,030
Sandstone, medium-grained, green	50	5,080
Watson fault	.....	5,080
Blackstone Formation		
Shale, dark grey, silty, slickensided; minor sandstone	230	5,230

—	Thickness	Depth
	Feet	Feet
Blairmore Group		
Shale, pale green, silty	30	5,260
Sandstone, medium-grained, green	20	5,280
Shale, pale green and brown; bentonitic	50	5,320
Shale, brown, tuffaceous and bentonitic	20	5,350
Sandstone and shale: medium-grained green sandstone and green shale	10	5,360
Shale, pale green	30	5,390
Shale, pale brown, bentonitic, with brown mica flakes	10	5,400
Shale, pale green and brown, bentonitic	20	5,420
Missing	20	5,440
Shale, pale green; minor brown shale	40	5,480
Missing	10	5,490
Fault	.....	5,490
Alberta Group (Blackstone ? Formation)		
Shale, dark grey, silty; minor grey sandstone at 5,560 to 5,580 feet; missing at 5,500 to 5,520, 5,680 to 5,700, 5,730 to 5,750, 5,760 to 5,850, and 5,860 to 5,920 feet	430	5,920
Whaleback fault	.....	5,920
Belly River Formation		
Sandstone, medium- to coarse-grained, green	40	5,960
Shale, pale green, silty	70	6,030
Sandstone, medium- to coarse-grained, micaceous, green; minor green shale at 5,980 feet	110	6,140
Missing	64	6,204

Log of Quaich Globe No. 1 Well

Location: l.s. 12, sec. 35, tp. 9, rge. 3, W. 5th mer.

Elevation: 4,875 ± feet.

Geological log prepared by the writer after examination of the samples stored at the Geological Survey, Ottawa.

—	Thickness	Depth
	Feet	Feet
Wapiabi Formation		
Shale, dark grey, silty, with minor fine-grained, grey sandstone	80	80
Bighorn Formation		
Sandstone, fine-grained, grey to white	80	160
Shale, dark grey, silty	40	200
Sandstone, medium-grained, grey to white; angular sand grains	20	220
Blackstone Formation		
Shale, dark grey, silty; minor fine-grained sandstone throughout, abundant at 540 feet; bentonite at 330 feet	430	650

—	Thickness	Depth
	Feet	Feet
Blairmore Group		
Shale, pale green, silty, and brown, bentonitic at 670 feet	30	680
Sandstone, medium-grained, speckled; grains of white quartz and green and black chert	10	690
Shale, pale green, silty, and brown, bentonitic at 700 and 720 feet	40	730
Sandstone, fine-grained, green	20	750
Shale, pale green, silty	50	800
Sandstone, fine-grained, green	20	820
Shale, green and grey, tuffaceous	10	830
Sandstone, medium-grained, speckled grey	10	840
Shale, pale green; brown, bentonitic at 850 and 880 to 900 feet; fine-grained, green sandstone at 860 to 880 feet	70	910
Shale, pale green, silty, and grey, tuffaceous	30	940
Shale, pale green, silty	60	1,000
Shale, pale green, silty, and brown, bentonitic; brown, tuffaceous at 1,010 feet	60	1,060
Shale, pale green and maroon; medium- to coarse-grained, green sandstone at 1,090 and 1,130 feet	70	1,130
Shale, pale green, silty, and tuffaceous shale	50	1,180
Shale, pale green and maroon	20	1,200
Sandstone, fine-grained, green	20	1,220
Shale, pale green, and tuffaceous shale	30	1,250
Sandstone, fine-grained, green, and green shale at 1,270 and 1,290 feet	40	1,290
Sandstone, fine- to medium-grained, green, becoming coarse 1,330 to 1,350 feet; McDougall-Segur sand	110	1,400
Shale, pale green and brown	30	1,430
Missing	20	1,450
Sandstone, medium-grained, speckled grey	10	1,460
Fault	.....	1,460
Blackstone Formation		
Shale, dark grey, silty; minor fine-grained, grey sandstone	90	1,550
Blairmore Group		
Shale, pale green and brown; minor fine-grained, green sandstone at 1,560 and 1,570 to 1,590 feet	70	1,620
Sandstone, medium-grained, green	30	1,650
Fault	.....	1,650
Wapiabi Formation		
Shale, dark grey, silty; fine-grained, grey sandstone at 1,920 to 1,950 feet; bentonite at 1,860 and 1,960 to 2,030 feet	430	2,080
Bighorn Formation		
Sandstone, fine-grained, grey	70	2,150
Shale, dark grey, silty	30	2,180
Sandstone, fine-grained, grey, with chert pebbles	20	2,200
Blackstone Formation		
Shale, dark grey, silty; micaceous bentonite at 2,250, 2,280, and 2,330 feet; ironstone to 2,290 feet; medium-grained sandstone at 2,480 feet	290	2,490

Log of Socony Vacuum, Stimson No. 1 Well

Location: l.s. 12, sec. 5, tp. 15, rge. 2, W. 5th mer.

