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DEPARTMENT OF ENERGY, MINES AND RESOURCES

BULLETIN 168

STRUCTURE OF THE NORTHERN FOOTHILLS AND EASTERN MOUNTAIN RANGES, ALBERTA AND BRITISH COLUMBIA, between latitudes 53°15′ and 57°20′

E. J. W. Irish

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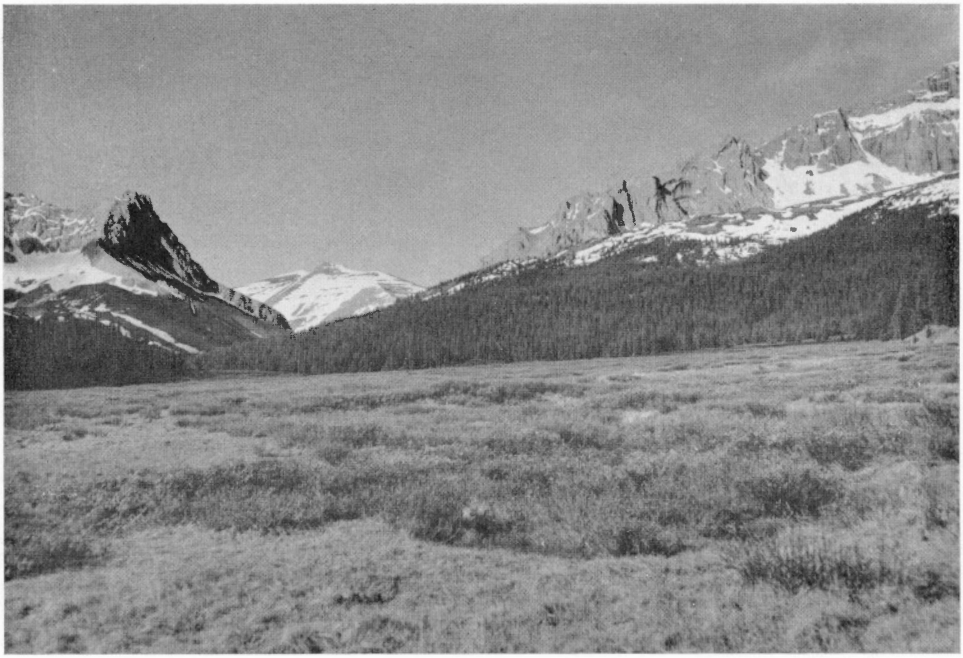

E.J.W.I. 1-8-54

PLATE I. View west through the Persimmon Range toward Eagles Nest Pass. The Rocky Pass thrust separates the overthrust Palaeozoic formations of the mountains from the Upper Cretaceous formations within the Lancaster syncline in the foreground.

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PREFACE

The Foothills belt and eastern ranges of the Canadian Rocky Mountains are regions of considerable geological complexity, where folds and thrust faults involve Palaeozoic, Mesozoic, and Tertiary strata. Many years of detailed systematic geological investigation have provided a means of interpreting the structures of this region.

In this report the author describes many of the folds and faults that have been mapped in: (1) a part of the foothills and mountains of Alberta, and (2) a part of the foothills and mountains of northeastern British Columbia. The report includes maps showing most of the folds and faults within the two areas under discussion, as well as several figures of individual structures, which illustrate the author's ideas regarding the origin of the folds and thrust faults and the temporal relationships between them.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, October 25, 1965

BULLETIN 168 — Die Struktur der nördlichen Vorberge und der östlichen Bergketten in Alberta und Britisch-Kolumbien
Von E. J. W. Irish

БЮЛЛЕТЕНЬ 168 — Структура северного предгорья восточной части горных цепей Альберты и Британской Колумбии
Э. Дж. У. Айриш

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STRUCTURE OF THE NORTHERN FOOTHILLS AND EASTERN MOUNTAIN RANGES, ALBERTA AND BRITISH COLUMBIA, BETWEEN LATITUDES 53°15′ AND 57°20′

Abstract

In the Foothills belt and eastern ranges of the Rocky Mountains in western Alberta, north of Athabasca River, and in British Columbia between Pine and Sikanni Chief Rivers, compressive stress has been relieved by the movement of large masses of strata relatively to the northeast on southwest-dipping thrust fault surfaces, and by mainly contemporaneous folding.

Most folds appear to be intimately related dynamically to an underlying thrust fault and/or to pass laterally along the strike into a thrust fault. The east-dipping axial planes of some folds and the present high angle of dip of many subsidiary thrust faults are both considered to be the result of southwestward rotation of the hanging-wall strata, owing to eastward movement on one or more underlying concave-upward thrust surfaces.

The spacing between thrust faults, their length, and the amount of movement on each are dependent, to a large extent, on the relative competency and thickness of the stratigraphic succession in that particular region. The same factors appear, also, to determine the relative predominance of either folding or faulting as a deforming process.

Résumé

Dans la zone des avants-monts et des chaînes de l'est des Rocheuses dans l'ouest de l'Alberta, au nord de la rivière Athabasca, et en Colombie-Britannique entre les rivières aux Pins et Chef Sikanni, le déplacement de masses considérables de strates vers le nord-est le long des surfaces de failles de poussée à pendage sud-ouest, ainsi que des plissements pour la plupart contemporains ont réduit les forces de compression qui existaient.

La plupart des plissements semblent être reliés intimement et dynamiquement à une faille de poussée sous-jacente, et semblent pénétrer latéralement dans une faille de poussée parallèlement à sa direction. Il semble que les plans axiaux à pendage Est de certains plissements et la pente prononcée de certaines failles de poussée secondaires soient le résultat d'une rotation, vers le sud-ouest, des strates du toit, due à un glissement vers l'est sur une ou plusieurs surfaces concaves sous-jacentes.

L'espacement entre les failles de poussée, leur longueur et l'ampleur des mouvements de chacune dépendent beaucoup de la compétence et de l'épaisseur relatives de la succession stratigraphique dans la région en question. Les mêmes facteurs semblent aussi déterminer la prédominance relative des plissements ou des failles comme procédé de déformation.

INTRODUCTION

Detailed stratigraphic studies and geological mapping of large areas of the Foothills and the eastern ranges of the Rocky Mountains north of Athabasca River by the Geological Survey of Canada have been in progress since 1944. In addition, much of this region has been investigated in recent years by field parties representing various oil companies.

Aspects of the stratigraphic succession throughout this area have been discussed by various authors, including McLearn and Kindle (1950), Muller (1961), Stott (1961, 1962), and Irish (1958, 1962, 1965), but little has been published regarding the structure. The object of this paper is to give a general account of the deformation and to discuss the possible origin of structures in this part of the Foothills and in the most easterly ranges of the Rocky Mountains.

Location of Areas

The area with which this paper is concerned consists of two parts (*see* Figs. 1 and 2, *in pocket*), the one located in the structurally deformed region of western Alberta between Athabasca and Wapiti Rivers and the other in the foothills and mountains of northeastern British Columbia. Structural data on these two areas are few at this time. North of Athabasca River the division between foothills and mountains is much less abrupt than between these two physiographic units in southern Alberta.

The information used in compiling the tectonic maps (Figs. 1 and 2) was obtained from the following maps published by the Geological Survey of Canada:

Map 838A — Pedley, Alberta
Map 843A — Entrance, Alberta
Map 905A — Brûlé, Alberta
Map 899A — Gregg Lake, Alberta
Map 963A — Moberly Creek, Alberta
Map 968A — Moon Creek, Alberta
Map 996A — Pierre Greys Lakes, Alberta
Map 1049A — Grande Cache, Alberta
Map 1041A — Copton Creek, Alberta
Map 1104A — Adams Lookout, Alberta
Map 37-1961 and *In press* — Halfway River, B.C.
Map 11-1961 — Pine Pass, B.C.
Map 12-1963 — Trutch, B.C.
Map 19-1961 — Dawson Creek, B.C.

MS received 7 June 1965.

A Table of Formations for each of the two regions discussed shows the stratigraphic succession involved in the structural deformation. Detailed descriptions of the formations are not presented.

Table of Formations

Northwestern Alberta

Era	Period: Formation or Group	Lithology	Thickness (feet)
CENOZOIC	PALEOCENE	Sandstone, shale, conglomerate	4,000±
MESOZOIC	CRETACEOUS		
	UPPER CRETACEOUS		
	Brazeau Formation	Sandstone, shale, conglomerate	7,000±
	Wapiabi Formation	Shale, silty shale	1,800
	Bad Heart Formation	Sandstone, shale, conglomerate	0–185
	Muskiki Formation	Shale	0–300
	Cardium Formation	Sandstone, shale, conglomerate	200–250
	Kaskapau (Blackstone) Formation	Shale, silty shale	1,800
	Dunvegan Formation	Sandstone, siltstone, shale	20–350
	LOWER CRETACEOUS		
	Fort St. John Group	Chert pebble conglomerate, shale, silty shale	400–500
	Luscar Formation	Sandstone, shale, coal	2,000±
	Cadomin Formation	Conglomerate, sandstone	30–200
	LOWER CRETACEOUS AND JURASSIC		
	Nikanassin Formation	Sandstone, shale	900–4,000
	JURASSIC		
	Fernie Group	Black limestone, shale, siltstone, sandstone	600–1,200
	TRIASSIC		
	Whitehorse Formation	Limestone, dolomite, silty dolomite, red and ochre shale, gypsum	80–1,118
	Sulphur Mountain Formation	Shale, silty shale, siltstone, dolomitic siltstone	934–1,000
PALAEOZOIC	LATE PALAEOZOIC		
	Rocky Mountain Group	Sandstone, sandy dolomite, cherty dolomite, chert	0–128
	MISSISSIPPIAN		
	Rundle Group	Limestone, dolomite, some shale	600–1,200
	Banff Formation	Shale, calcareous shale, limestone	470–660

Table of Formations (*Conc.*)

Northwestern Alberta

Era	Period: Formation or Group	Lithology	Thickness (feet)
PALAEOZOIC	MISSISSIPPIAN AND/OR UPPER DEVONIAN		
	Dark Shale Unit	Shale, grey to black, calcareous and non-calcareous	80–120
	DEVONIAN		
	UPPER DEVONIAN		870–1,200
	Palliser and Alexo Formations	Limestone and dolomite	
	Mount Hawk Formation	Silty limestone, argillaceous limestone, calcareous shale, massive limestone and dolomite	500
	Perdrix Formation	Argillaceous limestone and calcareous shale	750+
	Flume Formation	Limestone and dolomite	400+
	CAMBRIAN	Sandstone, quartzite, conglomerate	1,000+

Table of Formations

Northeastern British Columbia

Era	Period: Formation or Group	Lithology	Thickness (feet)
MESOZOIC	CRETACEOUS		
	UPPFR CRETACEOUS		
	Dunvegan Formation	Sandstone, conglomerate, shale	200–400
	LOWER CRETACEOUS		
	Fort St. John Group		
	Sully Formation	Shale	500–600
	Sikanni Formation	Sandstone	300
	Buckinghorse Formation	Shale	3,300–3,600
	Bullhead Group	Sandstone, conglomerate, siltstone, shale, coal seams	1,000–1,400
	JURASSIC AND CRETACEOUS		
	Minnes Group	Sandstone, conglomerate, siltstone, shale	2,000–3,350
	JURASSIC		
	Fernie Group	Shale, siltstone, sandstone, limestone	150–1,000

Table of Formations (*Conc.*)

