CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

MEMOIR 254

ALEXO AND SAUNDERS MAP-AREAS, ALBERTA

BY

O. A. Erdman

This document was produced by scanning the original publication.

Ce document est le produit d'une numérisation par balayage de la publication originale.

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1950

Price, $1 No. 2492

Looking westerly up North Saskatchewan River toward glaciated gap through Brazeau Range. The range has scarp contact with lower land on north side of the river (right-hand side of picture), but a gradational contact on the south side. (Pages 3, 45.)

CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

MEMOIR 254

ALEXO AND SAUNDERS MAP-AREAS, ALBERTA

BY

O. A. Erdman

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1950

Price, $1 No. 2492

CONTENTS

PAGE

Preface vii

CHAPTER I

Introduction 1
Location and means of access 1
Previous work 1
Field work and acknowledgments 2
Physiography 2
Topography 2
Drainage 3
Bibliography 4

CHAPTER II

Stratigraphy 7
General statement 7
Table of formations 8
Description of formations 7
Devonian 7
Exshaw formation 10
Mississippian 10
Banff formation 10
Rundle formation 11
Jurassic and Lower Cretaceous 11
Fernie group and Nikanassin formation 11
Lower Cretaceous 12
Cadomin formation 12
Luscar and Mountain Park formations 12
Upper Cretaceous 12
Blackstone formation 12
Bighorn formation 13
Wapiabi formation 13
Brazeau formation 14
Paleocene 14
Pleistocene and Recent 14

CHAPTER III

Structural geology 15
General statement 15
Folds 16
Symmetrical folds 16
Stolberg anticline, p. 16; Ram River anticline, p. 19; Ram River syncline, p. 20; warps in Bighorn formation southwest of Brazeau Range, p. 20; anticline west of Dutch Creek, p. 22; Philip Creek syncline, p. 22.
Asymmetrical folds 23
Brazeau Range anticline, p. 23; Tawadina Creek anticline, p. 25; Ancona syncline, p. 26; Weaver anticline, p. 27.
Overturned folds and recumbent folds 28
Minor folds and drag-folds 29
Chevron folds 31
Summary and conclusions 32
Culminations and depressions 34
General statement 34
Major culminations and depressions 35
Minor culminations and depressions 36
Deductions 37

CONTENTS—*Continued*

Structural geology—*Concluded* PAGE

Joints 38
General statement 38
Pattern of joints 38
Quality of joints 38
Spacing of joints 40
Dip of joints 41
Joints in Upper Cretaceous and Paleocene rocks 42
Joints and veins 42
Joints and faults 43
Summary 43
Faults 44
General statement 44
Major thrust faults 44
Fault No. 1, p. 44; fault No. 2, p. 44; fault No. 3, p. 46; fault No. 4, p. 46; fault No. 5, p. 46.
Minor thrust faults 47
Normal faults 48
Imbricate structure 49
Summary 50
Folded thrust faults 51
General statement 51
Historical sketch 51
Folded fault of Philip Creek 53
Folded fault of Dizzy Creek 54
General remarks, p. 54; Luscar window, p. 55; Rundle window, p. 55; Banff window, p. 56; relation of the separate windows, p. 57; extension of the folded fault, p. 58; evolution of Dizzy Creek folded fault, p. 60.
Significance of folded faults 60
Summary and conclusions 61
Summary of structural history 61

CHAPTER IV

Economic geology 63
Oil and gas 63
Coal 69

APPENDIX

Palæontology 73
General statement 73
List of Middle or lower Upper Devonian fossils 74
List of Upper Devonian fossils 75
List of Banff fossils 78
List of Rundle fossils 81
List of Fernie, Nikanassin, and Luscar fossils 82
List of Blackstone, Bighorn, and Wapiabi fossils 83
List of Paleocene flora 84
List of Paleocene fauna 85
Collection localities 86

Index 97

CONTENTS—*Concluded*

Illustrations

Map 884A. Alexo, Alberta.....In pocket
885A. Saunders, Alberta..... " "

Plate I. Brazeau Range and glaciated gap of North Saskatchewan River..Frontispiece
II. A. Devonian and Banff rocks south of North Saskatchewan River..... 91
B. Devonian rocks north of North Saskatchewan River..... 91
III. Exshaw formation in railway cut..... 92
IV. Axis of Stolberg anticline..... 93
V. Joints and ripple-marks in Luscar sandstone..... 94
VI. Section of folded thrust fault in valley of Dizzy Creek..... 95

Figure 1. Regional geology and structure in the vicinity of Alexo and Saunders map-areas.....In pocket
2. Structural features of Alexo and Saunders map-areas..... " "
3. Joints and major structures..... 39
4. Philip Creek folded fault.....In pocket
5. Folded fault of Dizzy Creek..... " "

PREFACE

Alexo and Saunders are adjoining map-areas within the Foothills belt of west-central Alberta. As such they partake in the structural, stratigraphic, and economic problems peculiar to this belt, and their mapping has afforded another link in an almost continuous chain of completed 1-mile areas extending northwesterly from the International Boundary to beyond Athabasca River.

The present report, based on field work by Dr. G. P. Crombie and the author in 1943 and by the author in 1944, is a somewhat modified version of the dissertation submitted to the University of Chicago in 1946 as partial fulfilment of a doctorate degree. It is concerned especially with the structural geology of the two areas, and a principal contribution is the account of well exposed folded faults in rocks of both Palæozoic and Mesozoic ages. Figures on various scales are presented to supplement the written accounts of these and other structural features, and to indicate both their local and regional relationships. In addition, brief chapters are written on the stratigraphy and economic prospects of the map-areas, and an appendix lists and classifies the numerous species of fossil fauna and flora collected.

The map-areas lie in potential territory for oil and gas accumulations and coal deposits. Possible oil structures are described, and some exploratory drilling has been done both within and near Saunders map-area, though without material success. Coal is being mined currently at Alexo and Saunders in the northern parts of the map-areas, and Dr. Erdman has mapped and listed all field locations of significant coal outcrops in these areas and has formed an estimate of the total available coal reserves.

The report is accompanied by geological maps of Alexo and Saunders map-areas, on a scale of 1 inch to 1 mile, and is illustrated by several plates and figures.

GEORGE HANSON,
Chief Geologist, Geological Survey of Canada

OTTAWA, January 15, 1949

Alexo and Saunders Map-Areas, Alberta

CHAPTER I

INTRODUCTION

LOCATION AND MEANS OF ACCESS

Alexo and Saunders map-areas (*See* accompanying maps 884A and 885A) lie in the Foothills belt of west-central Alberta between latitudes 52°15′ and 52°30′ north and longitudes 115°30′ and 116° west. Together they comprise an area of about 360 square miles situated about 80 miles north of Banff, an equal distance west of Red Deer, and some 100 miles southeast of Jasper. The first range[1] of the Rocky Mountains lies a few miles southwest of the map-areas, and the height of land, marking the Alberta-British Columbia border, about 60 miles southwest.

The map-areas are accessible by motor road or Canadian National railway, both of which cross the northern part. A cable ferry crosses North Saskatchewan River 1½ miles west of the village of Saunders. Within the map-areas, travel north of the river is facilitated by the motor road and railway and by lumber roads and trails. Access south of the river is by pack- and saddle-horse, and the area is served by forestry trails, lumber roads, part of the Ram River No. 1 well road, and trapper trails.

PREVIOUS WORK

Previous geological work by Allan and Rutherford (1923)[2] in Saunders Creek and Nordegg coal basins included that part of Alexo and Saunders map-areas lying north of North Saskatchewan River. Earlier published accounts by Dowling (1910, 1914), Rose (1915), and Stewart (1917) are more general, or deal specifically with coal. Malloch's pioneer work in the Bighorn basin (1911), northwest of the map-areas, is important in that he described and named formations that occur in the present map-areas. Evans' stratigraphical work included only the extreme south part of the Saunders sheet (1930). The more recent work, by B. R. MacKay, G. P. Crombie, J. F. Henderson, and H. H. Beach, of the Geological Survey of Canada, includes a series of twelve, 15-minute map-areas covering a narrow zone of the outer Foothills belt, extending for scores of miles both northwest and southeast of Alexo and Saunders map-areas. A part of this zone is shown on Figure 1. Much unpublished geological work has been done in Alexo and Saunders map-areas by oil companies.

[1] The expression "first range" refers to the easternmost range of the Rocky Mountains proper west of the two map-areas.

[2] Dates, in parentheses, are those of publications listed in the Bibliography at the end of Chapter I.

FIELD WORK AND ACKNOWLEDGMENTS

Geological field work in Alexo map-area was commenced in 1942 by B. R. MacKay, and nearly completed during 4 months of 1943 by G. P. Crombie (1944), with both of whom the writer was associated. The unfinished part of Alexo, and the adjacent Saunders map-area, were completed by the writer (1945) during the 1944 field season. A few critical locations were checked during the 1945 season.

The writer is indebted to Dr. G. P. Crombie, with whom he associated in mapping the Alexo map-area, whose published report and map are freely used. The late Professor R. T. Chamberlin, of the University of Chicago, gave valuable suggestions and criticisms during the course of the work.

The identification of the Palæozoic invertebrate fossils shown in the tabulated lists in the Appendix was done by Dr. Alice E. Wilson and R. A. C. Brown of the Geological Survey of Canada. Dr. F. H. McLearn and Dr. W. A. Bell of the Geological Survey of Canada reported on the Mesozoic invertebrate fossils and the Mesozoic and Cenozoic plant fossils, respectively. Dr. L. S. Russell, of the University of Toronto, identified the Cenozoic (Paleocene) invertebrates. Messrs. J. B. Webb of Imperial Oil Limited, Calgary, and L. M. Clark of the Shell Oil Company of Canada, Limited, Calgary, permitted the writer access to the files on the joint venture Imperial Shell Stolberg No. 1 well.

A. G. Jones and A. E. Kliske, and J. B. Currie, W. J. Glover, and E. H. Stinson rendered capable services as assistants during 1943 and 1944, respectively. The following persons provided valuable geological information in the field: Mr. W. E. Wuest of Imperial Oil Limited; Major E. F. Pullen, President and General Manager of Alexo Coal Company, Limited, Alexo; Mr. J. P. Brown, Mine Manager of Alexo Coal Company, Limited; and Mr. Owen Morgan, Mine Manager of Bighorn and Saunders Creek Collieries, Limited, Saunders. Messrs. F. Bradshaw and R. MacLaughlin, Alberta Government forest rangers, rendered many services.

PHYSIOGRAPHY

TOPOGRAPHY

The topographic features of the map-areas are northwest-trending valleys and ridges, typical of the Foothills of Alberta. The surface has a maximum topographic relief of about 3,600 feet; the lowest elevation, on North Saskatchewan River, is about 3,550 feet above sea-level, whereas the highest elevation, in Brazeau Range, is more than 7,130 feet. The area is topographically divisible into three parts: (1) the northeastern lowland, constituting about one-half the area; (2) Brazeau Range; and (3) the low plateau area southwest of Brazeau Range. Both the structure of the underlying bedrock, and the markedly differential resistance to erosion offered by the various lithological units, have been controlling factors in determining the nature of the topography.

The northeastern lowland is less than 5,000 feet in elevation, and has a maximum relief of about 1,200 feet. It is heavily wooded in most parts and includes many swamps or muskegs. Creeks follow meandering courses, and in general expose bedrock in their lower reaches. Knob-and-kettle

topography is common, with depressions as much as 50 feet deep. Easterly trending gravel ridges, possibly eskers, are prominent in parts of Saunders map-area. The lowland appears to have resulted from extensive erosion of the soft, Upper Cretaceous and Paleocene rocks, modified by later alpine glaciation. Much of it is underlain by low-dipping rocks, but moderate to high dips occur locally.