Elevation: 4,650 ± feet.

Geological log prepared by the writer after examination of the samples stored at the Geological Survey, Ottawa.

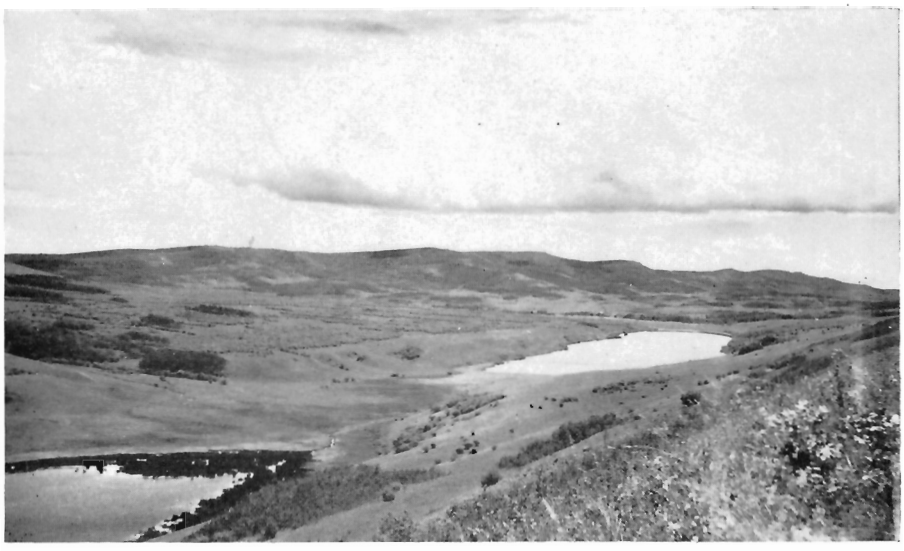
—	Thickness	Depth
	Feet	Feet
Drift	60	60
Blackstone Formation		
Shale, dark grey, silty; bentonite at 200 feet; slickensided at 220 feet	220	280
Sandstone and shale: dark grey, silty shale and fine-grained, dark grey sandstone; chert pebbles at 360 and 370 feet; may represent Bighorn formation in fault slice above Rice Creek fault, the upper branch occurring at 220 feet	120	400
Shale, dark grey, silty, slickensided at 420 to 460 feet	60	460
Rice Creek fault	.....	460
Wapiabi Formation		
Shale, dark grey, silty; ironstone and pyrite	120	580
Bighorn Formation		
Sandstone, fine-grained, grey; chert pebbles	10	590
Shale, dark grey, silty; minor sandstone	50	640
Sandstone, fine-grained, grey	60	700
Shale, dark grey, silty; ironstone at 770, 840, and 850 feet; sandstone at 780 to 840 feet	180	880
Sandstone, fine-grained, grey; chert pebbles	30	910
Blackstone Formation		
Shale, dark grey, silty; fine-grained, grey sandstone at 1,100, 1,140, 1,190 to 1,230 feet; blue, micaceous bentonite at 1,080 feet; slickensided throughout	350	1,260
Sandstone, fine-grained, grey	20	1,280
Shale, dark grey, silty; sandstone at 1,370, 1,380, 1,470 to 1,520 feet; blue, micaceous bentonite at 1,320, white at 1,410, grey, micaceous at 1,450 and 1,540 feet	310	1,590
Sandstone, fine-grained, grey, with angular pebbles of chert; 'The Grit'	10	1,600
Blairmore Group		
Shale, pale green, and grey, bentonitic	10	1,610
Sandstone, medium-grained, speckled greenish grey	20	1,640
Shale, pale green, silty, and brown, bentonitic at 1,640 to 1,660 feet	40	1,680
Sandstone, medium-grained, speckled grey	10	1,690
Shale, brown, bentonitic; tuffaceous at 1,760; pale green, silty at 1,710 to 1,730 feet	70	1,760
Shale, maroon and pale green	30	1,790
Shale, pale green, and brown, bentonitic; tuffaceous at 1,820 feet	50	1,840
Sandstone, fine-grained, green	20	1,860
Shale, brown, bentonitic; tuffaceous at 1,900 feet; pale green and maroon at 1,870 feet	40	1,900
Sandstone, medium- to coarse-grained, speckled grey, arkosic	30	1,930
Shale, pale green, silty; brown; maroon	20	1,950
Sandstone, medium-grained, speckled grey	10	1,960
Shale, brown, carbonaceous	20	1,980