Northeastern British Columbia

Era	Period: Formation or Group	Lithology	Thickness (feet)
MESOZOIC	TRIASSIC		
	Pardonet Formation	Limestone, calcareous siltstone	400–1,500
	Liard Formation	Calcareous sandstone, calcareous siltstone, limestone	1,300–2,200
	Toad Formation	Calcareous siltstone, some sandstone and limestone	1,200
	Grayling Formation	Shale	0–20
PALAEOZOIC	PERMIAN		
	Fantasque Formation	Chert	0–100
	PENNSYLVANIAN AND MISSISSIPPIAN		
	Stoddart Group		
	Kiskatinaw and Taylor Flat Formations	Sandstone, siltstone, shale, limestone	1,000
	Golata Formation	Shale, siltstone and limestone	200–400
	MISSISSIPPIAN		
	Prophet Formation	Chert, limestone, dolomite	1,400
	DEVONIAN		
	UPPER DEVONIAN	Shale, some limestone	1,450–3,000
	MIDDLE DEVONIAN	Limestone, dolomite, sandstone	800–1,500
	SILURIAN	Limestone, dolomite, sandstone, shale	3,000 ±
	ORDOVICIAN		
	LOWER MIDDLE, AND UPPER ORDOVICIAN	Limestone, dolomite, sandstone, shale	2,800 ±
	CAMBRIAN? AND ORDOVICIAN		
	UPPER CAMBRIAN? AND LOWER ORDOVICIAN	Limestone, argillaceous limestone, shale	700 ±
	CAMBRIAN		
	MIDDLE CAMBRIAN?	Quartzite, sandstone, siltstone, dolomite	1,500 ±
PRECAMBRIAN	PRECAMBRIAN		
	Misinchinka Group	Schist, phyllite, limestone and quartzite	5,000 ±

Foothills

The Foothills belt, underlain predominantly by Mesozoic rocks, is typically characterized by northwesterly trending ridges and valleys. This northwesterly alignment, conspicuous in the more westerly ridges, becomes progressively less well defined toward the northeast until, near the margin of the Plains, the ridges are irregular. The Foothills grade into the Interior Plains to the east by progressive decrease in relief, altitude, and structural deformation. Also, the transition from foothills to mountains is marked by a gradual increase in altitude and relief, and a change, generally, to more open folds of greater amplitude and to much less imbricate faulting.

In Alberta, north of Athabasca River, the width of the Foothills belt is not constant, owing to the northwest plunge of successive eastern ranges of the Rocky Mountains. Between Athabasca River and Mahon Creek, the belt is about 8 miles wide and is bounded on the southwest by Boule Range and Hoff Range south of Wildhay River and by the Hoff and Berland Ranges north of Wildhay River. The Hoff and Berland Ranges plunge to the northwest and lose their identity just south of Mahon Creek so that, beyond this point, the width of the Foothills is increased to about 16 miles, and their southwest boundary is now the more westerly Persimmon Range. This range also plunges to the northwest and dies out just south of

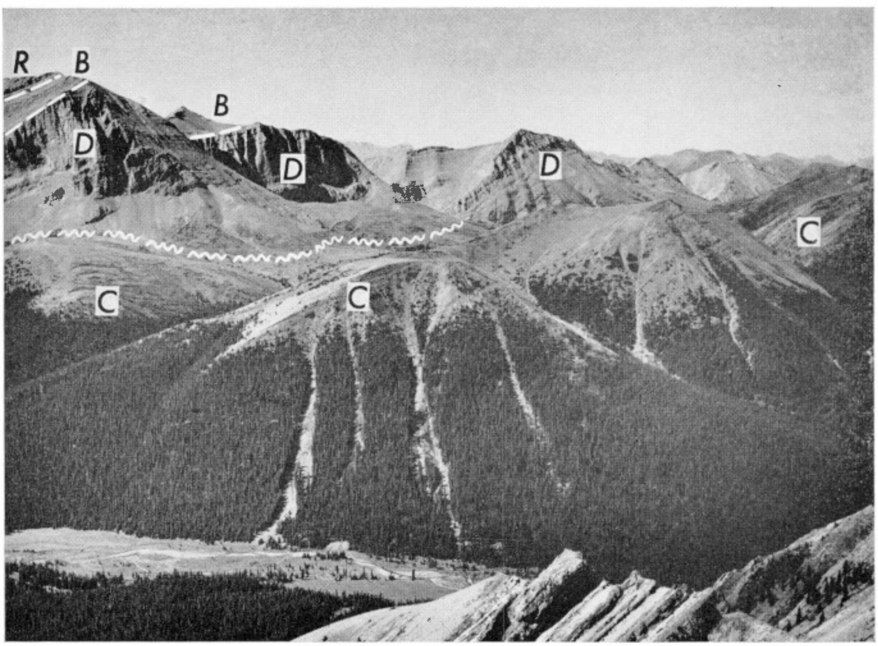

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PLATE II. View north of west across the valley of Moon Creek showing Palaeozoic strata thrust to the northeast over Cretaceous beds. Devonian Palliser Formation, D; Banff Formation, B; Rundle Group, R; Cretaceous strata, C.

Smoky River, north of which point the Foothills belt reaches its maximum width in Alberta of about 25 miles and is bounded on the southwest by the northern extension of De Smet Range.

In northeastern British Columbia between Pine and Sikanni Chief Rivers the Foothills are about 40 miles wide. There, as farther south in Alberta, the change from plains to foothills to mountains takes place both through an increase in altitude of the ridges and in structural deformation from northeast to southwest.

Rocky Mountains

The eastern ranges of the Rocky Mountains are, for the most part, underlain by Palaeozoic strata and consist of high, northwesterly trending ridges with elevations averaging 7,000 to 7,500 feet above sea-level. The Mountains are more rugged than the Foothills and present, typically, precipitous scarp faces to the northeast and more gentle slopes to the southwest (Pl. II). Folds are not as numerous as in the Foothills.

STRUCTURE

Relief of diastophic stresses has resulted in subparallel thrust faults and collinear folds. Between Athabasca and Wapiti Rivers, the general trend of the structures is about N50°W, but near Pine River the structures swing more to the north and, north of Peace River, the trend of both ridges and structures is about N23°W. Both faults and folds express a horizontal shortening and vertical thickening of the sedimentary veneer. The Mesozoic formations underlying the Foothills have, generally, been more severely contorted than the more competent Palaeozoic strata of the mountains. Both folding and thrust faulting were important types of deformation. The Mountain ranges owe their existence, mainly, to thrusting of more competent, massive Palaeozoic carbonate rocks relatively to the northeast along southwest-dipping thrust faults.

Faults

Thrust faulting is the dominant type of deformation in the Mountains and western Foothills and, although a few northeast-dipping faults have been mapped, most dip to the southwest. Such faults range from less than a mile to many miles in length, and from minute movements along small fractures to displacements of thousands of feet. In general, the surface traces of all faults are somewhat sinuous along the strike, although they maintain a general trend of about N50°W south of Pine River and about N23°W north of Peace River. In detail, however, some parts of a fault trace may be straight whereas others are very irregular, a condition that reflects a combination of erosion and changes in dip of the fault surface. Although there has been considerable displacement along some individual faults, the total shortening is distributed among several subparallel faults that are commonly *en echelon* in character.

The actual fault surfaces are rarely exposed so that their positions are in most places approximate or inferred from the distribution of the strata. Above timberline in the mountainous regions, some faults are readily traceable for limited distances because of the excellent exposure of the strata repeated by the faults (Pl. III). In a few places parts of the fault surface may be seen in cross-section on the mountainside. In such sections the angle between the bedding and fault surface is rarely more and generally less than 30 degrees. The fault surfaces exposed in cross-section are not conspicuous, even where large stratigraphic displacements occur. Where a fault can be observed in cross-section, the crush zone between the hanging-wall and foot-wall blocks is often no wider

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PLATE III. Steeply dipping back-limb thrust faults and repetitions of strata on the southwest side of the Berland Range, Alberta. R indicates the Rundle Group, and T the Triassic Sulphur Mountain Formation.

than an inch and fault gouge is rarely present. Fracturing both in the foot-wall and in the hanging-wall is normally restricted to a narrow zone only a few feet wide.

Generally, faults within the Mountains persist over greater distances, show a greater stratigraphic separation, and are more widely spaced than those in the Foothills. However, in the Pine River–Peace River region the strata in the mountains are broken by numerous, closely spaced faults. The Foothills in this region also show unusual characteristics. North of Peace River, thrust faults repeat the Mesozoic formations, but south of the river they die out and folds become the main type of deformation. Folded thrust faults that have been known in southern Alberta for many years (*see* Hume, 1941; MacKay, 1941; Hake, *et al.*, 1942; Douglas, 1950, 1958) are also present in both the foothills and mountains north of Athabasca River and northwest into British Columbia.

Folds

Folds range from small drags and crumples to anticlines and synclines more than a mile across. Some of these folds extend unbroken for many miles, but most are either truncated by faults at one end or the other, branch into several smaller folds, or are complicated by having smaller folds superimposed on their flanks. Many of the smaller single folds, both anticlines and synclines, plunge in opposite directions, producing double-ended or canoe-shaped structures.

Symmetrical folds are present, but in many of them the strike of the anticlines and synclines and the dip of their axial planes change from place to place

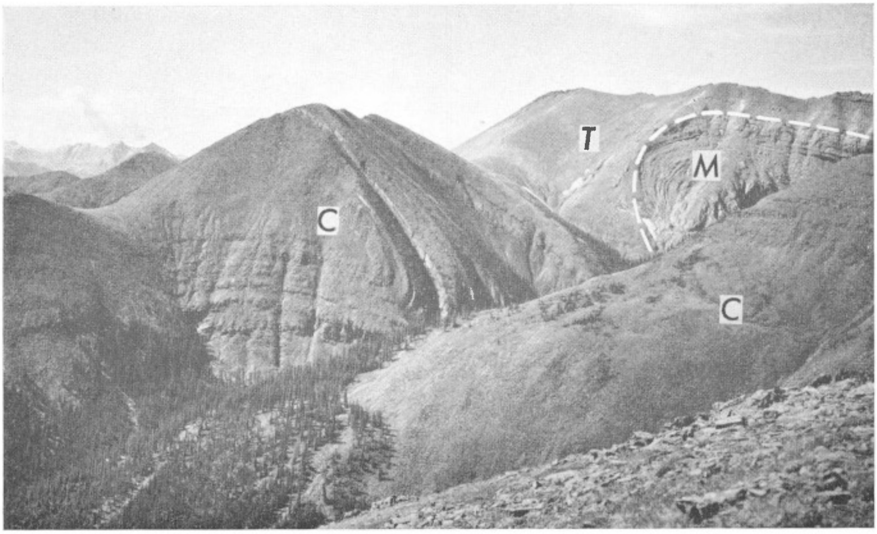

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PLATE IV. View south showing overturned Cretaceous formations in front of (northeast of) Berland Range in the Tip Top thrust sheet, near the head of Mumm Creek, Alberta. Mississippian is indicated by M, Triassic by T, and Cretaceous by C.