Brazeau Range trends diagonally across most of Alexo map-area and disappears to the southeast in the Saunders map-area. The range is composed of resistant Palæozoic limestones and softer shales, which are well exposed above an elevation of 6,000 feet. Plate I shows the catenary profile of the glaciated North Saskatchewan River Valley. The minimum thickness of the ice-sheet is indicated by the presence of glacially transported erratics on Brazeau Range, at elevations as high as 6,900 feet. The range exemplifies the effects of both lithology and structure in determining the topography. Folding and thrusting eastward of the resistant Upper Palæozoic rocks over soft Upper Cretaceous rocks has produced the northeast-facing scarps north of the river. South of the river, the anticlinal axes coincide closely with tops of ridges. Plate II A and B, respectively, show the axes of Brazeau Range anticline south of The Gap, where folding is broad, and north of The Gap, where folding is close. Brazeau Range submerges in the eastern side of Saunders map-area concomitantly with the disappearance of Upper Palæozoic rocks that plunge southeast below the surface. Prominent ridges reappear in the southeastern part of Saunders map-area, where northwest-plunging anticlines bring the resistant Upper Palæozoic rocks to the surface. The southwestern flank of Brazeau Range is a near-continuous dip-slope of resistant upper Rundle limestone. Differential erosion has produced typical 'flatirons'. In many places these dip-slopes show grooves or flutings caused by water erosion and weathering.

The low, plateau area southwest of Brazeau Range consists of warped basins and dissected inter-basin parts. Elevations are as high as 6,000 feet. An intimate relation of structure and differential erosion is well marked. The main structural units are broad, shallow synclines with intervening steep-crested anticlines; the stratigraphic units constitute a hard, thin, Bighorn formation, lying between the soft, thick, Blackstone shales below, and Wapiabi shales above. Topographic basins capped with Bighorn sandstone coincide with structural basins or synclines, and stream valleys in many places coincide with the axes of the intervening breached anticlines. The resistant, Bighorn sandstone is breached at the axes of anticlines because of its relative thinness, and because tension fractures at the axis facilitated erosion. This type of erosion along anticlinal axes contrasts with that in the thick, massive, Upper Palæozoic rocks of Brazeau Range where anticlinal axes coincide closely with topographic highs.

Differential erosion of imbricate structures in Blackstone, Bighorn, and Wapiabi formations has resulted in a series of parallel ridges in the southwestern part of Alexo map-area.

DRAINAGE

Alexo and Saunders map-areas are drained by North Saskatchewan River and its tributaries. Both this river and its largest tributary, the Ram, are antecedent streams. Smaller streams, such as Gap, Dutch, and Philip

Creeks, are controlled by bedrock structure, and hence are subsequent. In the southwestern part of Alexo map-area, feeder creeks of the subsequent streams enter at right angles from higher ground, and produce a trellised pattern. Several of the small creeks heading in Brazeau Range are intermittent, and flow underneath rock rubble in their upper courses. North Saskatchewan River is glacier-fed from the west, whereas the source of North Ram River and smaller streams is more local. This accounts for the anomalous condition, during hot dry weather, of high water in the North Saskatchewan concomitant with low water in the Ram and smaller streams and, during cold, rainy weather, of a drop in the water level of North Saskatchewan River in contrast with the rise of smaller streams.

BIBLIOGRAPHY

Allan, John A., and Rutherford, Ralph L.: Saunders Creek and Nordegg Coal Basins, Alberta, Canada; Scientific and Industrial Research Council, Report No. 6, Fourth Annual Report on the Mineral Resources of Alberta, 1922, pt. 1, pp. 1-66 (1923).

Allan, J. A., Warren, P. S., and Rutherford, R. L.: A Preliminary Study of the Eastern Ranges of the Rocky Mountains in Jasper Park, Alberta; Roy. Soc., Canada, Trans., 3d ser., sec. IV, vol. XXVI, pp. 225-50 (1932).

Bailey, E. B.: Tectonic Essays Mainly Alpine; Oxford: At the Clarendon Press, 1935.

Beach, H. H.: Moose Mountain and Morley Map-areas, Alberta; Geol. Surv., Canada. Mem. 236, 1943.

Billings, Marland P.: Structural Geology; New York: Prentice Hall, Inc., 1942.

Bureau of Mines: Coal Mines in Canada; Division of Economics, No. 4-1 (1945).

Cadell, Henry M.: Experimental Researches in Mountain Building; Trans., Roy. Soc., Edinburgh, vol. XXXV, pt. 1, pp. 337-57 (1889).

Crombie, G. P.: Alexo Map-area, Alberta; Geol. Surv., Canada, Paper 44-18 (1944).

Crombie, G. P., and Erdman, O. A.: Alexo, Alberta; Geol. Surv., Canada, Paper 45-23, second preliminary map (1945).

Daly, Reginald Aldworth: Geology of the North American Cordillera at the Forty-Ninth Parallel; Geol. Surv., Canada, Mem. 38, 1912.

Dowling, D. B.: Coal Fields South of the Grand Trunk Pacific Railway, in the Foothills of the Rocky Mountains, Alberta; Geol. Surv., Canada, Sum. Rept. 1909, pp. 139-50 (1910).

——— North Saskatchewan River Coal Areas, Alberta; Geol. Surv., Canada, Sum. Rept. 1913, pp. 150-52 (1914).

Erdman, O. A.: Saunders Map-area, Alberta; Geol. Surv., Canada, Paper 45-24 (1945).

——— Cripple Creek, Alberta; Geol. Surv., Canada, Paper 46-22 (1946).

Evans, C. S.: Some Stratigraphic Sections in the Foothill Region, between Bow and North Saskatchewan Rivers, Alberta; Geol. Surv., Canada, Sum. Rept. 1929, pt. B, pp. 25-35 (1930).

Hage, C. O.: Folded Thrust Faults in Alberta Foothills west of Turner Valley; Trans., Roy. Soc., Canada, 3d ser., sec. IV, vol. XXXVI, pp. 67-78 (1942).

Hake, B. F., Willis, Robin, and Addison, C. C.: Folded Sheet Thrusts in the Foothills of Alberta; Proc. Geol. Soc. of America, 1934, p. 324 (1935).

——— Folded Thrust Faults in the Foothills of Alberta; Geol. Soc. of America, Bull. LIII, pp. 291-334 (1942).

Hayes, C. W.: Ringgold Folio, Georgia-Tennessee; Geologic Atlas of the United States, U.S. Geol. Surv., Folio No. 2 (1894).

Henderson, J. F.: Tay River Map-area, Alberta; Geol. Surv., Canada, Paper 44-26, (1944).

——— Fall Creek Map-area, Alberta; Geol. Surv., Canada, Paper 45-19 (1945).

Hills, E. Sherbon: Outlines of Structural Geology; New York: Nordeman Publishing Co., Inc., 1941.

Hume, G. S.: Waterton Lakes-Flathead Valley Area, Alberta and British Columbia; Geol. Surv., Canada, Sum. Rept. 1932, pt. B, pp. 1-20 (1933).

——— A Folded Fault in the Pekisko Area, Foothills of Alberta; Trans., Roy. Soc., Canada, 3d. ser., sec. IV, vol. XXXV, pp. 87-92 (1941).

Interim Geological Report, The Petroleum and Natural Gas Conservation Board, Calgary, Alberta (August 14, 1945; November 22, 1945).

Keith, Arthur: Maynardville Folio, Tennessee; Geologic Atlas of the United States, U.S. Geol. Surv., Folio No. 75 (1901).

——— Roan Mountain Folio, Tennessee-North Carolina: Geologic Atlas of the United States, U.S. Geol. Surv., Folio No. 151 (1907).

Kendall, P. F., and Briggs, Henry: The Formation of Rock Joints and the Cleat of Coal; Proc. Roy. Soc., Edinburgh, vol. LIII, 1932-33, pp. 164-87 (1934).

Kober, L.: Bau und Enstehung der Alpen; Berlin: Gebrüder Borntraeger, 1923.

Link, Theodore A.: Interpretations of Foothills Structures, Alberta, Canada; Am. Soc. Pet. Geol., Bull., vol. 33, No. 9, pp. 1475-1501 (1949).

Lugeon, M.: Les Grandes Nappes de Recouvrement des Alpes du Chablais et de la Suisse; Société Géologique de France, Bull., 4th ser., vol. I, pp. 723-822 (1901).

McConnell, R. G.: Report on the Geological Structure of a Portion of the Rocky Mountains, Accompanied by a Section Measured near the 51st Parallel; Geol. Surv., Canada, Ann. Rept. (new series), vol. II, 1886, pt. D, pp. 1-41 (1887).

MacKay, B. R.: Geology, Mountain Park Sheet, Alberta; Geol. Surv., Canada, Map 208A (1929).

——— Stratigraphy and Structure of Bituminous Coalfields in the Vicinity of Jasper Park, Alberta; Trans., Can. Inst. Min. and Met., vol. XXXIII, pp. 473-509 (1930).

——— Brazeau, Alberta; Geol. Surv., Canada, Paper 41-4 (1941a).

——— Bighorn River, Alberta; Geol. Surv., Canada, Paper 41-9 (1941b).

——— Folded Thrust Faults in the Brazeau River District, Alberta; Proc. and Trans., Roy. Soc., Canada, Abstract in Appendix C, 3d ser., sec. IV, vol. XXXV, pp. 189-90 (1941c).

——— Structural Problems in the Foothills of Central Alberta; Illustrated address given at the annual western meeting of the Canadian Institute of Mining and Metallurgy, at Edmonton, Alberta, Oct. 3 (1941d).

——— Foothills Belt of Central Alberta, Alberta; Geol. Surv., Canada, Paper 43-3 (1943a).

——— Wawa Creek, Alberta; Geol. Surv., Canada, Paper 43-10 (1943b).

Malloch, G. S.: Bighorn Coal Basin, Alberta; Geol. Surv., Canada, Mem. No. 9-E, 1911.

Mead, Warren J.: Notes on the Mechanics of Geologic Structures; Jour. of Geol., vol. XXVIII, pp. 505-23 (1920).

Peach, B. N., *et al.*: The Geological Structure of North-West Highlands of Scotland; Mems. of the Geol. Surv., Great Britain. Edited by Sir Archibald Geikie. Glasgow: James Hedderwick and Sons Ltd., 1907.

Rose, Bruce: Reconnaissance Along the Red Deer, James, Clearwater, and North Saskatchewan Rivers, Alberta; Geol. Surv., Canada, Sum. Rept. 1914, pp. 52-53 (1915).

Rutten, L. (ed.): Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën. The Hague, 1929.

Sanderson, J. O. G.: Geology of the Brazeau Area; Trans., Can. Inst. Min. and Met., vol. XLII, pp. 429-42 (1939).

Schardt, H.: Sur l'Origine des Alpes du Chablais et du Stockhorn en Savoie et en Suisse; Comptes Rendus des Séances de l'Académie des Sciences, vol. CXVII, pp. 707-9 (1893).

Sheldon, Pearl: Some Observations and Experiments on Joint Planes; Jour. Geol., vol. XX, pp. 53-79 and 164-83 (1912).

Shimer, Hervey W.: Upper Palæozoic Faunas of the Lake Minnewanka Section, Near Banff, Alberta; Geol. Surv., Canada, Bull. No. 42, Contributions to Canadian Palæontology, pp. 1-84 (1926).