—	Thickness	Depth
	Feet	Feet
Blairmore Group—Continued		
Sandstone, fine-grained, green; grey and green shale at 2,000 feet.	50	2,030
Shale, green, and brown, bentonitic; tuffaceous at 2,080 and 2,090 feet; maroon at 2,070 and 2,100 feet	70	2,100
Sandstone, fine-grained, green	10	2,110
Shale, pale green, silty; maroon at 2,130 and 2,150 to 2,170 feet; brown at 2,120, 2,150, and 2,170 feet	60	2,170
Sandstone, fine- to medium-grained, green; shaly at 2,200 feet; missing at 2,210 feet; coarse-grained with coal streaks at 2,250 feet; McDougall-Segur sand	80	2,250
Shale, pale green, silty, with brown shale at 2,270 feet; grey, carbonaceous with coal at 2,290 to 2,320 feet	70	2,320
Sandstone, fine-grained, green; missing at 2,350 feet	50	2,370
Shale, light grey; coal streaks at 2,400 feet	40	2,410
Sandstone, fine-grained, green; coal streaks at 2,430 feet	30	2,440
Shale, pale green; maroon at 2,480 feet	40	2,480
Sandstone, medium-grained, grey; coal streaks	40	2,520
Shale, pale green, silty; maroon at 2,570 feet; fine-grained, green sandstone at 2,540 feet and 2,580 to 2,600 feet	80	2,600
Shale, pale green, silty; grey at 2,640 feet	40	2,640
Sandstone, fine- to medium-grained, white, pure quartz; Home sand	10	2,650
Shale, light and dark grey	50	2,700
Limestone and shale: shale as above, with light brown, finely crystalline, argillaceous limestone	130	2,830
Shale, dark grey; ostracods and shell fragments in brownish grey, fissile, bituminous shale at 2,850 feet	40	2,870
Sandstone, fine-grained, calcareous, light grey	10	2,880
Shale, light grey, calcareous	10	2,890
Sandstone, medium- to coarse-grained, speckled grey; quartz and chert grains; Dalhousie sand	10	2,900
Kootenay Formation		
Shale, dark grey to black, carbonaceous; coal	40	2,940
Sandstone, fine-grained, dull black	20	2,960
Fernie Group		
Sandstone, medium-grained, light brown, pure quartz, glauconitic at 2,980 to 3,000 feet, micaceous 3,050 to 3,110 feet; dark grey shale at 3,020 and 3,030 to 3,050 feet; missing 3,010 feet; 'Brown sand'	150	3,110
Shale, black, silty, slickensided; glauconitic at 3,180 feet	70	3,180
Shale, black, fissile; bentonite at 3,190 and 3,290 feet; glauconitic at 3,190 to 3,220 and 3,250 feet; fine-grained, grey limestone at 3,220 to 3,250 feet	220	3,330
Sandstone, fine-grained, pyritic, light grey to brown	80	3,410
Shale, grey and brownish grey	50	3,460
Sandstone, fine- to coarse-grained, light grey to white, calcareous; quartz grains	30	3,490
Rundle Formation		
Member B		
Dolomite, calcareous, finely crystalline, dense, light grey	20	3,510
Dolomite, granular, finely crystalline, minutely porous with vugs, light buff	30	3,540
Dolomite, finely crystalline, dense, light grey; blue-grey chert at 3,570 feet	30	3,570
Dolomite, calcareous, arenaceous, light grey; very fine disseminated sand	10	3,580
Dolomite, finely crystalline, dense, light grey	10	3,590