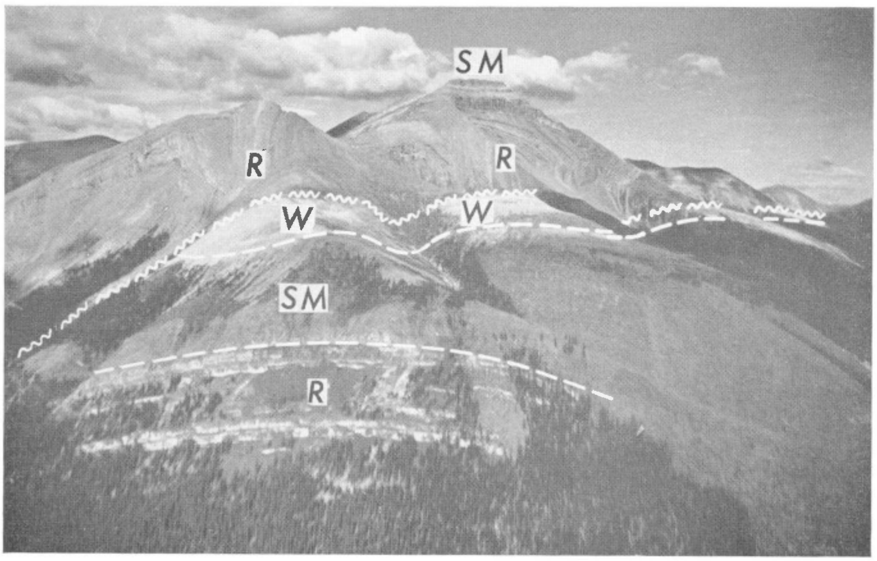

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PLATE V. View northwest along the Berland Range north of Moon Creek, showing a drag anticline on a thrust fault above the Hoff anticline. SM indicates the Sulphur Mountain Formation, W the Whitehorse Formation, and R the Rundle Group.

along the length of the fold. The steeper limb may be on the southwest at one place and on the northeast at another. Overturned folds are not common, but do occur locally. Immediately in front of the larger thrust faults folds are commonly overturned to the northeast (Pl. IV). Folds that are present at the extreme eastern limit of the overthrust strata, such as the Hoff anticline are also overturned to the northeast along parts of their lengths (Pl. V). In some instances folds in the strata above a major thrust fault have been overturned to the southwest because of the rotation of strata overlying the thrust. Such folds are on the southwest flank of the Persimmon Range above the Rocky Pass thrust and, to a lesser extent, on the southwest flank of both the Hoff and Berland Ranges. Folds of this type in the Jasper Park region are well illustrated by Mountjoy (1960).

Within the western foothills the anticlines are normally more compressed than the intervening synclines, but both types of folds tend to become more open towards the east. In the mountains, where folds involve thick sections of massive Palaeozoic carbonate rocks, the folds are much larger and broader than those within Mesozoic strata. The shapes of the folds may approach that of either an ideal similar fold or an ideal concentric fold, but generally are intermediate between these two types.

DESCRIPTION OF STRUCTURES

The structural geology of the foothills of western Canada is complicated and not yet thoroughly understood even where some subsurface control is available. North of Athabasca River, only a few wells have been drilled within the Foothills belt so that interpretations of subsurface structure must be based almost entirely on surface observations, and supported by relationships established elsewhere but assumed to apply generally.

That part of the Cordilleran region now occupied by the foothills and eastern part of the Rocky Mountains yielded to intense compressive stress mainly by a northeasterly movement on thrust faults that caused repetitions and a piling up of the beds involved (Pl. III). Within the overthrust masses or fault blocks the competent strata yielded by faulting and the incompetent beds mainly by folding. Evidence will be presented to support the contention that thrust faulting and folding of the less competent strata were more or less contemporaneous; that much of the folding was caused directly by the thrust movements; and that some folding may have persisted after movement on the faults had ceased. Because of variations in the direction and intensity of stress, lateral changes in thickness and competency of the sedimentary sections, and other factors, no two structures are exactly alike.

To place the structures of the region in the regional tectonic framework and to have some idea of the extent of the major thrust blocks, reference should be made to the regional tectonic maps (Figs. 1 and 2, *in pocket*).

Alberta North of Athabasca River

Rocky Mountains

Within the eastern ranges of the Rocky Mountains and, to a lesser extent, in the Foothills belt, the structure can best be described in terms of fault blocks. Such fault blocks consist of sequences of tilted strata that are somewhat deformed and are bounded by major faults. On the following pages the major thrust faults will be described briefly and parts of some of them will be used to illustrate particular structures. Their locations can be seen on Figures 1 and 2.

Boule Thrust

Along that part of the Boule thrust studied by the writer Devonian strata have been thrust northeastward over beds of Mesozoic age. The massive Palaeozoic strata have been folded and faulted to form the Boule Range above the fault.

Lang (1947) and MacKay (1929) examined the fault northwest of Brûlé station and observed dips of 30 to 45 degrees along the fault surface. A complete description of the Boule thrust and thrust block is given by Mountjoy (1960).

Hoff Thrust

Hoff thrust extends from near Brûlé Lake (where its southern extension is known as the Folding Mountain thrust) to a point just north of Moon Creek, a distance of about 48 miles. The fault surface dips southwest and strata of Palaeozoic age have been thrust to the northeast over Mesozoic beds. Along the surface trace of the fault the east limb of the Hoff anticline in the hanging-wall brings northeast-dipping strata of Mississippian and Triassic ages into fault contact with beds of Jurassic and Cretaceous ages. Maximum stratigraphic separation takes place between Wildhay River and Moon Creek. South of Wildhay River and north of Moon Creek progressively younger beds are present in the hanging-wall and are in contact with the underlying Cretaceous beds. On the basis of the interpretation given on Figure 1, inset A, the top of the Banff Formation is offset more than 4,000 feet along the Hoff thrust. North of Moon Creek most of the movement appears to have been transferred from the Hoff thrust to a more westerly thrust, the Mahon, which originates to the southeast as a minor thrust on the southwest flank of the Hoff anticline. The Mahon thrust fault can be mapped for at least 40 miles and extends northwestward to a point 4 miles south of Grande Cache Lake. Throughout most of its length Cretaceous strata are present in both the hanging-wall and the foot-wall along the surface trace of the Mahon thrust.

The Hoff anticline is the major structure within the Hoff fault block. It consists of an anticlinal fold extending northwesterly from just north of Athabasca River valley to just south of Muskeg River, a distance of about 72 miles. The fold plunges at both ends so that Palaeozoic formations are gradually overlain by progressively younger beds, and most of the associated structures lose their identity to the southeast and northwest. The plunge of this fold appears directly related to the stratigraphic displacement of the Hoff thrust fault. At its maximum development two southwest-flowing creeks have cut into the fold and exposed beds of both the Banff and Palliser Formations above the Hoff thrust fault (Pl. VI). This suggests that the fault surface at this locality may be following a stratigraphic zone just below the Palliser Formation and that the fault surface itself may be folded.

Between Wildhay River and Moon Creek the southwest flank of the Hoff Range consists of subsidiary 'back-limb thrusts' (*see* Douglas, 1950) that have produced repetitions or a piling up of relatively thin slices of strata involving Mississippian and lower Mesozoic beds (*see* Fig. 1, inset A, Fig. 2, and Pl. III). These faults, one of which persists northwestward as the Mahon thrust, cut across the strata at angles between 10 and 30 degrees, but both beds and fault surfaces now dip at angles between 45 and 75 degrees. The present steep dips are thought

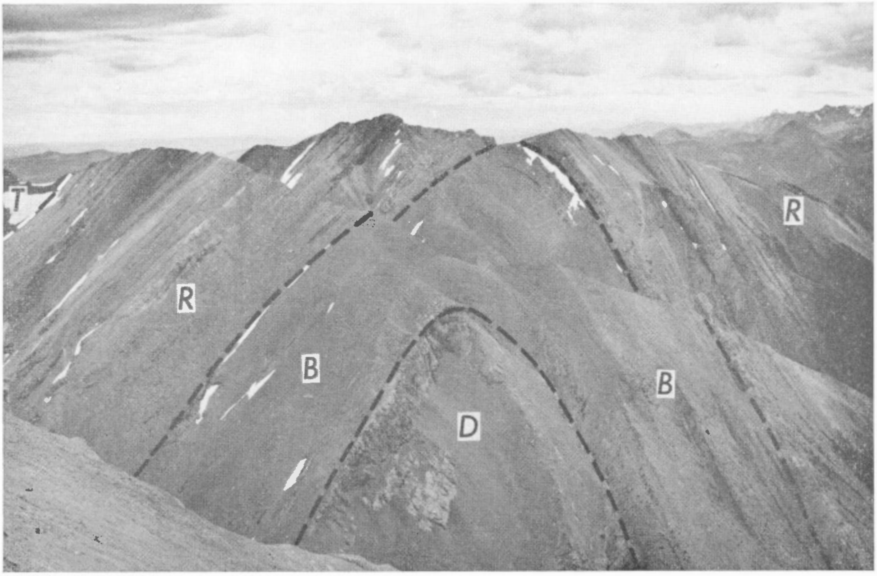

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PLATE VI. View southeast along the Hoff anticline just west of the lower part of Mumm Creek showing Devonian Palliser Formation (D), Banff Formation (B), Rundle Group (R), and the lower part of the Triassic succession (T).

to be due to rotation caused by development of the Hoff anticline (which is discussed under the heading "Drag Folds" later in this report). The stratigraphic displacement on these back-limb thrusts ranges from a few feet to perhaps hundreds of feet on the larger faults. At least two of them have been folded with the Hoff anticline, and the dip of the strata above and below the fault changes from southwest to northeast.

The remainder of the area between the southwest flank of the Hoff anticline and the Tip Top thrust block to the west is underlain mainly by Mesozoic strata. These beds have been compressed and rotated westward owing to movement over the Hoff thrust, and now form a large syncline. Several small thrust faults are present, of which two at least are thought to have northeast-dipping surfaces. Such east-dipping thrusts of small lateral displacement are considered to be additional adjustments to compression and related to curvature on the underlying Hoff thrust.

Tip Top Thrust

Between Wildhay River and Berland River Devonian and Mississippian formations have been thrust relatively to the northeast over Cretaceous strata. To the northwest, beyond Berland Range, the fault continues as far as Sulphur River, with Cretaceous beds in both the hanging-wall and foot-wall. A study of aerial photographs indicates that the fault extends to the southeast of Wildhay River and probably is continuous with the Boule thrust. If so, the fault is at least 92 miles long.

Stratigraphic separation on the Tip Top thrust is at a maximum just north of Little Berland River, where beds of the Devonian Mount Hawk Formation are exposed in the hanging-wall. The amount of dip-slip movement along the fault there cannot be estimated, but may be several thousand feet according to the writer's interpretation of the structure. Southeast of Little Berland River, first Banff and then Rundle beds are in fault contact with beds of Early Cretaceous age. Beyond the northwestern end of the Berland Range the fault involves only the Upper Cretaceous Kaskapau Formation at the surface. The thrust surface appears to be within Devonian strata either in or below the Mount Hawk Formation as in the case of the Hoff thrust. The two unnamed west-dipping thrusts to the northeast are assumed to be splays from the Tip Top thrust, as they merge with that fault (Fig. 1).

Berland Range is about 2 miles wide and extends from Wildhay River to Berland River 32 miles to the northwest. The massive carbonate beds of the Palliser and Banff Formations and the Rundle Group present a precipitous face to the northeast and a dip slope of between 30 and 50 degrees to the southwest (Pl. II). On this dip slope, two subsidiary thrust faults (back-limb thrusts) have produced three repetitions of the Mississippian and Triassic beds within the hanging-wall of the Tip Top thrust. These faults dip to the southwest at angles between 45 and 75 degrees and their steepness is considered to be due to rotation as in the Hoff Range. Folds are few within the Berland Range.

West of the Berland Range and east of the Rocky Pass thrust is another area underlain principally by Mesozoic strata where compressive stress has been relieved by the formation of tight folds and numerous thrust faults. West-dipping thrusts predominate, though several minor east-dipping faults are present.