Stansfield, E., and Lang, W. A.: Coals of Alberta, Their Occurrence, Analysis and Utilization; Sci. Ind. Res. Coun., Alberta, Rept. No. 35, pp. 1-174 (1944).

Staub, R.: Zur Tektonik der Südöstlichen Schweizeralpen. Beiträge zur Geologischen Karte der Schweiz,, Neue Folge, XLVI. Lieferung 1. Abteilung. Berne: A. Francke, 1916.

Stewart, J. S.: Coal Mines of West Central Alberta; Geol. Surv., Canada, Sum. Rept. 1916, pp. 94-106 (1917).

Warren, P. S.: Age of the Exshaw Shale in the Canadian Rockies; Amer. Jour. Science, 5th ser., vol. XXXIII, pp. 454-57 (1937).

Western Examiner (Calgary, Alberta), vol. XVII (Dec. 15, 1945; Jan. 12, 1946).

Willis, Bailey: Stratigraphy and Structure, Lewis and Livingstone Ranges, Montana; Geol. Soc., America, Bull. XIII, pp. 305-52 (1902).

——— Report on an Investigation of the Geological Structure of the Alps; Smith. Misc. Coll., vol. LVI, pp. 1-13 (1912).

Willis, Bailey, and Willis, Robin: Geologic Structures, 3d ed. revised. New York and London: McGraw-Hill Book Co., Inc. 1934.

CHAPTER II

STRATIGRAPHY

GENERAL STATEMENT

All the rocks exposed within Alexo and Saunders map-areas are of sedimentary origin. They represent formations ranging in age from Devonian to Paleocene, and have an exposed aggregate thickness of more than 13,000 feet. No Permian or Triassic strata are known to be present. The Fernie and Nikanassin formations, and the Luscar and Mountain Park formations, were mapped separately in Alexo map-area, but have been combined in the Saunders area (*See* Maps 884A, 885A). The stratigraphic sequence between late Upper Cretaceous and Paleocene is interrupted by a large thrust fault (Fault No. 2, Figure 2) that cuts diagonally across the map-areas from northwest to southeast. The fault has overridden a few thousand feet of strata that appear nowhere at the surface in these map-areas. Northeast of this fault, rocks of uppermost Cretaceous and Paleocene ages cannot be separated effectively, and are mapped together.

The Palæozoic formations consist of shales, limestones, and dolomites of marine origin. They are exposed mainly in Brazeau Range in Alexo map-area, and as small inliers in Saunders map-area. Mesozoic formations underlie most of the southwestern half of the map-areas; they are composed chiefly of sandstones and shales of continental origin, separated in early Upper Cretaceous time by a thick series of shale of marine origin. Undivided rocks of late Upper Cretaceous and Paleocene ages occupy the northeastern half of the map-areas; they constitute several thousand feet of interbedded sandstones and shales, with minor amounts of conglomerate, carbonaceous shale, and coal; all are of continental origin.

An erosional disconformity between Palæozoic and Mesozoic formations marks the absence of the Pennsylvanian, Permian, and Triassic systems, and the lowest part of the Jurassic. The Rocky Mountain and Spray River formations of Pennsylvanian (or Permian) and Triassic ages, respectively, are present in Bighorn Range about 12 miles west of Alexo map-area (MacKay, 1941b). The Spray River formation also occurs in the first range of the Rocky Mountains about 20 miles southwest of Brazeau Range (Erdman, 1946). Conglomerates within the Cretaceous system are suggestive of erosional contacts, and an erosional unconformity separates the pre-Pleistocene consolidated strata from overlying unconsolidated drift.

DESCRIPTION OF FORMATIONS

DEVONIAN

Strata of Middle or Upper Devonian age constitute the oldest series exposed in the area. The rocks are in part correlated faunally with Devonian beds of the Banff and Jasper areas (Shimer, 1926; Allan, *et al.*, 1932), but the lithology appears to resemble more closely that of the Jasper

TABLE OF FORMATIONS

Period or system	Epoch or series	Formation and thickness	Character
		Feet	
Quaternary	Pleistocene and Recent		Deposits of gravels in stream valleys, gravel ridges, and deposits of till in the northeastern part of the area
		Unconformity	
Tertiary	Paleocene	Paskapoo (in part)	Brown and grey, arkosic sandstone, interbedded with green mudstone and shale; tuff, bentonite, and carbonaceous rock are common. Commercial coal at Alexo and Saunders mined from coal-bearing series
		Disconformity (?)	
Cretaceous	Upper Cretaceous	Brazeau (including Edmonton equivalents) 4,700	Grey and green sandstone and sandy shale; gritty carbonaceous sandstone, and maroon weathering sandstone. Lower part exposed in area
		Wapiabi 1,400–1,600	Black shale and sandy shale; scattered concretions and bands of rusty weathering limestone
		Bighorn 275–300	Resistant, siliceous sandstone member at top and bottom; a thicker, soft shale and shaly sandstone member in middle
		Blackstone 1,300	Soft, thin-bedded, black, fissile shale; ironstone concretions and limy bands
	Lower Cretaceous	Mountain Park 650–750	Grey and green weathering, gritty sandstones, and interbedded shales; conglomerates
		Luscar 850–1,175	Interbedded, thin-bedded sandstones, shales, and carbonaceous rocks; commercial coal seams
		Cadomin 20–80	Resistant, chert and quartz pebble-conglomerate and interbedded sandstone
		Nikanassin 360–	Upper part: alternating shale and sandstone, more shaly and thinner in Saunders map-area; lower part: persistent, hard, bedded, black, cherty, phosphatic limestone
Jurassic		..... 600 Fernie	

TABLE OF FORMATIONS—*Concluded*

Period or system	Epoch or series	Formation and thickness	Character
		Unconformity	
Carboniferous	Mississippian	Rundle 620–645	Upper part: thick, massive, light weathering limestone, and limy dolomite; middle part: soft, thin-bedded, shaly limestone; lower part: massive coarse-grained limestone
		Banff 617–626	Thin-bedded limestone and shaly limestone, platy at base; cherty bands in lower part
Devonian	Upper Devonian	Exshaw 6	Fissile, paper-thin, black shale part.
		593	Shaly limestone and limestone above, and thick, massive, saccharoidal dolomite below; thin sandstone at base
	Lower Upper Devonian or Middle Devonian	1,200+	Upper part: bedded limestone and cream weathering, silty, calcareous shale; lower part: black shaly limestone and limy shale

area. As the basal part of the succession is concealed, no new formational names are introduced. A black shale, believed to be that of the Exshaw formation, occurs at the top of the succession[1] (Warren, 1937).

Devonian rocks outcrop in Brazeau range of Alexo map-area. The most complete section is in The Gap of North Saskatchewan River where about 1,800 feet of Devonian strata are exposed. Fossil evidence indicates that the lower 1,200 feet are of Middle or early Upper Devonian age. The total thickness of Devonian strata is probably between 2,000 and 2,500 feet, an estimate derived from the calculated figure of 2,300 to 2,350 feet for the Devonian strata encountered in Altoba Clearwater No. 1 well in Limestone Mountain map-area, about 40 miles southeast along trend; and from a thickness of 2,250 feet for the Devonian in the first range of the Rocky Mountains, about 20 miles south of The Gap of North Saskatchewan River (Erdman, 1945). The overlying contact with the Banff formation of Mississippian age is apparently conformable. Rocks underlying the Devonian in Cripple Creek map-area to the south of Alexo map-area are Upper Cambrian in age.[2]

The Devonian rocks are divisible into lithologic units, especially on weathered outcrops (Plate II A and B). The lowermost 300 feet of black, shaly limestone and limy shale are overlain by 500 feet of thin-bedded,

[1] Cook, Ian M.: The British American Oil Company, Limited, Calgary, collected *Tornoceras* cf. *uniangulare* from the outcrop of this black shale shown in Plate III. Personal communication, 1947.

[2] Wilson, A. E.: Geol. Surv., Canada, report after examination of fossils (1946).

silty and calcareous shales that weather a distinctive cream colour. Above the cream weathering shales are 387 feet of strata composed of a lower 120 feet of alternating massive limestone and thin-bedded limestone, which forms 'ribboned' cliffs, grading upward into a succession of thin-bedded, fine-grained limestone, shaly limestone, and calcareous dolomite. Several feet of hard, white sandstone occur at the top.

A resistant, thick-bedded, dense to porous, saccharoidal dolomite overlies the sandstone. This dolomite is of widespread occurrence, and is uniform in appearance. It is a prominent ridge-forming rock in the first range of the Rocky Mountains in Cripple Creek map-area, and in parts of the next range west. It can be recognized in oil well specimens from Tay River and Limestone Mountain map-areas to the southeast. The dolomite measures 419 feet in thickness in the vicinity of Dizzy Creek. It appears to have responded competently to deformation in contrast with the underlying, cream weathering, calcareous shales.

Overlying the saccharoidal dolomite are 174 feet of shaly limestone and limestone, the upper 74 feet of which are predominantly massive limestone. The lower contact with the saccharoidal dolomite is gradational, whereas the upper contact, with the Exshaw shale formation, is sharp.

Fossils, mainly brachiopods, are abundant at a few horizons in the Devonian section.[1] *Spirifer jasperensis* occurs near the base of the exposed Devonian; *Atrypa* is present in strata between the cream weathering shale below and saccharoidal dolomite above; *Spirifer whitneyi* and its variations, and *Schizophoria striatula* with its variations characterize the Upper Devonian directly below the Exshaw shale. The cream weathering shale member contains few fossils and none was found in the saccharoidal dolomite.

Exshaw Formation. This formation is composed of 6 feet of fissile, paper-thin, black shale, and is best exposed in a railway cut a short distance west of Alexo map-area (*See* Plate III). The upper contact with the Banff formation is distinct. The shale is notable for its widespread extent through the Foothills and Plains of Alberta.

Lithologically the Exshaw shale bears a closer affinity to the thin-bedded Banff rocks above than to the underlying massive Devonian limestone below. However, *Tornoceras* cf. *uniangulare* found in the railway cut has been considered to be a diagnostic Upper Devonian fossil.

MISSISSIPPIAN

Banff Formation. This formation directly overlies the Exshaw shale, and underlies the Rundle formation of Mississippian age. Banff rocks outcrop in Brazeau Range, and in a small inlier on Tawadina Creek. The formation is 617 feet thick on the ridge north of Dizzy Creek and 626 feet thick in the Ram River No. 1 well on Tawadina Creek. It is composed of beds that are softer than those of the underlying Devonian (excluding the Exshaw), or overlying Rundle formations, and generally forms gentle scree slopes (Plate II A). The rocks are essentially thin-bedded limestones and shaly limestones, platy near the base, but interbedded for about 200 feet above the platy zone with cherty bands. The upper part of the formation is generally thin-bedded, shaly limestone. Its contact with the overlying Rundle formation is sharp.

[1] The complete list of fossils collected from the Devonian strata is given in Appendix to this report.

A prolific fauna, chiefly brachiopods, has been found within the upper 200 feet of the Banff formation. Several species of productoids and spirifers constitute the most numerous fossils. The complete list of fossils is included in the Appendix to this report.

Rundle Formation. The Rundle formation overlies the Banff and underlies the Fernie group of Jurassic age. The contact with the Fernie is unconformable. The Rundle outcrops as a peripheral strip around Brazeau Range, and forms an almost continuous dip-slope on the southwestern flank of the range. Rundle strata also outcrop as inliers on North Saskatchewan River west of Brazeau Range, and in the southern part of Saunders map-area. The thickness of the formation varies from 620 to 645 feet, the latter measurement being obtained from the well exposed section in Dizzy Creek Valley (Plate VI).