—	Thickness	Depth
	Feet	Feet
Rundle Formation—Continued		
Member B—Continued		
Dolomite and anhydrite: light brown, finely crystalline, dense dolomite and white, granular and massive anhydrite; anhydrite appears to have occupied vugs in dolomite....	20	3,610
Dolomite, light to dark brown, finely crystalline; with grey dolomite to 3,610 feet; granular below 3,660 feet; pyrite in small vugs at 3,680 feet.....	70	3,680
Dolomite and anhydrite: light brown and grey, finely crystalline, dense to granular dolomite; white, granular and massive anhydrite.....	30	3,710
Dolomite and limestone: light brown, granular, porous, bitumen filling, becoming calcareous at 3,740 feet; limestone below 3,750 feet with no porosity.....	60	3,770
Limestone, coarsely crystalline, light brown.....	10	3,780
Dolomite, calcareous, arenaceous, finely crystalline, buff; very fine disseminated sand.....	10	3,790
Dolomite and anhydrite; finely crystalline, light brown and granular anhydrite.....	20	3,810
Dolomite, finely crystalline, brown, dense to granular; arenaceous with bitumen specks at 3,890 feet; white, granular anhydrite at 3,830 and 3,860 feet.....	80	3,890
Member A		
Limestone, coarsely crystalline, brown.....	30	3,920
Limestone, dolomitic, finely crystalline, brown, with brown and grey chert at 3,925 and 3,935 feet.....	30	3,950
Limestone, coarsely crystalline, light brown.....	25	3,975
Limestone, dolomitic, finely crystalline, dense, dark grey.....	10	3,985
Limestone, coarsely crystalline, light buff.....	70	4,055
Limestone, dolomitic, medium crystalline, light grey.....	10	4,065
Limestone, coarsely crystalline, light buff.....	65	4,130
Limestone, arenaceous, light grey; very fine, disseminated sand.....	15	4,145
Limestone, finely crystalline, light brown; coarsely crystalline, light buff at 4,150 to 4,160, 4,165 to 4,215, 4,250 to 4,350, 4,360 to 4,390, and 4,410 to 4,470 feet; porosity with bitumen specks at 4,430 to 4,450 and 4,340 feet.....	325	4,470
Limestone, finely crystalline, dark grey; coarsely crystalline, light buff at 4,490, 4,520, and 4,550 feet; missing at 4,510 feet.....	80	4,550
Limestone, finely crystalline, light brown; buff chert at 4,555 and 4,565 feet.....	20	4,570
Limestone, finely crystalline, dark grey; coarsely crystalline, dark brown at 4,580 feet; buff chert at 4,630 feet.....	80	4,650
Limestone, coarsely crystalline, dark brown; finely crystalline, dark grey at 4,660 to 4,700 and 4,720 feet; buff chert at 4,675 to 4,700 feet.....	90	4,740
Limestone, arenaceous and argillaceous, dark brown with reddish tinges, finely crystalline.....	5	4,745
Limestone, finely crystalline, dark grey; coarsely crystalline, light buff at 4,770 and 4,790 feet; grey and buff chert to 4,785 feet.....	75	4,820
Limestone, coarsely crystalline, light buff, in part highly sheared and slickensided.....	40	4,860
Limestone, finely crystalline, dark grey, with grey chert; coarsely crystalline, light buff at 4,880, 4,910 to 4,950, 4,970 to 5,000, and 5,020 to 5,040 feet.....	180	5,040

—	Thickness	Depth
	Feet	Feet
Banff Formation		
Limestone, finely crystalline, dark grey; dark grey chert at 5,100 feet; coarsely crystalline, dark brown at 5,070 and 5,120 feet.	100	5,140
Willow Creek and Meinsinger faults (merged)	.....	5,140
Blairmore Group		
Sandstone, calcareous, fine-grained, light brown, with carbonized plant remains; slickensided black shale and coal; may be Kootenay	10	5,150
Sandstone, medium-grained, green	10	5,160
Shale, dark grey to black, slickensided, rare coal, greenish grey at 5,180 feet	60	5,220
Sandstone, medium-grained, green	10	5,230
Shale, dark grey and green, slickensided; coal at 5,200 feet	30	5,260
Sandstone, medium-grained, green to grey; speckled micaceous at 5,280 feet	30	5,290
Shale, dark grey and green, slickensided	20	5,310
Sandstone, coarse-grained, speckled grey	10	5,320
Shale, dark grey, slickensided; mostly green at 5,370 and 5,400 feet; mostly brown at 5,370 and 5,390 feet	90	5,410
Sandstone, medium-grained, green	10	5,420
Shale, dark grey	10	5,430
The above interval of Blairmore strata lying below the Willow Creek and Meinsinger faults appears similar lithologically, although thicker, to the interval between 2,250 and 2,410 feet depth.		