Rocky Pass Thrust

The Rocky Pass thrust underlies the Persimmon Range for 32 miles and probably extends many miles farther both northwest and southeast. The fault surface is inclined to the southwest and is thought to follow a horizon within the Devonian for several miles before cutting down to a stratigraphically lower zone. According to the writer's interpretation of the structure (*see* Fig. 1, inset B), this thrust has a dip of about 35 degrees near its surface trace. At its maximum stratigraphic separation Devonian strata occur in the hanging-wall with Lower Cretaceous strata lying beneath the fault, and to the northwest the thrust brings first Mississippian and then Triassic beds in fault contact above the Jurassic Fernie Group. The maximum stratigraphic separation within the region mapped is roughly 8,300 feet and takes place between latitude 53°30′ and a point 18 miles north of this latitude. Along this part of the thrust, strata of the Flume Formation overlie beds of the Cretaceous Nikanassin Formation. As with the Tip Top and Hoff thrust faults, the Rocky Pass thrust follows the Mount Hawk–Flume–Perdrix zone along strike for many miles.

The northwestern limit of the Whistler thrust is not yet known, but that part within the area mapped lies just east of the Rocky Pass thrust, and merges with the principal fault where it crosses Persimmon Creek. This splay involves only Jurassic and Cretaceous strata.

The Persimmon Range homocline that passes northward into the southwest flank of the Persimmon anticline is the most easterly structure above the Rocky Pass thrust from its southeastern end to its northwestern extremity just west of longitude 119°00′. Within the Persimmon Range from about 3 miles northwest of latitude 53°30′N, Devonian and Mississippian formations are exposed. No folding was observed there and the strata are repeated only once by a thrust fault. Farther northwest as the displacement on the thrust decreases, several small folds are developed within the Palaeozoic formations, and the northwestern end of the range consists of a single anticlinal fold known as the Persimmon anticline. Numerous small, subparallel anticlines and synclines are along the southwestern slope of the range. These small folds are overturned with the axial planes dipping steeply to the northeast.

The large valley between the Persimmon Range and the Monoghan anticline is underlain by both Triassic and Jurassic strata. The structure there is not well known because of the paucity of rock exposures. In the southeastern part, Fernie shales are highly contorted and broken by numerous small thrust faults, but the northwestern part appears to be a normal syncline. The Monoghan anticline, between 2 and 3 miles wide at the surface, is an asymmetrical fold with beds on the northeast limb dipping between 65 and 70 degrees and on the southwest limb between 60 and 65 degrees. Strata of the Rundle Group are exposed along the crest and limbs of the anticline, but beds of both the Banff and Palliser Formations are present in the core, and are exposed where Sulphur River and two east-flowing creeks have cut into the fold. Triassic strata are present low on the flanks. There appears to be no major thrust fault below this anticline and it is, therefore, considered to be a secondary structure within the Rocky Pass 'fault block'. Mississippian formations have been thrust northeastward over Triassic rocks along two thrust faults that occur southwest of the Monoghan anticline.

Foothills

The foothills east of the Boule Range do not appear to contain any major west-dipping thrust faults. The two major structures there are the Pedley thrust and the Entrance syncline.

Pedley Thrust

This is an east-dipping thrust of relatively small displacement that has brought Brazeau strata up over Edmonton–Paskapoo beds. The Entrance syncline, lying west of the thrust fault, is a broad, open fold extending about 15 miles northwesterly from latitude 53°15′. Between this syncline and the Boule Range the structure is complex, but involves only Cretaceous strata. Small folds and both east- and west-dipping faults are present.

Wildhay Thrust

This is the most easterly structure between latitudes 53°30′ and 53°45′ north. Although along part of its length this fault is a complex fault zone rather than a single thrust, it has been mapped as a single fault from just south of latitude 53°30′ northwesterly to about 8 miles north of latitude 53°45′, a distance of 30 miles. The fault surface dips northeast at a small angle, and along most of its length strata of the Wapiabi Formation have been thrust relatively to the southwest over beds of the Brazeau Formation. To the southeast this fault appears to terminate in Brazeau strata but may be a northern extension of the Pedley thrust.

Moberly Thrust

This fault with its splays extends northwesterly from Wildhay River for about 42 miles. It is subparallel with the highly contorted zone in front of the Hoff thrust and forms the northwestern limit of it. The southwest-dipping Moberly thrust is thought to be a splay of the Hoff thrust and to join the Hoff thrust just north of Wildhay River. Cretaceous formations only are displaced at the present surface and the maximum stratigraphic separation is about 1,500 feet.

Muskeg Anticline

This fold extends southeasterly from latitude 54°00′ for about 24 miles. It lies along the eastern edge of the disturbed belt in this region. The fold is relatively open and about a mile wide at the present surface, the attitude of the beds suggesting a slight asymmetry with the steeper limb of the southwest. Wapiabi strata are exposed at the centre of the fold. No definite evidence of faulting has yet been obtained. However, 3,200 feet of Kaskapau strata was penetrated in the Muskeg No. 1 well. This is about 1,000 feet more than has been measured at surface exposures and, therefore, may be a repetition by thrust faulting. It is possible, also, that this increased thickness is due to squeezing of the soft shale into the anticline between the more competent Dunvegan and Cardium Formations.

Copton Anticline

Copton anticline is a narrow, rather compressed fold along the northeastern edge of the disturbed belt northwest of the Muskeg anticline. It extends northwesterly from Smoky River for about 35 miles, exposing strata of the Kaskapau Formation along the axis over most of its length. The fold is one of the longest and most regular of the anticlines within the foothills north of Athabasca River valley. It is nearly symmetrical and the southwest limb is truncated by the Muskeg thrust.

Muskeg Thrust

This fault, extending nearly 65 miles, is the most easterly of the large west-dipping thrust faults in the northern part of the region mapped in Alberta. South of Smoky River it appears to be folded (*see* Fig. 1). There the trace of the fault swings northeastward from the west limb of the Copton anticline across the trend of the Mason syncline, to the west limb of the Muskeg anticline.

For about 7 miles northwest of Smoky River the uppermost part of the Luscar Formation forms the hanging-wall of the Muskeg thrust and is in fault contact with beds of the Kaskapau Formation in the Copton anticline, giving a stratigraphic separation of about 2,800 feet. Toward each end of the anticline the stratigraphic separation decreases as the fault follows progressively younger formations. Along the east flank of the Mason syncline Wapiabi beds are thrust over Brazeau strata. There the dip of the fault near the surface trace is about 30 degrees.

The Mason syncline is a broad open fold about 20 miles long and from 4 to 6 miles wide within the hanging-wall of the Muskeg thrust fault. Strata of the Brazeau Formation are present within the syncline, whereas those of the Wapiabi, Cardium, and Kaskapau Formations are on the limbs.

Mason Thrust

This thrust, about 68 miles long, is between 4 and 6 miles southwest of the Muskeg thrust. It extends from just south of Berland River, where it is *en echelon* with the Mahon thrust, northwest to a point about 5 miles south of Smoky River. There it bifurcates, the more easterly splay apparently dying out just north of Smoky River, and the more westerly branch extending northwestward to a point 4 miles west of longitude 119°30′ and about latitude 54°05′N (*see* Fig. 1, inset C). From its southeastern extremity the thrust follows closely the northeast limb of the Cabin Creek anticline for about 10 miles. It then swings more northerly and follows, to the point where it branches, the northeast limb of the Susa Creek anticline. The surface trace of the eastern branch forms a series of irregular curves just south of Smoky River before straightening again as it dies out a few miles north. The irregular surface trace of this fault is due to a combination of the topography and the low dip of the fault surface in this region. The fault surface is exposed in the deep valleys of two small creeks, where it can be seen to be folded with strata of both the foot-wall and the hanging-wall (*see* Fig. 1, inset C).

The more westerly branch of the Mason thrust extends northwesterly within the Luscar Formation. The surface trace is relatively straight, indicating a rather steep dip near the surface over this distance. Along most of the length of the Mason thrust Lower Cretaceous Luscar and Nikanassin and Jurassic Fernie beds were thrust relatively to the northeast over those of the Lower Cretaceous Dunvegan and Kaskapau Formations. Strata of the Fort St. John Group, and Dunvegan and Kaskapau Formations are present in the hanging-wall for about 3 miles just north of latitude 53°45′, where a small salient brings the fault trace farther east. The fault there has cut up-section about 1,000 feet in a horizontal distance of about 1,500 feet, indicating an angle of about 35 degrees between the fault and the bedding.

Cabin Creek Anticline

The largest fold within the Mason thrust block is the Cabin Creek anticline, which extends as a single fold from a point near latitude 53°35′N and longitude 118°15′W, northwesterly to 53°45′N latitude (*see* Fig. 1). There at its culmination (and where it starts to plunge to the northwest) the single fold is replaced by two anticlines with an intervening syncline. The more easterly of these subsidiary folds dies out a few miles to the northwest and is called the Sterne Creek anticline. The total length of the two anticlines is about 72 miles.

At the culmination of the structure near the head of Cabin Creek the fold is 3 to 4 miles wide, and strata of the Rundle Group are exposed along the axis for about 4 miles. From its culmination the anticline plunges to the northwest and southeast, bringing younger formations successively over the fold until only Luscar strata are exposed. The fold is somewhat asymmetrical, as dips on the northeast limb are steeper than those on the southwest limb. On the northeast flank the strata dip between 60 and 75 degrees, whereas those on the opposite flank dip between 35 and 50 degrees to the southeast.

Sterne Creek Anticline

The Sterne Creek anticline extends northwest from the Cabin Creek structure for about 36 miles. The fold is fairly symmetrical and is a simple anticline for some miles northwest of its southern end. From there north it becomes more complex, due to the development of minor folds on the flanks. It occurs mainly within Luscar strata, though both Cadomin and Nikanassin beds are exposed where the anticline is cut by Grande Cache Lake, Smoky River, and Sheep Creek valleys.

Susa Creek Anticline

The Susa Creek anticline is a relatively narrow, irregular fold forming the most easterly structure in the hanging-wall above the Mason thrust between Muskeg River and Smoky River, a distance of about 24 miles. The axis is sinuous and is only very generally parallel with the surface trace of the Mason thrust. The fold ranges in width from a mile to 2 miles. Strata on the flanks dip between 45 and 70 degrees; at one place the steeper dip is to the northeast and at another it is to the southwest. Nikanassin strata are exposed along the axis except for two small areas of the Fernie Group, which outcrop where the fold is cut by the valleys of Susa and Mason Creeks.

Cowlick Thrust

The Cowlick thrust fault extends northwesterly from a point near longitude 118°45′W and latitude 53°45′N to a point west of longitude 119°30′, a distance of at least 65 miles. Its southeastern end is just east of the northwestern extremities of the Mahon and Tip Top thrusts, and *en echelon* with them. The Cowlick dips to the southwest; movement relatively to the northeast over most of its length has brought either Nikanassin or Luscar strata up over beds of the Luscar

Formation. Thus, in spite of its length, the maximum stratigraphic separation on the fault is probably not more than 2,500 feet. It seems likely that one of the main stratigraphic zones followed by this thrust is in the Fernie Group or lower part of the Nikanassin Formation.

The largest fold within strata above the Cowlick thrust is the Sulphur River syncline that extends from about 3 miles south of Muskeg River northwesterly to a point west of the area mapped. It has a maximum width at the surface of about 4 miles near longitude 119°00′ and latitude 53°50′N, but gradually narrows both to the northwest and southeast. The largest fault affecting the syncline is the northern end of the Tip Top thrust, which truncates the southeastern 16 miles of the southwest limb of the fold. Kaskapau shales within the syncline are poorly exposed.

Two miles west of the Sulphur River syncline, and separated from it by a faulted anticline, is the Roddy Creek syncline. This syncline is 18 miles long and, like the Sulphur River fold, is mainly underlain by shale of the Kaskapau Formation. Beside these synclines, the strata above the Cowlick thrust are folded into numerous small anticlines and synclines and broken by several small thrust faults. Some of the latter have thrust surfaces that dip northeasterly.