The Rundle, throughout the map-areas, is divisible into three lithologic units or members. The lowest member is a massive, light weathering, coarse-grained limestone, about 170 feet thick. The middle member, about 130 feet thick, consists of soft, buff, thin-bedded, shaly limestones that form saddles or notches (Plate VI). The upper member is a white to ash-grey weathering, massive limestone and limy dolomite, containing cherty bands and nodules near the upper contact. This upper member is 345 feet thick in the vicinity of Dizzy Creek. The massive members of the Rundle are resistant to weathering, and dip-slopes of the upper member form typical 'flatirons' southwest of Brazeau Range.

Dry, black residue of hydrocarbons is disseminated in pores of the lower and upper members of the Rundle, and in places is concentrated in fractures. Fossils are scarce, the most numerous forms being cup corals and species of spirifers. Fossils collected in the Rundle formation are listed in the Appendix to this report.

JURASSIC AND LOWER CRETACEOUS

Fernie Group and Nikanassin Formation. The Jurassic Fernie group is in sharp, unconformable contact with the underlying Rundle; and the Lower Cretaceous Nikanassin formation is in distinct contact with the overlying Cadomin conglomerate. The contact between Fernie and Nikanassin appears gradational. The formations are exposed in the flank of Brazeau Range, and in scattered outcrops in the southwestern part of Saunders map-area. In Alexo map-area the combined strata have an aggregate thickness of between 500 and 600 feet, of which the lower 270 to 330 feet are considered Fernie on the basis of general lithology (Crombie, 1944). In Saunders area the aggregate thickness of the same succession of strata ranges between 360 and 440 feet and there the Nikanassin has been mapped with the Fernie group. In both areas a hard, bedded, black, cherty, phosphatic limestone occurs in the lower 120 to 160 feet of the series. The overlying strata consist of an alternation of shale and sandstone bands that changes within short distances and becomes thinner and more shaly toward the southeast. In most places the Fernie strata, as well as those of the overlying Nikanassin, Cadomin, and basal part of the Luscar formation, are structurally conformable with the underlying Upper Palæozoic rocks.

Fossils are confined to a few thin zones: a coquina bed of pelecypods of Lower Jurassic age caps the phosphatic limestone. Some bands of

sandstone above the limestone carry pelecypods of possible late Jurassic or very early Cretaceous age. The Fernie, Nikanassin, and Luscar fossils are tabulated in the Appendix to this report.

LOWER CRETACEOUS

Cadomin Formation. The thin Cadomin conglomerate, between the Nikanassin sandstone below and Luscar sandstone above, is an excellent horizon marker of the Lower Cretaceous series. It is equivalent to the basal conglomerate of the Blairmore group as mapped by Beach and Henderson in areas to the southeast (Beach, 1942, p. 7; Henderson, 1944, p. 2, and 1945, p. 2).

The Cadomin formation consists of 20 to 80 feet of massive chert and quartz pebble-conglomerate interbedded with coarse sandstone. The matrix is siliceous, and binds the pebbles into a resistant, brittle mass, which in most places develops good jointing. No fossils were seen in this conglomerate.

Luscar and Mountain Park Formations. Luscar and Mountain Park strata underlie much of the southwestern parts of both map-areas, but are generally poorly exposed. The Luscar formation comprises the coal-bearing beds overlying the Cadomin conglomerate and underlying the non-coal-bearing beds of the Mountain Park formation. The latter underlies the Blackstone formation of Upper Cretaceous age. The contact between the Luscar and Mountain Park is indefinite; the formations were mapped separately in Alexo map-area, but because of poorer exposures were mapped as a unit in Saunders map-area.

The Luscar has an estimated thickness of 850 to 900 feet in Alexo map-area, and a calculated thickness of 1,175 feet in Saunders map-area. The Mountain Park is 650 feet thick in Brazeau map-area (MacKay, 1941a and 1943) west of Alexo, and is 700 to 750 feet thick in Saunders map-area.

The Luscar formation consists of interbedded, thin-bedded sandstones, shales, and carbonaceous rocks, containing coal seams of mineable thicknesses in the upper part. The overlying Mountain Park formation is composed of thin- and thick-bedded, gritty sandstone, weathering grey and green, interbedded with grey shales. Conglomerate occurs within the formation. A persistent chert pebble-cobble band of variable thickness marks the upper contact of the Mountain Park.

Luscar and Mountain Park strata appear incompetent, as they have responded to stresses in many localities by minor folding, close folding, or minor faulting. In places the coal seams of the Luscar formation are crushed, sheared, or slickensided.

The Luscar and Mountain Park strata are of continental origin. Gastropods and pelecypods are numerous in a shale zone in upper Luscar beds; plant fossils occur in the coal-bearing beds of the Luscar above the shale zone. Fossils are rare in Mountain Park strata.

UPPER CRETACEOUS

Blackstone Formation. The Blackstone, the oldest of the Upper Cretaceous formations, underlies much of the low-lying area south of North Saskatchewan River, southwest of Brazeau Range; it also occupies a zone less than 2 miles wide south of the river, northeast of the range. The formation is about 1,300 feet thick; poor exposures and local folds make precise measurements impossible. It consists almost entirely of thin-

bedded, black, fissile, soft shales of marine origin. Scattered, lens-shaped, lime-ironstone concretions, as much as 6 feet in diameter, were observed within the lower 300 feet of the formation; smaller concretions of a similar type occur within the upper 300 feet; and several thin bands of limestone appear toward the middle of the formation.

Deformative stresses have produced more complex folds in the incompetent Blackstone shales than in the overlying Bighorn sandstones.

Inoceramus labiatus and *Watinoceras* sp. occur throughout a zone a few hundred feet thick in the central part of the formation, and fish scales and vertebræ are present in shaly sandstone near the base. The fossils collected are listed in the Appendix.

Bighorn Formation. This formation grades sharply into the underlying Blackstone shales and is in sharp contact with the overlying Wapiabi formation. Surface exposures of Bighorn in the Alexo map-area are confined chiefly to the area south of North Saskatchewan River, southwest of Brazeau Range. There, low dipping, resistant Bighorn sandstone, resting on soft Blackstone shales, forms an extensive area of low-plateau or mesa topography.

In Alexo map-area, southwest of Brazeau Range, the Bighorn is 275 to 320 feet thick, and is divisible into three lithologic units. The lower and upper members are predominantly hard, siliceous sandstones each about 50 to 70 feet thick. Gritty and conglomeratic facies may appear in both these members within a relatively small lateral extent. The middle member is chiefly soft shale and shaly sandstone. The thickness of the Bighorn decreases eastward (MacKay, 1943a, 1943b).

The Bighorn formation, despite its relative thinness, folds gently in the low-plateau area southwest of the Brazeau Range, in contrast with the minor, close folds in the underlying Blackstone shales. However, in the southwestern corner of Alexo area the Bighorn sandstone members are faulted, and the faults are localized in either the shale member of the Bighorn or in Blackstone or Wapiabi shales (Crombie, 1944, p. 16).

The Bighorn is of marine origin. The lower sandstone member is characterized by several species of *Inoceramus*, and the upper sandstone member by the persistent *Cardium pauperculum*. The latter fossil has lent its name to equivalent strata in map-areas in the southern Foothills of Alberta. The Appendix lists all fossils collected from the Bighorn formation.

Wapiabi Formation. The Wapiabi is the youngest Upper Cretaceous formation of marine origin. It is exposed in Alexo map-area north of North Saskatchewan River (northeast of Brazeau Range), and in the southern and southwestern parts of Alexo map-area. No Wapiabi is exposed in Saunders map-area.

The estimated thickness of the Wapiabi, based on outcrops, is 1,500 to 1,600 feet southwest of Brazeau Range and 1,400 feet northeast of the range. The formation consists of black, sandy shale that contains concretions and concretionary bands of rusty weathering limestone. The lower contact with the Bighorn is distinct, but the more sandy upper part is transitional into the Brazeau formation.

Scaphites ventricosus is common in the lower several hundred feet of shales, and *Baculites* occurs within the upper 300 feet of the formation. The complete list of fossils collected from Wapiabi beds is given in the Appendix.

Brazeau Formation. The Brazeau includes the Upper Cretaceous strata lying between the Wapiabi and strata of Paleocene age. Beds equivalent to Edmonton in age may be present in the upper part of the Brazeau formation as mapped. Only the lower Brazeau contact was observed in the map-area.

About 1,500 feet of lower Brazeau beds occupies a syncline north of the North Saskatchewan, northeast of Brazeau Range. Brazeau rocks may underlie some of the area northeast of Fault No. 2 (*See* Figure 2), but lack of horizon markers and diagnostic lithology necessitates the mapping of possible Brazeau rocks with those of Paleocene age.

The lower section of Braezau rocks consists of grey and green, coarse to gritty sandstone and sandy shale, replaced upward by gritty, carbonaceous sandstone and maroon weathering sandstone. The Brazeau formation has an estimated thickness of about 4,700 feet in Wawa Creek map-area (MacKay, 1943b) to the northwest. No diagnostic fossils were collected in Brazeau strata.

PALEOCENE

Rocks mainly or entirely of Paleocene age, probably chiefly those of the Paskapoo formation, underlie most of Alexo and Saunders map-areas northeast of Fault No. 2 (*See* Figure 2). The oldest Paleocene rocks, as identified by plant fossils, occur about 400 feet above a cobble-conglomerate band at the core of the Stolberg anticline on North Saskatchewan River, and 675 to 800 feet below the lowest coal seam of the coal-bearing beds mined at Alexo and Saunders. Brazeau rocks may occur on the axis of the Stolberg anticline in other parts of the map-areas or on the northeastern limb of the Ancona syncline, but in the absence of horizon markers the whole area northeast of Fault No. 2 has been mapped as undivided Upper Cretaceous(?) and Paleocene.

Rocks of recognizable Paleocene age consist of friable, brown and grey, medium-grained, arkosic sandstones, interbedded with grey-green and green mudstones and shales. Carbonaceous rocks, tuff, and bentonite beds are common. The coal-bearing series, about 500 feet thick, contains at least five coal seams ranging from 1 foot to 6 feet in thickness. Plate IV shows the typical appearance of interbedded sandstones and shales of Paleocene age.

The thickness of Brazeau(?) and Paleocene rocks exposed in the area is 5,100 feet, as measured in a structural section on the northeastern limb of the Stolberg anticline. The strata are entirely of freshwater origin. Plant fossils, pelecypods, and gastropods are common. The tabulated lists of flora and fauna collected in the large area northeast of Fault No. 2 (Figure 2) are given in the Appendix.

PLEISTOCENE AND RECENT

Typical boulder clay containing unsorted, striated pebbles and cobbles occurs in widely separated parts of the map-areas northeast of Fault No. 2. Well-defined easterly trending gravel ridges are prominent in upper Trout Creek Valley, and between Trout Creek and North Saskatchewan River. The ridges are composed of poorly sorted pebbles and cobbles of quartzite, chert, sandstone, and a little limestone. Glacial erratics occur in the eastern part of Alexo map-area at elevations up to 6,900 feet. No gneiss, schist, or granite erratics were found. Therefore, the fluvioglacial and morainal deposits appear to have had their sources in the area of sedimentary rocks to the west.

CHAPTER III

STRUCTURAL GEOLOGY

GENERAL STATEMENT

Alexo and Saunders map-areas lie in the folded and faulted Foothills belt of the first range of the Rocky Mountains. Figure 1 shows their geographical and structural setting in relation to the mountain front in west-central Alberta. The information for much of the area has been generalized and compiled mainly from Preliminary Map 43-3 (MacKay, 1943a), and from geological reports and maps of the Geological Survey of Canada. For more detailed information the reader is referred to the various preliminary maps whose names are designated on the regional map.