PLATE II

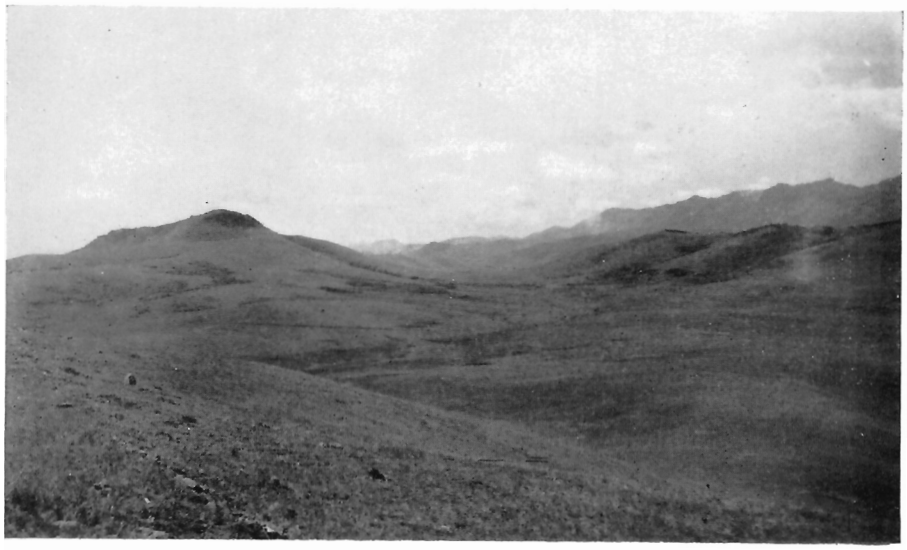


A. Chain Lakes, northwest Langford Creek. The lakes occupy an abandoned, glacial meltwater channel, which has been divided up by small deltas deposited by streams flowing from the Porcupine Hills to the left. (Page 9.)

B. Contact between the Rocky Mountain formation (above) and Member D of the Rundle formation, west flank of Livingstone Range, 5½ miles south of The Gap. Top of surveying rod marks base of Rocky Mountain arenaceous dolomites. Contact is unconformable, as may be seen to the right where 3 feet of calcareous shale and grey limestone are missing. (Page 18.)

97972

A. Erosional unconformity at the base of the Porcupine Hills formation on North Creek, sec. 19, tp. 11, rge. 1. Underlying beds are Willow Creek. (Page 49.)



93214

B. Looking south from sec. 3, tp. 10, rge. 2. Basal Belly River strata of Watson syncline cap tree-covered butte in left distance. Watson thrust lies immediately to the left, and passes through foreground to the right. Maxmont No. 1 well seen in the central distance on west flank of Watson anticline, which forms ridge in Belly River strata in right middle distance. Livingstone Range on horizon. Glacial debris covers valley in Wapiabi strata. (Page 62.)

PLATE IV

Looking south towards Thunder Mountain from north of The Gap. In central foreground is overturned Livingstone anticline in basal Rundle and core of Banff. Gap syncline passes through crest of Thunder Mountain; Gap anticline and fault to right. Glacial cirque developed along Gap syncline. (Page 69.)

93216

A. Looking south from sec. 6, tp. 10, rge. 2, across valley of Todd Creek in left middle distance. Belly River strata underlie sparsely wooded ridges. Alberta strata in broad valley in front of Livingstone Range, separated from Belly River by Todd Creek fault. (Page 75.)

B. View showing folded Lewis thrust, looking south from base of Tornado Mountain. West-dipping Palæozoic strata form the High Rock Range of the Rocky Mountains to the right. Rundle caps crest of ridge; Banff forms cliff; Exshaw shale follows line of vegetation; Devonian strata below. Lewis thrust lies at about top of talus line, dipping west. To the left: west flank of syncline in Palæozoic rocks; Lewis thrust at about top of talus, dipping east; east-dipping Belly River strata lie exposed on bare spur in the central foreground. (*Photograph courtesy of R. Thorsteinson.*) (Page 86.)

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