Sulphur River Thrust

This thrust lies southwest of the Roddy Creek syncline and extends northwest from near Smoky River to (and beyond) 119°00′W longitude. The southern 14 miles of the surface trace of the fault is relatively straight. It then bifurcates, the two branches remaining roughly parallel and between a quarter and half a mile apart. Over most of its length it has Luscar strata in the hanging-wall near the surface trace. The stratigraphic separation may be as much as 1,000 feet where Luscar strata have been thrust over beds of the Fort St. John Group. Within the strata above the Sulphur River thrust are several small folds and thrust faults involving Lower Cretaceous strata at the surface. The faults are minor west-dipping thrusts, with the exception of the Mount Stearn fault.

The Mount Stearn fault is the longest thrust fault in this part of the area in which the hanging-wall has moved relative to the southwest. It is 24 miles long and extends from near the point of intersection of latitude 53°45′N and longitude 119°00′W, northwesterly to the vicinity of Sheep Creek, where it approaches very close to the west branch of the Sulphur River thrust. Along most of its length, strata of the Nikanassin Formation have been thrust southwest over Luscar strata, but displacements are not known. This east-dipping thrust fault is considered to be a form of adjustment to the squeezing of beds above the Sulphur River thrust (*see* Fig. 1, inset D).

Mount Russell Thrust

This fault is apparently continuous from just north of Wildhay River northwesterly to the vicinity of Sheep Creek a distance of 72 miles. Over most of this length the fault maintains a gently sinuous trace, but just west of longitude

119°15′ and on the north side of Smoky River, the angle of dip of the fault surface suddenly becomes much smaller. From this point to the northwestern end of the thrust, the surface trace remains very irregular. The change from relatively steep to gentle dip can be seen in cross-section in the cliffs at the head of a small south-flowing creek about 2 miles north of Smoky River (Pl. VII). There, strata of the Fernie Group form the hanging-wall with Nikanassin strata in the foot-wall. Beds above and below the fault are anticlinally folded, though there is little northeast dip to the fault because it is cutting up-section quite steeply within the Nikanassin beds, which are themselves dipping gently northeast (*see* Fig. 1, inset E).

At most places along the fault Nikanassin beds form the hanging-wall, but between Muskeg River and longitude 119°00′W, a distance of about 7 miles, beds of Jurassic, Triassic, and Mississippian ages are in fault contact with Nikanassin strata in the foot-wall. The maximum stratigraphic separation of about 7,000 feet is along this part of the fault trace. Northwest and southeast of this region the stratigraphic separation decreases.

The region southwest of the Mount Russell thrust and northeast of the Llama Mountain anticline is underlain mainly by the Lower Cretaceous Nikanassin Formation. Structurally it consists of numerous, long, tightly folded, subparallel anticlines and synclines. Those thrust faults that do occur are not

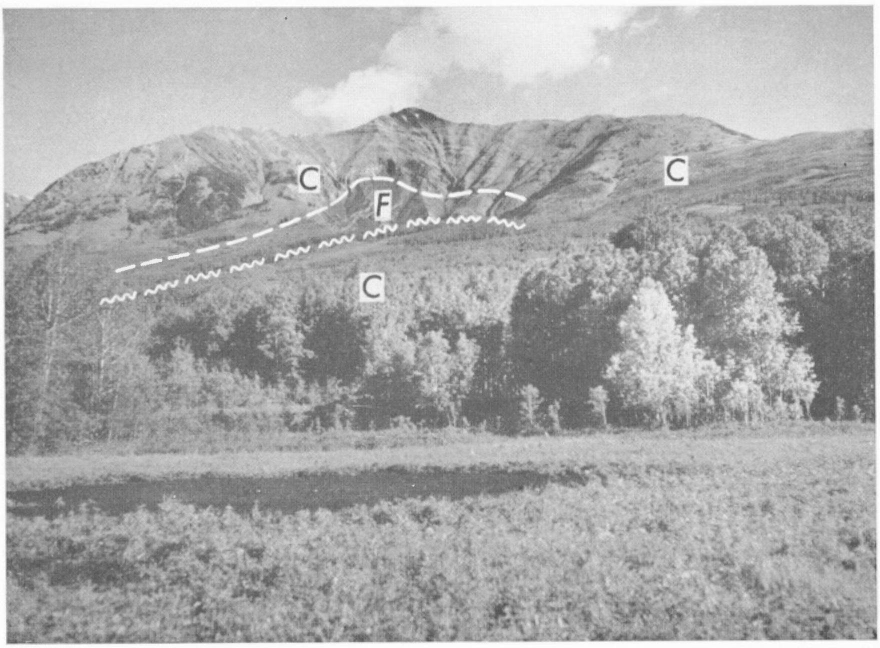

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PLATE VII. View north from Smoky River showing gulch in mountain where the Mount Russell thrust is folded. Jurassic Fernie shale (F) is thrust over Cretaceous Nikanassin sandstone (C).

persistent for any great distance and have a small displacement. This decrease or lack of thrust faults and increase in the number, size, and length of folds in the region is coincident with a great thickening of the Jurassic and Lower Cretaceous formations. The greatly increased thickness of the Mesozoic succession may be the reason that stress has been relieved there principally by folding, whereas farther northeast the thinner Mesozoic section is broken by large and small thrust faults.

Northeastern British Columbia

There is no clear structural or topographic division between mountains and foothills in that part of northeastern British Columbia discussed in this paper. An arbitrary boundary is placed at the surface trace of the Mount Brewster thrust. West of this fault the strata exposed are predominantly of Palaeozoic age whereas east of the fault the strata are mainly Mesozoic. In the general region between Pine and Sikanni Chief Rivers the width of the Rocky Mountains is a minimum, and the Foothills belt is correspondingly wide and probably at a maximum width (*see* Fig. 2).

Rocky Mountains

A division of the Rocky Mountains into sub-provinces, such as that employed by North and Henderson (1964) in the Bow River valley, and by Mountjoy (1960) in the Athabasca River valley region, is not feasible in the Pine River valley–Sikanni Chief River valley district of British Columbia. The mountain ranges there are narrow and consist principally of a series of thrust slices that repeat strata of the Palaeozoic formations. North of Peace River one major persistent fold is present, but all others appear to be minor crumples within the thrust sheets. South of Peace River no persistent folds of any size have been mapped.

The major faults within the mountains are west-dipping thrusts and, although imbrications occur, the faults or fault zones are normally continuous for many miles along strike. At most places within the mountains both the strata and the fault surfaces dip between 60 and 85 degrees to the southwest, but the faults actually cut across the beds at an average angle of between 10 and 30 degrees. It is evident, therefore, that, prior to the westward rotation of the strata, the original dip of the fault surfaces was probably between 15 and 40 degrees to the southwest. Three of the larger thrusts have been named and are described here.

Mount Brewster Thrust

This is the most easterly fault included within the mountains. It extends northwesterly from the vicinity of Peace River valley to a point in the Graham River valley at about latitude 56°45′N. North of this point it could not be traced with any certainty. Near latitude 57°00′, a large thrust fault, considered to mark the eastern limit of the mountains, can be traced for several miles south into the valley of Graham River, and may be the northern extension of the

Mount Brewster thrust. If so, the minimum length of this fault is 78 miles. Near latitude 57°00′ Silurian strata overlie Mississippian beds along the fault. Near Peace River valley Mississippian and Pennsylvanian beds overlie Triassic rocks. South of Peace River this fault has not been recognized, though it may persist some miles southeast within Triassic beds. Thus, throughout most of its length, this thrust, near its surface trace, follows a zone within Mississippian strata. The possible northern extension of the fault near latitude 57°00′ has Devonian and Silurian strata both in the hanging-wall and in the foot-wall. The fault is folded in this region. The maximum stratigraphic separation along the fault is about 6,000 feet, but at most places it is closer to 2,000 feet.

Nabesche Thrust

The next important fault west of the Mount Brewster thrust is the Nabesche thrust, whose trace can be followed from north of latitude 57°00′ southward to the south side of Peace River valley. Its continuation farther to the south has not yet been determined (*see* Fig. 2, inset F).

Between Halfway River valley and the valley of Horn Creek the trace of the Nabesche thrust is very sinuous around the east slope of the mountains forming the west side of Graham River valley. Along this part the dip of the fault surface is considered to be small. At Horn Creek the trace swings west and then south again to follow the west flank of the Bernard anticline. From this point it turns east around and over the nose of the plunging anticline, forming an S-curve before turning south again to pass through Mount Brewster. Silurian beds and in places the upper part of the Ordovician succession commonly occur in the hanging-wall of the thrust, whereas either Upper or Middle Devonian beds lie beneath the fault. Where the trace of the fault turns south after crossing the nose of Bernard anticline, however, first Devonian and then Mississippian beds are directly above the fault surface, with Mississippian strata below.

Just north of Peace River this thrust appears to pass into Triassic strata but, like the Mount Brewster thrust, it has not been mapped in the Triassic beds south of Peace River valley. In the writer's opinion it seems more reasonable that, rather than terminating south of the river, both the Nabesche and Mount Brewster thrusts continue for some distance farther south.

Stratigraphic separations along the thrust range from about 1,800 feet near Peace River to more than 2,400 feet farther north. Throughout most of its length the thrust appears to follow a zone within the lower part of the Silurian succession, but, where it swings east over the southern end of the Bernard anticline, it has cut stratigraphically upward through the Devonian and into Mississippian strata in just over 3 miles. Thus, over this distance, the approximate angle between the fault surface and the bedding of the hanging-wall block is between 15 and 20 degrees. Also, over this distance the dip of the fault surface changes from southwest to northeast over the fold, and then back to southwest where the fault trace turns south again. Along the west flank of the Bernard anticline the inclination of the fault surface is estimated to be about 60 degrees.

This fault, with its overlying strata, is thought to have been folded when the Bernard anticline was formed. Subsequent erosion has removed the faulted strata from the crest of the main part of the fold. From west to east the fault cuts beds progressively higher in the stratigraphic succession and, due to the south plunge of the fold, successively younger strata are preserved above the fault from north to south.

Mount Burden Thrust

The Mount Burden thrust is the next large thrust to the west, and is assumed to enter the region under discussion near latitude 56°50′N and longitude 124°00′W. From there its trace maintains a course south and east for about 48 miles to where it, also, is folded over the Bernard anticline. From this point it turns east and north over the fold and then south again to cross Peace River near 123°15′ west longitude just south of 56°00′ north latitude.

From its northern end to where the fault is folded over the anticline, Ordovician beds have been thrust northeastward over Silurian beds. On the nose of the plunging Bernard anticline, higher strata of the Ordovician sequence occur in the hanging-wall and are in fault contact with Middle Devonian and then Upper Devonian beds. Still farther east, where the trace turns south again, Silurian and then Devonian beds occur above the fault and are thrust over uppermost Palaeozoic and Triassic beds. The extension of the Mount Burden thrust south of Peace River can be followed with certainty for only a few miles, but the zone probably continues for many miles to the southeast.

Stratigraphic separation along the mapped part of this thrust fault ranges between 6,300 feet and 4,000 feet. The fault surface close to the trace is considered to dip at between 60 and 65 degrees southwest on the west side of the Bernard anticline, but at much smaller angles where it is folded and following zones within the Silurian and Devonian successions.

Several other thrust faults occur west of the Mount Burden thrust. All appear to dip steeply to the southwest and to involve mainly Cambrian, Ordovician, Silurian, and Devonian beds. However, along the most westerly fault mapped north of Peace River, rocks of the Precambrian Misinchinka Group have been thrust over Cambrian and Ordovician strata.

Bernard Anticline

The Bernard anticline (Fig. 2, inset F) is the only major fold in the mountains within the area under discussion. It is an open, somewhat asymmetrical fold, between 4 and 6 miles wide at the surface, and can be traced from near the head of Horn Creek southeasterly almost to Peace River, a distance of 45 miles. The fold plunges both to the northwest and southeast.