The major folds and faults of Alexo and Saunders map-areas are collinear with the trend of Brazeau Range and with the more prominent structures that extend for scores of miles northwest and southeast beyond the borders of these map-areas. Brazeau and Clearwater Ranges[1] are the outermost outliers of Palæozoic rocks of the Rocky Mountains, and are situated 15 to 24 miles northeast of the first range. They owe their existence to thrusting of large masses relatively northeast along southwest-dipping thrust faults. The ranges are anticlinal structures, in places somewhat breached, and Brazeau Range reaches elevations as high as 7,130 feet above sea-level. Rocks as old as Upper Devonian are exposed in the cores of the ranges.

The outliers of the inner Foothills, consisting, from northwest to southeast, of Nikanassin[2], Bighorn[3], and Limestone Ranges, are from 6 to 10 miles northeast of the first range of the Rocky Mountains. These outliers trend parallel with the outliers of the outer Foothills, and attain elevations of more than 8,600 feet. Rocks as old as Devonian are exposed in the cores of these ranges. The ranges are breached or eroded anticlines, presenting scarp faces toward the northeast, and sloping southwest with the dip of the bedrock.

The first range of the Rocky Mountains trends northwest, parallel with the trend of the outlier ranges. Except for valleys of large antecedent streams the first range is continuous in the area represented in Figure 1. Elevations in Mountain Park map-area, about 60 miles northwest of Brazeau map-area, are greater than 10,000 feet, but decrease to the southeast, so that maximum elevations in Cripple Creek map-area are about 8,500 feet. The rocks of the first range are westerly dipping, folded and strike-faulted masses of Palæozoic age, as old as Cambrian. Thrust faulting repeats sections of both Palæozoic and Mesozoic formations southwest of the first range (MacKay, 1929, 1930; Erdman, 1946). The first range, as

[1] Clearwater Range and Limestone Range are unofficial names used by the writer to denote two Palæozoic outliers. Clearwater Range lies from about 15 to 20 miles northeast of the first range and Limestone Range lies about 6 to 10 miles northeast of the first range.

[2] In Cadomin and Mountain Park map-areas.

[3] Extending through George Creek, Wapiabi Creek, and Bighorn River map-areas.

well as the outlier ranges mentioned above, has been thrust relatively northeastward over younger rocks so that directly in front of most of the ranges, and partly buried by them, are large basins of Upper Cretaceous and younger sedimentary rocks. Limestone Range may be an exception, but the range is mostly unmapped and may conform with the general pattern in its southern part.

The relationship of the ranges to the basins is illustrated in Figure 1. The youngest rocks, Paleocene, occur in synclines northeast of the outer outlier ranges. There the folds are broad and open, and much less faulted than in the area between the outer ranges and the first range of the Rocky Mountains.

The structure in Alexo and Saunders map-areas is similar in most respects to that of the Foothills belt of west-central Alberta. The relief of diastrophic stresses has resulted in northwest-trending, collinear, chiefly asymmetrical folds; and in parallel or subparallel thrust faults (*See* Maps 884A, 885A, and Figures 1 and 2). Folds vary in magnitude from minute drags to large folds 4 miles and more between adjacent anticlinal and synclinal axes. Generally, and this is especially true of smaller folds, the southwestern limbs of the anticlines are gentle, whereas the northeastern limbs are steep to overturned. Throws of faults vary from minute movements along small fractures to displacements of several thousands of feet in the large thrust faults. Most faults dip southwest.

A great variety of folds and faults is represented in the map-areas, and is classified and discussed according to type. Major structures are denoted by name or number as given on the structural map (Figure 2). The extensions of structures beyond the limits of Alexo and Saunders map-areas are shown on the regional structural map (Figure 1). Folded thrust faults were studied in more detail and are discussed under a separate heading.

The intensity of deformation, as indicated by progressively closer and tighter folds and by frequency in occurrence of faults, increases from northeast to southwest, or from the outer Foothills toward the first range. The mappable folds and faults are shown on the accompanying structural map (Figure 2).

FOLDS

SYMMETRICAL FOLDS

Stolberg Anticline. The Stolberg anticline is a broad, near-symmetrical structure in the northeastern parts of Alexo and Saunders map-areas. The name was applied by Allan and Rutherford (1923, p. 27) to a structure whose axis crosses approximately through the site of Stolberg, on the Canadian National railway. The anticline trends north 48 degrees west across north-central Saunders map-area, and north 55 degrees west across the northeastern part of Alexo map-area, for a total distance of 20 miles within these map-areas. It continues northwest for about 8 miles through unmapped territory and terminates near the central part of Wawa Creek map-area (MacKay, 1943b). The anticline apparently continues southeast across 6 miles of unmapped territory southeast of Saunders map-area, and terminates within Tay River map-area (Henderson, 1944).

The Stolberg anticline in Wawa Creek map-area is nearly symmetrical and steeply dipping; its flanks are cut by faults lying within a mile of either side of the axis. The dips of the limbs range from 20 to 60 degrees with the maxima near a structural high or culmination about 3 miles northwest from the east margin of Wawa Creek map-area. The plunge of the Stolberg anticline at the eastern margin of this map-area is about 10 degrees southeast. Near the northern margin of Alexo map-area the anticline is broader, the dips are lower, and faulting is less common. Dips of beds are there less than 20 degrees for half a mile on either side of the axis. Minor faults appear on the southwestern limb. The plunge is indeterminable, but low.

A structural section along North Saskatchewan River (*See* Map 884A) indicates that the anticline is symmetrical for about 2 miles on either side of the axis. Plate IV shows horioztnal beds on the crest of the structure on North Saskatchewan River at the mouth of Shunda Creek. Dips steepen progressively southwest from the axis, along North Saskatchewan River, as minor folds and the large thrust fault (Fault No. 2, Figure 2) are approached. The limbs of the Stolberg anticline in the vicinity of North Saskatchewan River dip less than 10 degrees for more than a mile on each side of the axis. No faulting is apparent at the surface except for a minor, low-angle, southwest-dipping fault exposed on the river about a mile west of the axis. The distance from the axis to Fault No. 2 is a little less than 3 miles, and for more than 2 miles southwest of the axis the beds dip regularly southwest. Minor folds appear on the southwestern limb of the anticline about half a mile east of Fault No. 2. The dips of the northeastern limb of Stolberg anticline, in the vicinity of Taunton Creek, are less than 15 degrees for a distance of about 2 miles northeast of the axis. Two, local, minor folds occur on the northeastern limb about a mile northeast of the axis, on the western side of Saunders map-area. These are a low-dipping, symmetrical minor anticline and syncline that become even gentler to the southeast. A few minor faults, both normal and thrust, are present in the coal mines at Alexo and Saunders.

Southeast of North Saskatchewan River, in the vicinity of Trout Creek, the dips of the northeastern limb are in general less than 15 degrees. Beds on the southwestern limb are exposed only near Fault No. 2, where moderate to high dips prevail.

In the vicinity of Rough Creek, southeast of Trout Creek, the dips on the northeastern limb are in general less than 12 degrees, and the few dips measured on the southwestern limb are from 10 to 24 degrees. No minor folds or faults are apparent on the northeast flank of the anticline.

The most complete section across the Stolberg anticline is on main Ram River in the southeastern part of Saunders map-area, and beyond the eastern margin of the map-area. Dips at twelve localities on the northeastern limb for 3 miles from the axis of the anticline average 7 degrees northeast, whereas dips at eighteen localities on the southwest limb, for the same distance from the axis, average 12 degrees southwest.

Drift conceals much rock in Tay River map-area, but the dip on the southwestern limb on Prairie Creek averages 15 degrees, whereas the average dip on the northeastern limb, for a distance of 2 or 3 miles from the axis, is about 4 or 5 degrees northeast.

The distance, in Alexo and Saunders map-areas, between the axis of the anticline and the No. 2 fault varies between 2½ and 3½ miles. In

Wawa Creek map-area the distance is about 3 miles, but subsidiary folds and faults are present. The comparable interval in Tay River map-area is 3½ to 4 miles (Henderson, 1944).

No reliable data are obtainable on the plunge of the Stolberg anticline in Alexo and Saunders map-areas due to lack of diagnostic horizon markers. Definite northwestern and southeastern plunges are known to occur in Wawa Creek map-area (MacKay, 1943b). On Ram River, a short distance east of Saunders map-area, the convergence of strikes near the axis of the anticline suggests a northwesterly plunge. The belief is that within Alexo and Saunders map-areas the crest of Stolberg anticline is nearly horizontal, with undulations along strike forming local, gentle highs and lows (culminations and depressions) that are in places not recognizable on the surface. An analogous situation is believed to exist for the Ancona syncline to the northeast.

In the valley of Ram River, each limb of the Stolberg anticline exposes nearly 5,000 feet of sedimentary rocks. The rocks are interbedded clay shales, and soft, grey-green sandstones, with minor amounts of coal, carbonaceous shale, and conglomerate. Due to the extreme variation of lithology in these rocks of continental origin correlation was not possible between rocks of the southwestern and northeastern limbs, nor between rocks of the northeastern limb on Ram River and rocks of the same limb on Rough Creek 5 miles northwest. The stratigraphic position of the beds on the crest of the anticline on North Saskatchewan River is estimated, by means of commercial coal seams occurring on the limbs, to be about 5,500 feet above the top of the Wapiabi formation.

Information on the anticline at depth is obtained from data of Imperial Shell Stolberg No. 1 well being drilled at or near the axis of the anticline, about 4 miles northwest of the north edge of Alexo map-area. The geological data from the Petroleum and Natural Gas Conservation Board of Alberta indicate that the well commenced in the Brazeau formation and bottomed, at a depth of 13,747 feet, within the Banff formation. The normal thickness of the beds was increased by about 50 per cent because of duplication by thrust faults, and by crumpling of softer formations. The major recognizable faults are in the Wapiabi and Rundle formations. The faults cause the repetition of parts of the Brazeau and Wapiabi, and Fernie and Rundle, respectively. Compared with the thickness of formations as obtained in mapping nearby areas, the drilled, unfaulted thickness of the Wapiabi agrees closely; the drilled thickness of the Bighorn is more than double the mapped thickness, and the drilled thickness of the Blackstone is 60 per cent greater than the mapped thickness. The Mountain Park, Luscar, and Cadomin apparently show fair conformity in their drilled and mapped thicknesses; but the Nikanassin and Fernie beds show a greater thickness in the well than in exposures. The unfaulted thickness of the drilled Rundle appears to conform to its normal thickness in outcrop. Judging from the response to stresses of the different strata in outcrop, it is believed that the competent Bighorn rocks in the well have been thickened by thrust faults, and the Blackstone, Nikanassin, and Fernie by crumpling or close folding.

The structure of the Stolberg anticline at depth is believed to become progressively simpler toward the southeast, in keeping with the broader limbs and the progressively gentler surface dips in that direction. The

anticline is believed to attain its broadest and simplest conformation in the vicinity of Ram River, and to reflect its low surface dips to depths as deep as to the Rundle rocks. Thrust faults may modify the structure at depth, but the presence of the adjoining broad Ancona syncline to the northeast appears to preclude the occurrence of any major fault to the depth where the large thrust is reached whose surface trace crosses the northeastern part of Saunders map-area.