Strata of Silurian age are exposed along most of its length and over most of its width. Devonian carbonate and shale strata form a band along each limb and around each end except where obscured by the Nabesche thrust. The fold is broad and rather flat-topped so that the strata first dip at a small angle for about

2 to 3 miles on either side of the fold axis, and then at much greater angles. Dips on the southwest side increase to about 65 degrees and those on the northeast limb change abruptly to between 75 and 80 degrees.

The Bernard anticline does not appear to represent the leading edge of a large 'fault block', though the region immediately east of the fold is severely faulted and folded.

Foothills

The Foothills belt is bounded on the west by the Mount Brewster thrust and on the east by Butler Ridge, Hackney Hills, and other ridges along strike to the northwest and southeast. Folding, rather than faulting, appears to have been the most important form of structural deformation within the Mesozoic formations.

North of Peace River are several rather short, southwest-dipping thrust faults, but most of these have resulted from the breaking of tightly compressed anticlines, and begin and/or terminate in compressed, asymmetrical anticlines; stratigraphic separation usually ranges from a few tens of feet to less than 1,000 feet. Only one or two of these thrust faults extends south of Peace River where relief of stress within the Mesozoic strata has been brought about almost entirely by folding.

The Carbon thrust is probably the largest in this region. It has its beginning in an anticline near Cypress Creek in the north, extends southeast for at least 75 miles, and is one of the few faults to persist south of Peace River. Maximum stratigraphic separation ensues about 20 miles north of Peace River, where strata of late Mississippian and Pennsylvanian ages have been thrust over beds of Triassic age.

Folds within the foothills region consist of a succession of tightly folded anticlines, most of which are faulted near their axes, separated by broad synclines with gently inclined limbs. Asymmetrical anticlines with steeply dipping northeast flanks are conspicuous, but in some of them the asymmetry is reversed. Some anticlines have relatively flat crests, with steeply dipping limbs, and in such cases the change of dip between the flat top and the steep limb is normally very abrupt. Individual folds are the most common, though some change along strike from simple anticlines to anticlinoria composed of several smaller folds. South of Peace River valley the folds are generally more irregular in size, shape, and trend than those to the north of the valley.

Throughout most of the region both northwest and southeast plunges are common, but a marked change takes place at about latitude 56°20′N. From there to south of Peace River valley the plunge of all folds is to the southeast.

DISCUSSION

Zones of Slippage

Any discussion of structure must consider zones of slippage or décollement zones. Such zones may be defined as beds or larger lithological units of relatively weak rocks that lie between more competent strata and, under stress, show a tendency to localize faults parallel with the bedding. The ease of deformation of such zones acts to decrease frictional resistance so that the overlying rocks are moved over the ones below for great horizontal distances. The stronger, more competent strata above and below the zone or zones of slippage are commonly intersected by the faults. Zones of slippage or décollement are not restricted to a particular type of rock, though fissile marine shales and coal seams are among the most effective for facilitating fault movement.

Such zones have been recognized and/or assumed for many years in southern Alberta. Hake and others (1942) suggested a zone of parting beneath the Devonian strata for the Front Ranges near the North Saskatchewan River, but did not elaborate on this idea. North and Henderson (1954) concluded that there is likely a nearly flat thrust fault below the Front Ranges that originated as a near bedding-plane-fault.

North of Athabasca River valley there are few data to prove the existence of large, flat, sole faults or even the localization of thrusts within slippage zones for any great horizontal distance. That such zones probably play a part in the structural deformation is indicated by the fact that, both in the mountains and foothills, major thrust faults follow particular stratigraphic horizons parallel or subparallel with the bedding for great distances along the strike. This suggests that these same horizons may be followed for some distance at depth and across the strike. Suggestive also is the fact that in the mountains small thrusts exposed in cross-section can be seen to originate along bedding planes and then to cut across the bedding at a small angle.

Those zones considered to be important as zones of slippage in the eastern ranges and Foothills of Alberta north of Athabasca River include the Banff Formation of Mississippian age; the Mount Hawk–Flume–Perdrix Formations (Devonian); the Fernie Group–Lower Nikanassin Formation (Jurassic); the Luscar Formation (Early Cretaceous); and the Blackstone (or Kaskapau) and Wapiabi Formations (Late Cretaceous).

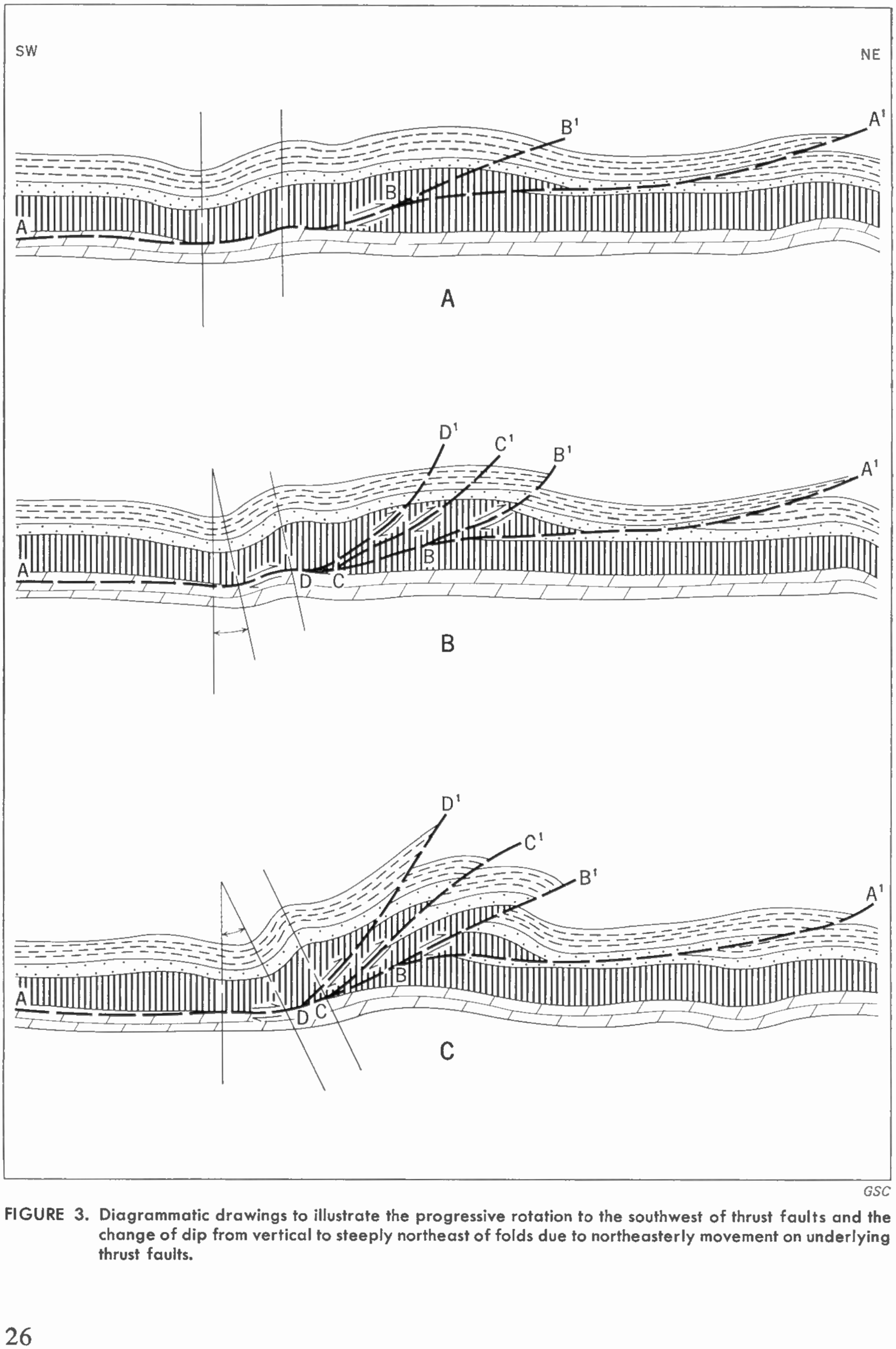


FIGURE 3. Diagrammatic drawings to illustrate the progressive rotation to the southwest of thrust faults and the change of dip from vertical to steeply northeast of folds due to northeasterly movement on underlying thrust faults.

Shale formations such as the Fernie Group, Kaskapau and Wapiabi Formations, and also the Luscar Formation because of its coal and shale content, are contorted and sheared where over-ridden by a thrust plate.

In northeastern British Columbia it is more difficult to determine preferred zones of slippage because of a general facies change in the Palaeozoic succession from shaly beds in the west to massive carbonate strata farther east. Thrust faults are present that have Devonian, Silurian, Ordovician, and, perhaps, Upper Cambrian strata above the fault surface. In the Mesozoic strata faults appear to be associated principally with the shaly beds of the Stoddart Group of late Palaeozoic age, the lower part of the Triassic succession, and the Jurassic Fernie Group.

Thrust Faults

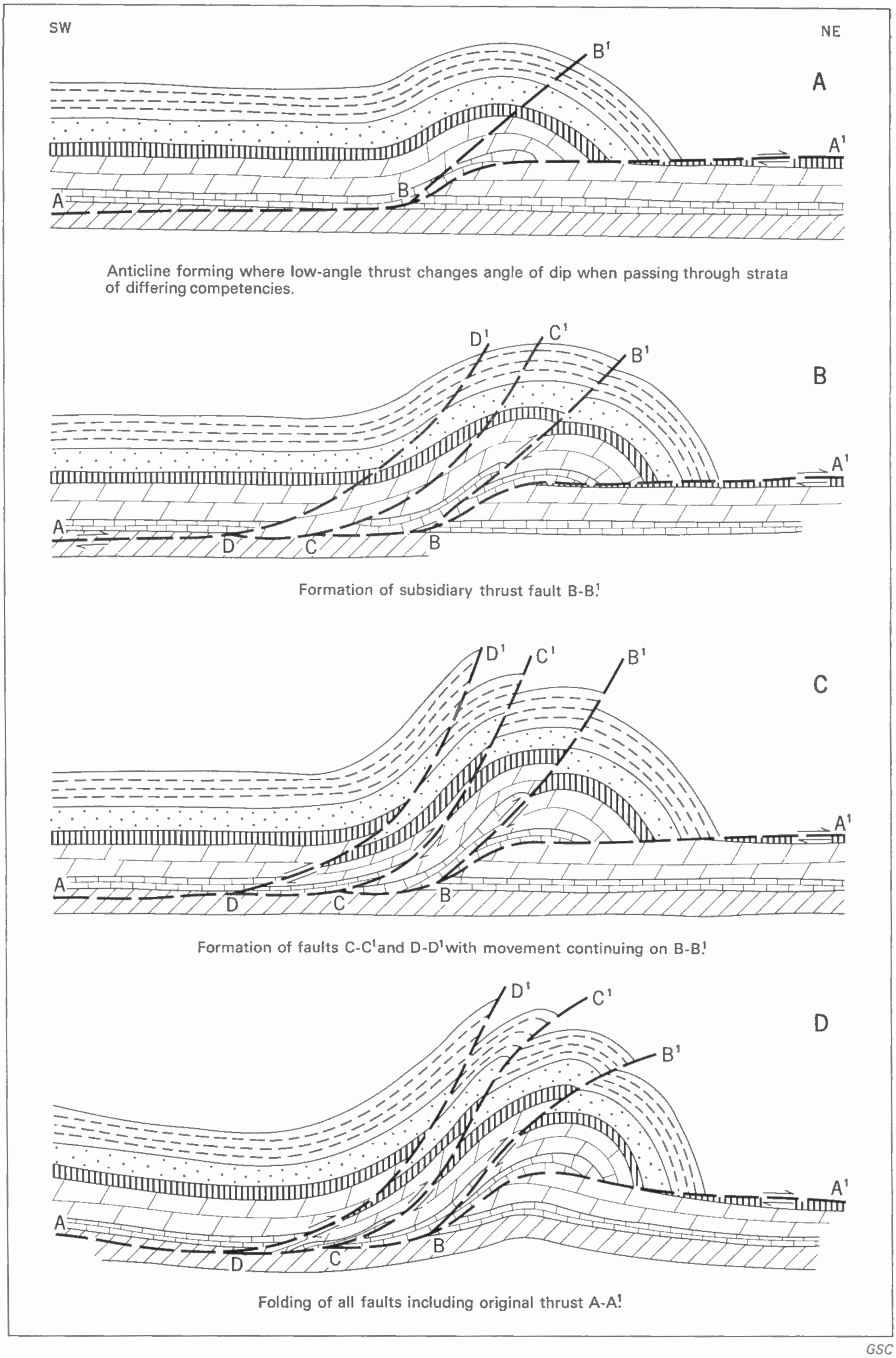
Relief of compressive stress throughout the area was accomplished mainly by the west-dipping thrust faults. Such thrust faults are thought to be initiated by failure of the rocks along physically weak stratigraphic zones. A fault may remain in such zones for a considerable distance as a bedding-plane fault before cutting upward stratigraphically at a small angle through more competent strata. It will tend to break through the competent beds at a much greater angle until it reaches a higher zone of bedding-plane slippage (*see* Rich, 1934; Douglas, 1950; Irish, 1965). The resulting fault is, therefore, from its initiation, step-like and may have some upward concavity. The probable origin of such faults is illustrated on Figure 3 (*see* also Douglas, 1950; Mountjoy, 1960b; Irish, 1965).

However, the positions and behaviour of those thrusts at depth cannot be predicted with reasonable certainty where no data are available. Their formation and course are dependent to a large extent on the thickness and arrangement of competent and incompetent strata within the succession. Generally, thrust faults will be fewer, longer, and of greater displacement in a thick succession of competent strata than in a less competent succession, as for example, from the central part to the eastern ranges of the Rocky Mountains.

Drag Folds

In some places anticlinal folds occur in the hanging-wall at the advance edge of a thrust mass. These are thought to have been initiated by the forward and upward movement of the strata above those parts where the fault cuts steeply across competent strata before flattening again as it enters less competent beds. Further movement of these over-riding beds may cause such embryo folds to increase in size, to become more compressed, and to become asymmetrical with a steep northeast flank and a more gentle southwest flank (Pl. V).

The writer considers that several of the anticlines within the region here discussed probably originated in this manner and were also folded with the underlying thrust fault subsequent to the cessation of movement on the fault surface. Figure 3 illustrates the initiation of these drag-folds (*see* also Rich, 1934; Douglas, 1950; Irish, 1965; Mountjoy, 1960b), and Figure 4 is the writer's interpretation of how the Hoff anticline probably formed.



Anticline forming where low-angle thrust changes angle of dip when passing through strata of differing competencies.

Formation of subsidiary thrust fault B-B!

Formation of faults C-C¹and D-D¹with movement continuing on B-B!

Folding of all faults including original thrust A-A!

FIGURE 4. Diagrammatic cross-sections to illustrate the formation of drag anticlines by northeast movement on thrust fault surface and southwest rotation of back-limb thrust faults.

As a fold such as the Hoff anticline is initiated where the original fault passes from one stratigraphic horizon to another at a higher level (Rich, 1934), it is conceivable that other folds farther east within the same thrust sheet and, in other thrust sheets, are directly related spatially and mechanically to changes in stratigraphic position of the underlying thrust from one zone of bedding-plane slippage to another. Folds originating in this manner may be restricted to the advance edge of the thrust mass.

Back-Limb Thrusts

Relief of stress in the back limb or more gentle flank of an asymmetrical anticline is partly accomplished by the formation of one or more thrust faults. If more than one fault is required, a number of superimposed thrust slices results.

The Hoff anticline is a good example of such a fold, and the use of the term 'back-limb' thrust (Douglas, 1950) has been extended here to include also the southwest-dipping homocline above the Tip Top thrust. Both structures have numerous subsidiary thrust faults on their southwest flanks. They may or may not merge with the major fault at depth. These back-limb thrusts, as well as the strata they cut, now have very steep dips to the southwest. That this was not always so is indicated by the relatively small angle between the bedding and the fault surfaces, assuming that the attitude of the strata when the faults were initiated was essentially horizontal.

Rotation of Thrust Faults

The present steep dips of strata above a thrust fault and of any subsidiary thrusts cutting strata of the hanging-wall have resulted partly from the northeastward movement of the strata on the underlying thrusts. Movement on each underlying fault rotates all strata above it more to the southwest. According to Mountjoy (1960b), the amount of this rotation is dependent on the number of underlying thrust faults, and to some extent is proportional to it.

Figure 4 illustrates the possible sequence of events that has produced the series of steeply dipping and folded faults in the Hoff Range. The sequence of events is thought to have been as follows:

1. Initiation of a major thrust fault A-A′ and subsidiary thrust B-B′ in originally flat-lying strata (Fig. 4A). Thrusting of the overlying strata to the northeast initiated a fold caused by a steepening of the dip of the fault surface.

2. Further movement on fault A-A′ and movement on fault B-B′ and the development of two more easterly faults C-C′ and D-D′ (Fig. 4B). Movement on fault A-A′ and particularly the upward movement on the concave upward surface of B-B′ rotated and steepened all overlying beds, faults, and pre-existing folds.

3. Movement on faults C-C′ and D-D′ as well as further movement on fault B-B′ (Fig. 4C). All strata above thrust A-A′ by this time were being compressed rather than moving eastward on the fault surfaces.

4. Additional compression, resulting in folding on thrusts A-A′, B-B′, C-C′, and a further steepening of the back-limb thrusts as well as strata above each fault (Fig. 4D).

During this deformation the fault slices were rotated, resulting in steeper dips of both the faults and the bedding from their original attitudes. On Figure 4 the faults were assumed to have formed successively from northeast to southwest. This assumption seems most logical, but it is not known if there is a definite time sequence in any one direction for the formation of these thrusts, or, indeed, if there is any directional order of formation.

Folding of Thrust Faults

Figure 4 illustrates how some thrust faults in the area under discussion may have been folded. If a considerable amount of movement takes place on the subsidiary faults before maximum development of the anticline, those faults, together with the strata above them, that are in part over the anticline will be involved in any further compression of the fold. Such faults and the beds above them must be folded to some degree, the ones closer to the axis of the anticline generally being bent more than those farther west on the flank. Several structural features in the mountains and foothills suggest that some folding took place after movement on at least some of the thrust faults had ceased.

The Muskeg thrust, as mapped, appears to overlie the Copton anticline and underlie the Mason syncline. The most logical explanation is that both folds developed subsequent to the fault, but if so, evidence of this should exist at the south end of the anticline above the fault and the north end of the syncline below the fault. Such evidence has not been found. If folding is not subsequent to faulting, then separate faults must underlie the two folds and the Muskeg thrust should die out below the Mason syncline.

A similar situation exists with respect to the large Bernard anticline north of Peace River. There both the Nabesche and Mount Burden thrusts are folded over the anticline and below a complex synclinal area to the southeast. Such structures are difficult to explain except by some folding subsequent to formation of these large overthrusts.

The Mount Russell thrust is folded within an anticline just north of latitude 63°30′, and the east branch of the Mason thrust is also folded with beds above and below. Some folding may have been contemporaneous with the faulting, but folding must have persisted after movement on the fault had ceased.

Folds

Most of the anticlines and synclines within both mountains and foothills are thought to have been formed contemporaneously with the motion on the thrust faults. Folding within each thrust block was an additional means of relieving differential stress. The southwestward rotation caused by movement on underlying, concave-upward thrust faults would tend to partly inhibit further northeastward movement on the hanging-wall block, and thus might cause increased compression of any folds within that block. Most folds on the southeast slope of each fault block are in the Mesozoic formations now exposed at the surface. Whether or not these structures persist at depth in the more competent Palaeozoic rocks is not known. Such crumpling is more typical of the Mesozoic rocks of the Foothills than of the massive, competent, Palaeozoic strata in the Rocky Mountains. The intimate inter-relationship of faulting and folding is illustrated also by the fact that many faults terminate upward, or pass laterally along the strike, into anticlinal folds.

The present attitude of the axial surfaces of many folds is related directly to underlying thrusts. In some places the folds have been rotated by displacement on the underlying concave-upward fault surface so that their axial planes now dip to the northeast. Such folds are found in Triassic strata east of the Rocky Pass thrust.

In northeastern British Columbia, although some thrusts occur within the Foothills, the Mesozoic strata are deformed predominantly by folds. The anticlines are normally narrow and tightly folded and are separated by wide synclines with gently flaring limbs. Thrust faults, where they are present north of Peace River, have usually resulted from the breaking of compressed anticlines, and some of them pass laterally into unbroken symmetrical anticlines.

It seems reasonable to assume, therefore, that many tightly folded and apparently unfaulted anticlines may be underlain by thrust faults on which some movement has taken place, but which have not broken through to the surface. The position and amount of stratigraphic displacement below the surface on such faults may well explain the asymmetry of many folds, particularly those with steep, southwest-dipping limbs.

East-Dipping Thrust Faults

In the Alberta Foothills belt, thrusts on which the hanging-wall has moved relatively to the west are fairly common along the eastern limit of the disturbed strata, which is along the western limb of the Alberta syncline. No such east-dipping faults were recognized along the eastern edge of the foothills in northeastern British Columbia. The formation of these east-dipping thrusts was probably a late event in the total process of deformation. It is probable that such faults were initiated after the strata had been folded so that the attitude of the sedimentary layers, in places, was inclined at an angle such that relief of stress was more easily accomplished by the movement of strata relatively to the southwest.

Much the same origin is postulated for the east-dipping thrust faults in the more contorted parts of the foothills and mountains. These are normally short faults of relatively small stratigraphic separation found in the folded hanging-wall of a thrust block. When stress can no longer be relieved by further movement on the underlying west-dipping thrust and when folds in the hanging-wall block become compressed, east-dipping breaks occur where the attitude of the bedding is appropriate, or at positions dependent on a change of dip of the underlying thrust from steep to less steep. Such faults have a relatively large vertical component of movement, and further shortening is accomplished in this manner. Whether or not an east-dipping fault is present rather than the first stages of an additional west-dipping thrust is thought to be determined mainly by the attitudes of the folded strata above the west-dipping thrust or thrusts. The position of an east-dipping thrust is probably determined by the same attitudes.

Normal Faults

No large normal faults were recognized throughout this part of the Foothills and Mountains.

Influence of Basement Structures

In the region between Pine and Peace Rivers in northeastern British Columbia there is evidence to suggest some basement influence on the surface structures. The writer suggests that the Peace River basement high may have extended westward far enough to have influenced deposition under the present Rocky Mountains and Foothills south of Peace River valley. Farther east under the Plains, an uplift or arch existed during early Palaeozoic times, such that the early Palaeozoic formations are either missing or are very thin over this structure. During Mississippian times this arch disappeared by block faulting and the subsequent Mesozoic formations are relatively thick.

Evidence that this arch existed under the site of the present mountains and foothills is suggested by the following statements.