In summary, the Stolberg anticline is a broad, near-symmetrical structure, about 45 miles long, of which the central 20 miles lies within Alexo and Saunders map-areas. The anticline follows a sinuous, northwesterly trend, averaging north 45 degrees west, northwest of Alexo map-area, north 50 degrees west through the map-areas, and north 35 degrees west southeast of Saunders map-area. The anticline plunges southeast at the eastern edge of Wawa Creek map-area; elsewhere the plunge is unknown, but is believed to undulate gently. From its northwestern to southeastern extremity the structure becomes progressively more open and less faulted, but remains slightly asymmetrical, with the steeper dips on the southwestern limb. The steeper dips on this limb appear due to the large thrust fault (Fault No. 2, Figure 2), and they become steeper on this limb as the fault is neared. The Upper Palæozoic and contiguous rocks are believed to be arched conformably with the rocks at the surface. The depth to the large thrust fault whose trace crosses the extreme northeastern part of Saunders map-area is not known.

Ram River Anticline. The name Ram River anticline is applied to a structure whose axis crosses main Ram River directly south of the southern edge of Saunders map-area (*See* Figure 2). The structure represents the northern part of a main anticline of Clearwater Range. It is nearly symmetrical, the limbs dip moderately, and its northern extremity lies about 3 miles northwest of the southern edge of Saunders map-area. The anticline increases in magnitude southeastward through Fall Creek map-area (Henderson, 1945) and ends in the southern part of Tay River map-area (Henderson, 1944). It may cross the unmapped Limestone Mountain map-area to become part of the Clearwater anticline of Marble Mountain map-area (Beach, 1942). The total mapped length, excluding the possible southeastern extension, is about 20 miles. The symmetry of the anticline is maintained throughout most of its length; the dips on the limbs in Saunders and Fall Creek map-areas are, in general, less than 50 degrees, whereas the dips on the limbs in Tay River map-area to the southeast in few places exceed 20 degrees. No minor folds occur on the northeastern limb in the sandstones and shales of the Luscar and Mountain Park formations.

The general plunge of Ram River anticline is northwesterly, exposing older Palæozoic rocks progressively southeastward. A low, local southeastern plunge may occur about 2 miles northwest of the south margin of Saunders map-area (*See* Figure 2). The anticlinal axis undulates along strike southeast of Saunders map-area. A culmination or structural high occurs in Tay River map-area about 5 miles southeast of Saunders map-area. The oldest rocks exposed at the core of the anticline in Saunders map-area are lower beds of the Rundle formation; rocks of the Banff formation are exposed a short distance southeast of the map-area.

A clue to the structure at depth may be derived from a study of attitudes in older formations exposed by the northwesterly plunge. *En échelon* folds appear at the northwestern extremity of the anticline in Luscar and Mountain Park beds, but southeastwards, where competent Palæozoic rocks occur, one major anticline replaces the minor folds. Many of the Palæozoic outliers in this region are bounded by large thrust faults on their northeastern sides; such a fault is absent in this anticline, but in its stead occurs a broad, unbroken syncline. Northeast of this syncline is a second Palæozoic outlier bounded on the northeast by the usual thrust fault. The Ram River anticline constitutes the inner outlier of a double range, and is symmetrical in contrast with the usual asymmetrical anticlines of the outlier ranges. The large thrust fault northeast of Tawadina Creek anticline dips southwest at a low angle for at least a mile, but the depth to this fault in Ram River anticline is not known. Altoba-Clearwater No. 1 well, drilled in Limestone Mountain map-area on the probable southeastward extension of this structure, traversed a regular stratigraphic section for the full 3,000 feet of its drilled depth; no faulting is apparent, and dips at depth are conformable with those at the surface.

Ram River Syncline. This syncline is the major structure lying between Tawadina Creek anticline and Ram River anticline (*See* Figure 2). It is broad and symmetrical, and is identifiable for about 3½ miles northwest of the southern margin of Saunders map-area. Farther northwest the single synclinal axis is replaced at the surface by three minor folds. The syncline is traceable southeastward through Fall Creek map-area into Tay River map-area for a continuous mappable length of about 20 miles.

The limbs of the structure dip from 20 to 30 degrees, and symmetry is maintained southeast from the Saunders map-area throughout the length of the syncline, with the exception of 6 miles in the extreme southeast where the northeasterly dips become steeper than those on the southwestern limb. This limb remains simple throughout the length of the syncline, but the northeastern limb is modified by drag-folds in the southern part of Saunders map-area, and by minor folds in Fall Creek and Tay River map-areas. These subsidiary or minor folds are apparent at the surface where they are associated with incompetent Lower Cretaceous sandstones and shales, and disappear in Tay River map-area where competent Palæozoic rocks outcrop. The direction of plunge of the syncline is not well indicated in Saunders map-area; in the northwestern part the syncline locally plunges toward the southeast; to the southeast the plunge changes to the northwest; and Palæozoic rocks outcrop at the surface in Tay River map-area.

Ram River syncline seems to illustrate control of structure by lithology. South of Saunders map-area, where the competent, Upper Palæozoic rocks outcrop, the syncline formed as a broad, gentle, simple fold; but northwest along strike, where younger, incompetent strata appear due to the northwesterly plunge, the single syncline is replaced by closer, minor folds. Apparently, Ram River syncline continues northwestward in the buried Palæozoic rocks as a single syncline regardless of the superficial folds in Mesozoic rocks.

Warps in Bighorn Formation Southwest of Brazeau Range. Bighorn strata in Alexo map-area are involved in northwest-trending, low-dipping, symmetrical folds or warps within a zone about 3 miles wide, between Gap Creek and the Weaver anticline (*See* Map 884A and Figure 2). These

warps do not appear in the underlying Blackstone, Mountain Park, or Luscar beds. The synclines of these structural features stand out as topographic highs, and owe their existence to the resistant sandstone of the Bighorn formation lying between the easily eroded Wapiabi and Blackstone shales. The warped Bighorn strata cap a large part of much of the area south of North Saskatchewan River and attain elevations as much as 6,200 feet. The soft Blackstone shales below the Bighorn weather rapidly and in places produce continuous scarps around the warped mesa. Evidence of the former widespread extent of these features is indicated by the occurrence of several, small, residual, warped buttes of bighorn rocks (*See* Map 884A).

Four, low-dipping, broad folds cross parts of the main saddle, and dips on the limbs are generally less than 10 degrees. Dips of beds both northeast and southwest of this feature are steeper. The part of Philip Creek syncline underlain by Bighorn strata is a butte-like residual; dips are as high as 50 to 60 degrees, and faults complicate the structure. Another butte of lower Bighorn strata occurs near Lynch Creek, where dips are as much as 50 degrees. This butte differs from those above in being structurally asymmetrical, more closely folded, and modified by slice faults. No warped mesa of Bighorn rocks occurs southwest of Lynch Creek.

The folds or warps in the main saddle plunge toward a common centre to form a structural and topographic low. Local plunges toward the centre in the rocks of the butte in the southwestern part of Alexo map-area have resulted in a spoon-shaped structural and topographical depression. All the saddles or buttes in Bighorn strata, with the exception of that near Lynch Creek, are the result of weathering of Wapiabi shales above a monoclinally or synclinally warped, thin, resistant formation. The Bighorn formation has been eroded from most of the anticlinal warps by reason of the inherent weakness at the crest, and because the anticlines were raised higher by folding than the corresponding synclines and, therefore, were subject to more active erosion. Thus the tendency is for the occurrence of breached anticlines and contrasting synclinal saddles. In the few places that the anticlines in Bighorn strata are not breached, the dips are low, so that these folds were neither raised far nor weakened by tensional fractures at the crest; even so, at two such locations (sec. 19, tp. 38, rge. 13, and sec. 20, tp. 38, rge. 14) the stage of erosion toward a breached anticline is well advanced (*See* Map 884A).

The structure at depth in this area of warped Bighorn rocks is not known. Despite its thinness, the Bighorn formation has reflected stresses by deformation in a competent manner. A clue or indication of the structure in underlying rocks is obtained from their attitudes along strike, where these are revealed at lower elevations or by plunging folds, as well as across strike, where folding brings up older formations. Both along and across strike, the major, broad folds in the Bighorn are supplanted by minor folds and drag-folds in Blackstone, Mountain Park, and Luscar strata. The upper part of the Blackstone does appear to fold conformably with the Bighorn. Map 884A and Figure 2 show minor folds in lower Blackstone, Mountain Park, and Luscar formations of North Ram River and Jock, Easy, and Nice Creeks, replacing broader, gentle folds of Bighorn along strike. However, less than a mile northwest from Jock Creek, a low, regular fold in the competent Rundle and adjacent overlying formations

replaces the numerous minor folds of Jock Creek. The structure in the Rundle rocks, as revealed along strike, should compare closely with the structure in Rundle rocks at depth, where Bighorn rocks outcrop. Thus, apparently, the thin, strong Bighorn formation deformed competently in much the same manner as did the underlying massive Rundle formation.

Anticline West of Dutch Creek. A peanut-shaped area of Rundle strata in North Saskatchewan River Valley on the west side of Alexo map-area appears to be a structural dome, but the feature is chiefly an erosional part of a minor, symmetrical anticline. The dips on the limbs of the fold are mainly less than 12 degrees, but the east limb is modified by a thrust fault and a reversal of dips less than a mile from the axis. The dips of the west limb persist regularly to the western edge of the map-area. No closure is indicated. The anticline is mappable for about a mile along strike, and is replaced southeast of North Saskatchewan River by minor folds in Lower Cretaceous strata.

Philip Creek Syncline. The name is applied to a symmetrical structure in the southwestern part of Alexo map-area whose axis, for part of its length, lies in Philip Creek Valley. The syncline trends northwest across Alexo map-area for about 9 miles, and is mapped northwest for more than 2 miles in Brazeau map-area (MacKay, 1941a). It is traceable to the southeast into Cripple Creek map-area for about 3 miles (Erdman, 1946), or for a total mappable length of about 14 miles. The syncline is nearly symmetrical throughout Alexo map-area; dips of the limbs are commonly between 25 and 50 degrees, but lower dips prevail in the southeastern part. The average plunge of the syncline is southeast, in harmony with the plunge of the Weaver anticline lying to the northeast (*See* Figure 2). The rate of plunge for 8 miles is about 100 feet a mile southeast. The plunge is not uniform, but varies or undulates along strike, so that in the northwestern 4 miles of its length the rate is about 150 feet a mile southeast.

Rocks as old as upper Luscar occur in the axial region of the fold in the upper part of Jock Creek, and rocks as young as lower Wapiabi occur in the central and southeastern parts. The surface trace of the axial plane of the syncline throughout part of its course closely coincides with the topographic high of a ridge, but through another part of its course it occupies the valley of Philip Creek. The whole of the Bighorn formation as well as basal Wapiabi is present there, in contrast with only the lower Bighorn strata that veneer the broad, high area to the north.

The Philip Creek structure is unique among other synclines exposed in the map-areas in that the normal stratigraphic section of basal Wapiabi and Bighorn strata is repeated, as in a double-decked sandwich, and the whole is folded together. The contact between the two series of beds is a fault that is folded with the strata. It is described later under 'Folded Thrust Faults'.