1. The Silurian and Devonian formations appear to thin from northwest to southeast across Peace River valley.
2. A thinning of the Cambro–Ordovician succession probably extends southward across Peace River valley.
3. Strata of Mississippian age increase in thickness from northwest to southeast.
4. An increase in sandy strata and sand content of carbonate strata southwards across Peace River indicates increasing proximity to a land mass.

The assumption of a basement high in this region might also explain certain structural features that differ there from most places in the Mountains and Foothills.

No folds of any size are in the Palaeozoic rocks as they are farther south where a thick succession of these competent rocks occurs. Instead, the region just south of Peace River valley is broken by numerous west-dipping thrust faults, producing a series of relatively thin thrust plates. In the Foothills the situation is reversed. The Mesozoic rocks are intensely folded but few thrust faults have reached the surface.

The structural high north of Peace River is replaced south of the river by a structurally low area. All folds, including the Bernard anticline, plunge southward across Peace River from about latitude 56°20′N. Thus, progressively younger strata are found at the surface from northwest to southeast. The localization of this southerly plunge may be the result of the thinning in this direction of pre-Mississippian strata. The Jurassic–Cretaceous succession is particularly thick in the foothills region south of Peace River, and these strata have yielded to stress by folding rather than thrust faulting.

A similar region of relatively thick Jurassic–Cretaceous rocks occurs as a northwest-trending area just north of 53°45′N latitude in Alberta, and again the Mesozoic strata are folded intensely but are rarely faulted. The lack of faulting in these two areas must be due to the nature and thickness of the stratigraphic succession, but the greater depositional thickness of Jurassic and Cretaceous strata in the two regions may not be due to the same cause. Basement influence on the Laramide structures in the Alberta part of the region discussed here may be present, but is not evident from existing data.

SUMMARY

1. The region discussed has been deformed by a series of parallel or subparallel, southwest-dipping thrust faults and related folds that have a northwest structural trend. Such thrust faults are believed to have been initiated as bedding plane thrusts. Along their surface traces, major thrust faults commonly parallel particular stratigraphic horizons in the hanging-wall for long distances, and may also follow these same horizons for some distance across the strike.

2. Most folds and thrust faults are believed to be contemporaneous in origin, though some folding may have persisted after movement on the west-dipping faults had ceased.

3. The presence and number of both thrust faults and folds is related to the thickness, arrangement, and physical properties of the rock units within the succession.

(a) In the mountains where a thick succession of massive and competent Palaeozoic strata is present, thrust faults are longer, of greater displacement, and more widely spaced than where the section is much thinner.

(b) Within the relatively less competent Mesozoic strata of the foothills, folds and thrust faults are more numerous and the latter of smaller displacement than in the mountains, but where the Mesozoic succession is abnormally thick, folds are the dominant form of deformation at the present surface.

4. Major thrust faults and most of the folds in the hanging-wall block are intimately related mechanically as well as spatially.

(a) Some thrust faults pass latterly into anticlines.

(b) Many anticlines are directly related to changes in stratigraphic position of the underlying thrust fault from one zone of bedding plane slippage to another.

5. The present steep angle of dip of many back-limb thrusts and the strata they cut is thought to be caused by:

(a) the enlarging or 'rolling-up' of the anticlines formed in the hanging-wall where the thrust changes from a small to a larger angle of dip;

(b) the northeastward movement on one or more underlying concave-upward thrust faults.

6. Most folds are asymmetrical with their axial surfaces dipping southwest or northeast. Both directions of asymmetry may occur at different places along the same anticline.

7. Many folds having northeast-dipping axial planes have resulted from rotation of the thrust sheets in which they occur. This rotation is due to movements of thrust sheets above one or more concave-upward thrust surfaces. The amount of rotation of the axial planes of the folds is, in part, related to the number of underlying thrust faults (Mountjoy, 1960).

8. Structural complexities are generally associated with the more incompetent strata.

9. Generally when one thrust decreases in stratigraphic displacement an adjacent and parallel thrust increases in stratigraphic displacement, producing an *en echelon* pattern.

10. East-dipping thrust faults along the eastern limits of the foothills were probably initiated after folding had oriented the strata into a position favourable for this type of break. East-dipping faults above a major west-dipping thrust fault are considered as adjustment features due to compression of the folded beds. In both these instances the east-dipping thrust faults are late events in deforming processes.

SELECTED BIBLIOGRAPHY

Allan, J. A., Warren, P. S., and Rutherford, R. L.
1932: A preliminary study of the eastern ranges of the Rocky Mountains in Jasper Park, Alberta; *Trans. Roy. Soc. Can.,* 3rd. ser., vol. 26, sec. 4, pp. 225–249.

Chamberlain, R. T.
1945: Basement control in Rocky Mountain deformation; *Am. J. Sci.,* vol. 243A, Daly Memorial Volume, pp. 98–116.

Choquette, A. L.
1959: Theoretical approach to foothills and mountain deformation of western Alberta; *J. Alta. Soc. Petrol. Geol.,* vol. 7, no. 10, pp. 234–237.

Douglas, R. J. W.
1950: Callum Creek, Langford Creek, and Gap map-areas, Alberta; *Geol. Surv. Can.,* Mem. 265.
1958: Mount Head map-area, Alberta; *Geol. Surv. Can.,* Mem. 291.

Dowling, D. B.
1912: Geology of Roche Miette map-area, Jasper Park, Alberta; *Geol. Surv. Can.,* Sum. Rept. 1911, pp. 201-219.

Frebold, H.
1957: The Jurassic Fernie Group in the Canadian Rocky Mountains and Foothills; *Geol. Surv. Can.* Mem. 287.

Goodman, A. J.
1960: Review of some hypotheses on mountain building; *Alta. Soc. Petrol. Geol.,* vol. 8, no. 8, pp. 215–227.

Hage, C. O., and Webb, J. B.
1955: Notes to accompany cross-section of Foothills Belt east of Jasper Park; *Alta. Soc. Petrol. Geol.,* Guide Book, Fifth Ann. Field Conference, pp. 129–130.

Haites, T. B.
1960: Transcurrent faults in western Canada; *J. Alta. Soc. Petrol. Geol.,* vol. 8, no. 2, pp. 33–78.

Hake, B. F., Willis, R., and Addison, C. C.
1942: Folded thrust faults in the foothills of Alberta; *Bull. Geol. Soc. Am.,* vol. 53, pp. 291–334.

Henderson, G. G. L., and Dahlstrom, C. D. A.
1959a: First order nappe in Canadian Rockies; *Bull. Am. Assoc. Petrol. Geol.,* vol. 43, pp. 641–653.

Hubbert, M. K.
1951: Mechanical basis for certain familiar geologic structures; *Bull. Geol. Soc. Am.,* vol. 62, pp. 355–372.

Hubbert, M. K., and Rubey, W. W.
1959: Role of fluid pressure in mechanics of overthrust faulting; *Bull. Geol. Soc. Am.,* vol. 70, no. 2, pp. 115–206.

Hume, G. S.
1941: A folded fault in the Pekisko area, Foothills of Alberta; *Trans. Roy Soc. Can.*, 3rd ser., pt. IV, pp. 87–92.
1957: Fault structures in the Foothills and Eastern Rocky Mountains of Southern Alberta; *Bull. Geol. Soc. Am.*, vol. 68, pp. 395–412.

Hunt, A. D., and Ratcliffe, J. D.
1959: Triassic stratigraphy, Peace River area, Alberta and British Columbia; *Bull. Am. Assoc. Petrol. Geol.*, vol. 43, no. 3, pt. 1, pp. 563–589.

Irish, E. J. W.
1945: Pedley, Alberta; *Geol. Surv. Can.*, Map 838A.
1947: Gregg Lake, Alberta; *Geol. Surv. Can.*, Map 899A.
1949: Moon Creek, Alberta; *Geol. Surv. Can.*, Map 968A.
1950: Copton Creek, Alberta; *Geol. Surv. Can.*, Map 1041A.
1951: Pierre Greys Lakes, Alberta; *Geol. Surv. Can.*, Map 996A.
1951: Pierre Greys Lakes map-area, Alberta; *Geol. Surv. Can.*, Memoir 258.
1958: Charlie Lake, British Columbia; *Geol. Surv. Can.*, Map 17-58.
1962: Halfway River Map-area, British Columbia; *Geol. Surv. Can.*, Map 37-1961.
in prep.: Halfway River Map-Area, British Columbia; *Geol. Surv. Can.* Memoir 357.
1965: Geology of the Rocky Mountain Foothills, Alberta, between latitudes 53°15′ and 54°15′ north; *Geol. Surv. Can.*, Memoir 334.

Irish, E. J. W., and Eccles, J. K.
1963: Adams Lookout, Alberta; *Geol. Surv. Can.*, Map 1104A.

Irish, E. J. W., and Thorsteinsson, R.
1957: Grande Cache, Alberta; *Geol. Surv. Can.*, Map 1049A.

Lang, A. H.
1947: Brûlé and Entrance map-areas, Alberta; *Geol. Surv. Can.*, Memoir 244.

Link, T. A.
1949: Interpretations of Foothills structures, Alberta, Canada; *Bull. Am. Assoc. Petrol. Geol.*, vol. 33, pp. 1475–1501.

MacKay, B. R.
1929: Brûlé Mines Coal Area, Alberta; *Geol. Surv. Can.*, Sum. Rept. 19, 1928, Pt. B, pp. 1–29.
1941: Folded thrust faults in the Brazeau River District, Alberta; *Proc. Roy. Soc. Can.*, 3rd ser., vol. 35, pp. 189–190 (abstract).

McGugan, A., and Rapson, J. E.
1961: Permian stratigraphy and the Post-Carboniferous unconformity, Jasper Area, Alberta; *Edmonton Geol. Soc.*, Third Annual Field Trip, Guide Book.

McLearn, F. H., and Kindle, E.
1950: Geology of northeastern British Columbia; *Geol. Surv. Can.*, Memoir 259.

Mountjoy, E. W.
1960a: Miette, Alberta; *Geol. Surv. Can.*, Map 59–40.
1960b: Structure and stratigraphy of the Miette and adjacent areas, eastern Jasper National Park, Alberta; unpublished Ph.D. thesis, University of Toronto.

Muller, J. E.
1961: Pine Pass map-area, British Columbia; *Geol. Surv. Can.*, Map 11-1961.

North, F. K., and Henderson, G. G. L.
1954: Summary of the geology of the southern Rocky Mountains of Canada; *Alberta Soc. Petrol. Geol.*, Guide Book, Fourth Ann. Field Conference, pp. 16–81.

Pelletier, B. R.
1961: Triassic stratigraphy, Rocky Mountain Foothills, northeastern British Columbia; 94J and 94K; *Geol. Surv. Can.*, Paper 60-2.

Pelletier, B. R., and Stott, D. F.
1963: Trutch map-area, British Columbia; *Geol. Surv. Can.*, Paper 63-12.

Rich, J. L.
1934: Mechanics of low-angle overthrust faulting as illustrated by the Cumberland thrust block, Virginia, Kentucky, and Tennessee; *Bull. Am. Assoc. Petrol. Geol.*, vol. 18, pp. 1584–1596.

Sikabonyi, L. A., and Rogers, W. J.
1959: Palaeozoic tectonics and sedimentation in the northern half of the west Canadian basin; *J. Alta. Soc. Petrol. Geol.*, vol. 7, no. 9, p. 193.

Stott, D. F.
1961: Type sections of some formations of the Lower Cretaceous Fort St. John Group near Pine River, British Columbia; *Geol. Surv. Can.*, Paper 61-11.

1962: Cretaceous rocks of Peace River Foothills; *Edmonton Geol. Soc.*, Fourth Annual Field Trip, Guide Book.

Tozer, E. T.
1961: The sequence of marine Triassic faunas in Western Canada; *Geol. Surv. Can.*, Paper 61-6.

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