A similar situation obtains for the Philip Creek syncline as for the gentle warps of Bighorn beds southwest of Brazeau Range. The syncline in the vicinity of Philip Creek is a simple fold, about a mile in breadth, and affects beds of the lower Wapiabi, Bighorn, and upper Blackstone formations. However, on Jock Creek to the northwest, the syncline is replaced or modified by minor folds in lower Blackstone and Mountain Park beds. The minor folds are believed to affect the Lower Cretaceous rocks at depth, but not the Upper Palæozoic strata, which are believed to be folded com-

petently but more closely than in the area of the warped Bighorn folds. This conclusion was reached from comparison with the response to stresses of Bighorn and Rundle beds in the area of warped Bighorn beds to the northeast. There the Bighorn and Rundle, as exposed along strike, are similarly broadly folded, whereas the intervening formations are strongly contorted. The Philip Creek syncline exposes moderately steeply dipping Bighorn beds, and the belief is that the underlying Rundle and other Palæozoic formations are folded in a corresponding manner. Consider the competent Upper Palæozoic rocks, when subjected to stress, deformed in a manner dependent on their thickness and competency, the confining pressures, and the amount and nature of deforming stresses. Sympathetic deformation in the overlying few hundred feet of sediments, even if lithologically different, would be due to, and controlled by, the deformation of the competent Upper Palæozoic strata. Higher in the stratigraphic section, as in the incompetent, interbedded shales and sandstones of the Luscar and Mountain Park, and in the Blackstone shales, the stress is dissipated in the formation of drag-folds and minor faults, rather than propagated as in the competent older formations. The Bighorn formation, though relatively thin, was under a smaller confining pressure, and, being situated between a few thousand feet of incompetent strata below and 1,500 feet of incompetent shales above, reacted competently to the lesser active stresses in a manner corresponding to the more massive Rundle, which was under a greater confining pressure, and subject to a larger active stress. The above argument assumes a type of basement control plus lithological difference in formations to explain the manner of response of formations to stresses. The effect of lithological control of structure is quite evident, but no data support the assumption of basement control in the true sense.

ASYMMETRICAL FOLDS

Brazeau Range Anticline. This name is applied to a prominent, asymmetrical anticline of Brazeau Range that continues northwestward, from near the eastern margin of Alexo map-area, diagonally across Brazeau and Wawa Creek map-areas (*See* Figure 1). The total mapped length of the anticline is 24 miles. The southeastern limit is near the head of Lundine Creek; farther southeast, the Brazeau Range plunges below the surface as a wide plate with no definite axial trace. The axis of the anticline follows a sinuous course across Alexo map-area, with an average trend of north 45 degrees west. The sinuous course is largely due to the southwest dip of the axial plane, as demonstrated by the trace of this plane across large, deep, stream valleys. South of North Saskatchewan River, the front of Brazeau Range trends eastward; but Brazeau Range anticline maintains its northwesterly course throughout Alexo map-area. In Wawa Creek map-area to the northwest, the anticline strikes north 60 degrees west (MacKay, 1943b).

Brazeau Range anticline is a typical asymmetrical fold of the Foothills belt of west-central Alberta, having a gentle southwestern limb and a steeply dipping or overturned northeastern limb. The dips on the southwestern limb steepen progressively to the southeast, increasing from 10 to 35 degrees, in Wawa Creek and Brazeau map-areas on the

northwest, to 25 to 45 degrees in the central and southeastern part of Alexo map-area. The dips of the northeastern limb throughout the extent of the anticline are steeply northeast to overturned.

Within Alexo and Saunders map-areas Brazeau Range constitutes a multiple-plunging structure with the main culmination or structural high about 3 miles north of North Saskatchewan River, and another prominent culmination about 4 miles southeast of the river (*See* Structure-section E-F, Map 884A, and Figure 2). The calculated elevation of the Banff-Devonian contact at the culmination north of the river is 7,500 feet, whereas the culmination south of the river at the same contact is about 7,000 feet. Each culmination corresponds closely with the topographic high at that place. An area of small closure occurs northwest of Alexo map-area, in Wawa Creek map-area, where the elevation of the Banff-Devonian contact at the axis is at 6,100 feet. The average plunge of rocks at the culmination south of North Saskatchewan River is 200 feet a mile southeast for 2 miles, but increases rapidly farther southeast, where the Palæozoic rocks plunge below the surface. The average plunge northwest is 100 feet a mile for 5 miles. The southeastern plunge of the rocks at the culmination north of the river is at the rate of about 1,000 feet a mile for a distance of nearly a mile. The average northwestern plunge is about 1,000 feet a mile for the first mile, decreases to an average of 120 feet a mile for the remaining northwestern extent of the anticline in Alexo map-area, and shows a local increase at the extreme northwestern part of the map-area to 400 feet a mile. A depression or structural low occurs about 2 miles northwest of North Saskatchewan River, but, unlike the culminations, it is not reflected in the topography; actually it occurs at much the same elevation as does the culmination to the northwest.

Brazeau Range anticline represents the main fold of Brazeau Range, and in the central part is the only fold. In the northwestern and southeastern parts of Brazeau Range subsidiary folds occur on the northeastern limb of the main fold. A direct relation exists between the presence or absence of the minor folds and the prominence of the northeast-facing scarp. North of the river, at places where no subsidiary folds occur, the scarp is pronounced (*See* Plate I); but south of the river, where minor folds appear and are accompanied by a change of topographic trend, the scarp disappears, and the change from the range on the southwest to the lowland on the northeast is transitional. The asymmetrical, subsidiary folds developed on the northeastern limb of the main anticline, south of the river, bring Palæozoic rocks to the surface. The trend of these folds is more easterly than that of the main anticline, and the abrupt change in trend of these subsidiary folds from that of the range north of the river is reflected in the surface trace of Fault No. 2 (*See* Figure 2), more than 2 miles to the northeast, which forms a broad arc convex toward the northeast. The subsidiary folds plunge in harmony with the main anticline in the area southeast of Dizzy Creek; at least two of the outer anticlines and the intervening syncline, crossing Dizzy Creek, are associated with a thrust fault that is folded similarly to the bedding folds. This folded fault is discussed under a later heading.

The oldest rocks of the map-areas are exposed at the core of the Brazeau Range anticline in the North Saskatchewan River Gap; they

are Devonian rocks about 2,000 feet below the Banff-Devonian contact. Deeply cut valleys such as this, showing a section of rocks half a mile thick, afford an opportunity to study the structure at depth (*See* Plate II B). The limbs of the anticline appear to dip consistently with depth, the northeastern limb remaining steep to vertical. About 500 feet of incompetent, grey, limy shales, underlain by 50 feet of black, fissile shales, are exposed near the axis in The Gap. These black shales are locally bowed and warped. A black, bedded limestone, lying below the black shale on the northeast vertical limb of the anticline near the axis, contains a series of offset calcite veinlets that appear to reflect slippage between beds during the stage of intense deformation.

The surface trace of the axial plane of Brazeau Range anticline is along and near the topographic high throughout the entire length of Brazeau Range in Alexo map-area, at only one place being more than half a mile distant from the crest of the range. The close coincidence of the anticline and a subsidiary topographic high of Brazeau Range is illustrated in Plate II A. The close correspondence of axis and topography is also adhered to in Wawa Creek map-area, with one minor exception where the axis lies a quarter mile southwest of the divide for a distance of a mile along strike (MacKay, 1943b).

Two wells, Shunda Oils No. 1, in l.s. 15, sec. 36, tp. 40, rge. 15, W. 5th mer., and Arrow Brazeau No. 1, in l.s. 5, sec. 9, tp. 41, rge. 15, W. 5th mer., were drilled on Brazeau Range anticline northwest of Alexo map-area. Both of the wells proved unproductive and were abandoned.

Tawadina Creek Anticline. The Tawadina Creek anticline is an asymmetrical structure whose axis crosses Tawadina Creek about 2½ miles above its junction with Makwa Creek. The anticline is about 10 miles long, and is confined to Saunders map-area. Southeast, in Fall Creek map-area, it seems to be replaced by minor folds in beds of the Blairmore group (Henderson, 1945). The anticline assumes a sinuous trend, averaging north 40 degrees west south of Tawadina Creek, and north 50 degrees west north of this creek. It loses its identity in the southern end of Brazeau Range. The trend is parallel with that of the branch of No. 2 fault (Figure 2) rather than with the main fault. Dips on the southwestern limb are, in general, less than 40 degrees; those on the northeastern limb are from 60 degrees northeast to overturned. The southwestern limb is about 1½ miles wide on Tawadina Creek; the breadth of the northeastern limb is not known, due to drift cover, but the limb itself is terminated within a mile northeast of the axis by a large thrust fault.

Tawadina Creek anticline is multiple-plunging. The principal culmination is about a mile southeast of Tawadina Creek. The northwestern plunge in Tawadina Creek Valley is as much as 20 degrees, whereas the average plunge southeast, between the culmination and Ram River, is about 8 degrees. A major depression occurs on Rough Creek, but undulations in plunge occur along strike between Tawadina and Rough Creeks. Another culmination occurs northwest of Rough Creek, but is of lower elevation than that southeast of Tawadina Creek. Near Ram River, where the Palæozoic rocks plunge southeast below the surface, the main anticline is replaced by numerous minor folds in Lower Cretaceous rocks.

The oldest rocks, comprising the upper 100 or 200 feet of the Banff formation, are exposed at the crest of the anticline on Tawadina Creek, and Ram River Valley exposes a small inlier of Rundle strata at the crest of the structure. In the subsidiary culmination, northwest of Rough Creek, the Rundle formation lies within 100 or 200 feet of the surface. The axis of the anticline, especially in the northern and southern extremities, coincides closely with the crest of the ridge.

The limestones and dolomites of the Rundle formation, near the core of the anticline in Tawadina Creek Valley, are closely folded. Fractures and joints are strongly developed. A short distance northeast of the axis the soft rocks of the middle member of the Rundle formation are vertical to overturned, and are thickened locally because of fracturing and faulting. Ram River No. 1 oil well, situated in Tawadina Creek Valley on the west limb of the northwest-plunging anticline, furnishes information on the structure at depth. The well commenced in lower Rundle strata and passed through the normal sequence of Banff beds and entered the Devonian at a depth of about 900 feet. Dips of the beds penetrated, including the upper 100 or 200 feet of Devonian strata, are from 30 to 40 degrees. A fault occurs at a drilling depth of 1,235 feet, and steeply dipping, strongly sheared sandstones of Paleocene age appear. The magnitude of the displacement confirms this to be Fault No. 2 (*See* Figure 2), which reaches the surface about a mile northeast of the well. The average dip of the fault is thus about 12 degrees southwest.

Tawadina Creek anticline is bounded on the northeast by a large thrust fault. The anticline is similar to many of those forming the outlier ranges of the Rocky Mountains, the main difference being its lesser magnitude. It is another example of simple, competent folding of Upper Palæozoic rocks replaced at the plunging ends by multiple, minor folds in the overlying incompetent shales and sandstones.

Ancona Syncline. The name Ancona was applied by Allan and Rutherford (1923, p. 27) to a structure in the northeast part of Saunders map-area whose axis crosses the Canadian National railway near the site of Ancona. The syncline is broad and gently asymmetrical, and trends across Saunders map-area on an average direction of north 45 degrees west. No detailed geological mapping has been done north of Alexo and Saunders map-areas and the syncline, presumably, persists across this section for about 18 miles to appear in Wawa Creek map-area, where it is designated the Colt Creek syncline (MacKay, 1943b). There the syncline is a southeast-plunging, asymmetrical structure, with southwest dips of from 20 to 30 degrees and northeast dips between 30 and 60 degrees. Thus, the syncline is typical of the asymmetrical folds of the Foothills belt. Its axis lies about 2½ miles northeast of the axis of the Stolberg anticline. The syncline was mapped for 9 miles in Saunders map-area, and continues southeast through unmapped country. In Saunders map-area it is broader, and the dips are more gentle than in Wawa Creek map-area. The southwest-dipping beds are steeper than those dipping northeast, so that in Saunders map-area the Ancona syncline has reverse symmetry from its northwest extension, the Colt Creek syncline. The dips on the southwestern limb are less than 20 degrees northwest and decrease progressively from the northwestern to the southeast part. Across a selected breadth in the northwestern part

of the map-area, they average 14 degrees northeast, whereas 8 miles to the southeast, across the same breadth of the limb, the average dip is 9 degrees northeast. The dips of the northeastern limb are shallow for a short distance northeast of the axis, but in the vicinity of Jackfish Creek they increase to 20 and 30 degrees southwest. This steepening of dips on the northeastern limb is attributed to the proximity to a large thrust fault (*See* Fault No. 1, Figure 2). The maximum width of the syncline is 5 miles for the southwestern limb and 3½ miles for the northeastern limb. The limbs are terminated respectively by the axis of the Stolberg anticline and by the No. 1 fault.

The plunge of the Colt Creek syncline in Wawa Creek map-area is locally about 15 degrees southeast. The only information on plunge in Saunders map-area is near the mouth of Sunset Creek where a local, low northwest plunge is apparent. The local plunge on North Saskatchewan River a short distance east of Saunders map-area is less than 10 degrees northwest. The axis of the fold may undulate along strike so that these local plunges do not necessarily signify the regional plunge. Based on coal seams as horizon guides, the regional plunge from the eastern side of Wawa Creek map-area to the eastern side of Saunders map-area is 2,000 feet southeast within a distance of 25 miles. However, because the plunge in part of Saunders map-area is northwest a large proportion of the regional plunge must occur within, or adjacent to, Wawa Creek map-area.

Ancona syncline is the major syncline of Alexo and Saunders map-areas, and exposes as much as 5,000 feet of mainly Paleocene strata on the limbs. The syncline broadens and is less faulted toward the southeast, in harmony with Stolberg anticline. The structure at depth is not known, but by analogy with the structure indicated in Imperial Shell Stolberg No. 1 well, and because beds dip more gently in Saunders map-area, the belief is that subsurface dips are of similar magnitude as surface dips to depths of 6,000 feet. However, the southwest-dipping fault northeast of the axis (Fault No. 1, Figure 2) should be present at depth on the northeastern flank. Nothing is known of the attitude of the fault at depth, but the steepening of beds northeastward from the axis of the syncline as the fault is approached suggests that the fault plane dips moderately, at least near the surface.

Weaver Anticline. The Weaver anticline is a major asymmetrical structure northeast of Philip Creek, named for the locator of an oil and gas claim on the structure. It was mapped in Alexo map-area from Jock Creek on the northwest to the south border of the map-area; it continues southeast across the northeastern corner of Cripple Creek map-area, and extends southeast for about 3 miles into Fall Creek map-area. The total mapped length of the anticline is 17 miles, 11 of which are in Alexo map-area. Drift conceals the northwestern extension of the anticline, and minor folds in Blairmore rocks replace the anticline in Fall Creek map-area. The anticline exhibits the reverse of the normal asymmetry of Foothills structures. Dips on the southwestern limb are commonly between 30 and 60 degrees, decreasing to 15 to 20 degrees in the extreme southeast part. Dips on the northeastern limb are commonly less than 40 degrees northeast, but decrease rapidly away from the axis, so that within half a mile they are as low as 10 degrees. The Weaver anticline marks the transition between a

zone of predominant folding on the northeast and one of imbricate faulting on the southwest. Dips in Bighorn and Blackstone formations northeast of the fold, as far as the rise of Brazeau Range, are commonly around 10 degrees, with few exceeding 30 degrees. However, dips in the same formations directly southwest of Weaver anticline are much higher, between 20 and 50 degrees, with few as low as 10 degrees.

Minor undulations may occur along strike, but the average plunge of the anticline is southeast, with no indication of closure to the northwest. The average rate of plunge in a distance of 6½ miles is about 150 feet a mile southeast. At the southern margin of Alexo map-area, or a short distance within Cripple Creek map-area, a depression crosses the axis, and the plunge changes to northwest. The anticline exposes rocks as old as Luscar in the northwestern part, and as young as upper Bighorn and lower Wapiabi in the southeast. It is breached throughout most of its length, and is bordered by vertical scarps of lower Bighorn rocks. The axis coincides closely with creek valleys, in contrast with the Brazeau Range and Tawadina Creek anticlines whose crests coincide with the higher parts of ridges. The Weaver anticline is formed of easily eroded shales above and below the thin, resistant Bighorn formation, in contrast with massive, resistant limestones and dolomites of the Brazeau Range and Tawadina Creek anticlines.

Wapiabi and Bighorn beds at the core of the Weaver anticline, in the southeastern part of the map-area, dip gently. The older rocks, as those of the Mountain Park and Blackstone formations, are steeply dipping, and minor folds appear in the Blackstone. The limbs of the anticline are modified by numerous minor folds and drag-folds in the incompetent Luscar rocks of Jock Creek Valley. In a tributary of Philip Creek close fracturing and steep dips were noted in upper Mountain Park beds exposed at the core of the anticline. If it be assumed that stresses were constant throughout the length of the anticline, the structure at depth at any one place should correspond with the structure along strike where, due to plunge, older strata are exposed. Low, regularly dipping Rundle rocks outcrop along North Saskatchewan River north of Jock Creek Valley, so that Rundle rocks at depth in the Weaver anticline are probably folded in a similar competent manner.

Weaver anticline is situated between two synclines, an unfaulted one on the northeast and the faulted and folded Philip Creek syncline on the southwest. The Weaver anticline may be faulted at depth, but lack of such evidence at the surface, and the unusual type of structural asymmetry at the surface as contrasted with the asymmetry of known faulted structures such as Brazeau Range and Tawadina Creek anticlines, suggest that no thrust faults occur at depth.

OVERTURNED FOLDS AND RECUMBENT FOLDS

Overturned and recumbent folds occur in various parts of Alexo and Saunders map-areas, but in general they are minor folds or drag-folds and are discussed later under that heading. Both Brazeau Range and Tawadina Creek anticlines are overturned throughout parts of their lengths.

A minor recumbent anticline is associated with Fault No. 2 (*See* Figure 2) where exposed on main Ram River in the southeast corner of Saunders map-area. The axial plane is low-dipping to the west, and small

drag-folds of similar attitudes to the main fold occur on its limbs. The trend of the fold is parallel with the surface trace of Fault No. 2, and apparently represents a stage in the same deformation. The fold was observed only in Ram River Valley, but may continue for some distance along strike, as borne out by the occurrence of tight minor folds southwest of the same fault in other parts of the map-areas. The recumbent northeast limb of the anticline is faulted by a southwest-dipping thrust fault (Fault No. 2, Figure 2). The actual fault contact appears in the field more as a fault zone than as a clean-cut fault plane. Dips on the southwestern limb of the anticline are about 30 degrees, whereas the northeastern limb is overturned, dipping southwest at low angles. Associated recumbent folds and overturned drag-folds indicate a southeast plunge. The rocks comprising the fold are the incompetent, interbedded sandstones and shales of the Luscar formation.

Relations between folding and faulting, which are of probable regional application, are well shown on main Ram River. These are:

(1) The folding is closest directly southwest of Fault No. 2, and the minor, asymmetrical folds to the southwest are progressively broader. The stratigraphy and lithology remain fairly constant and so are not a factor in the change in intensity of folding.

(2) The folds trend parallel with the adjacent fault on the northeast, indicating that the deformative stresses continued beyond the ultimate strength of the beds in the fold, and that the rocks sheared as a strike fault.

(3) As a corollary to the above statement, because of the high plastic limit of the incompetent, interbedded shale and sandstone, the shearing did not occur until the beds were overturned or recumbent. The low southwest dip of the axail plane suggests a similar low dip to the fault surface of No. 2 fault. This is verified at the Ram River No. 1 well on Tawadina Creek, about 3 miles northwest, where the average calculated dip of the fault for a distance of about a mile is 12 degrees southwest. The proximity of the fault to the surface may be due to elevation of the fault plane by folding subsequent to faulting.

Major folds and faults appear to have been different reflections of the same type of deformation; in this part of the map-area folding was apparently predominant during an earlier stage, and was replaced by faulting at a later stage. Minor folding at a still later stage is not readily demonstrable there, but is not excluded.

MINOR FOLDS AND DRAG-FOLDS

Minor folds and drag-folds occur throughout Alexo and Saunders map-areas, in some places developed on the limbs of major folds, in other places replacing major folds along strike. They range from small warps in the bedding to asymmetrical or recumbent folds. A description of some of the larger of these is given as an aid to the interpretation of the mechanics of deformation.

Minor folds are prominent in the south-central part of the map-areas, between North Ram River and Rough Creek. Blackstone, Mountain Park, and Luscar formations comprise the surface rocks. In general, the folds are low- to moderate-dipping, symmetrical to asymmetrical, and are best developed in the structural low or depression between the southeast-plunging Brazeau Range and the northwest-plunging Clearwater Range. Where

developed in Blackstone rocks the folds are more closely spaced, have steeper limbs, and tend to show normal asymmetry. Deformation in these rocks has been accomplished mainly by means of folds, and in a few places by small-throw, southwest-dipping faults.

A strongly crumpled and drag-folded zone occurs between North Saskatchewan River Gap and No. 2 fault (*See* Figure 2). The folds, both symmetrical and asymmetrical, are more numerous near the fault. They outcrop on both North Saskatchewan River and Dizzy Creek, and in many places are too closely spaced to be mapped. Half a mile southwest of the fault, the Bighorn formation is folded to the same degree as are the incompetent, underlying strata, whereas southwest of Brazeau Range it yielded to stresses by gently warping or slice-faulting. In the west part of Saunders map-area, the Bighorn formation is similarly situated with respect to the fault, and there also it is squeezed into tight folds whose limbs dip from 45 degrees to vertical. The great contrast presented by the Bighorn formation in the manner of accommodation to deforming stresses in different parts of the map-areas may be due to greater load or confining pressures during diastrophism. The decrease in thickness of the Bighorn toward the northeast, and the probable increase in proportion of shale, may be supplementary factors in explaining its incompetent behaviour northeast of Brazeau Range.

The minor folds in this part of North Saskatchewan River and Dizzy Creek differ in trend from any other folds of their size in the area in that they strike nearly east. This trend is transverse to that of the main folds of Brazeau Range, but is subparallel to the trend of the eastern folds of the range, south of the river, and to the trend of the branch of Fault No. 2 (*See* Figure 2). The easterly trend south of the river is directly related to the replacement of thrust faulting north of the river by these east-trending, medium-sized folds, which expose Palæozoic rocks for a considerable distance northeast of Brazeau Range divide. Map 884A and Figure 2 indicate that the occurrence of the east-trending minor structures, which cause the range to flare out toward the northeast, represent the added space requirements necessary for the replacement of a thrust fault by several minor folds along the strike. No tear faults are apparent in this zone. The Upper Palæozoic rocks of the minor folds in the vicinity of Dizzy Creek were faulted at a low angle previous to folding, whereas the Cretaceous rocks southwest of No. 2 fault were folded previous to large-scale thrust faulting. The substitution does not appear to necessitate a change in direction of diastrophic forces, but to involve, mainly, competency of rocks and confining pressures during the stages of deformation.

A set of typical asymmetrical minor folds is exposed on North Saskatchewan River where two synclines and an anticline lie within half a mile northeast of Fault No. 2. These folds are developed on the southwestern limb of the Stolberg anticline, and their linear extent is concealed by drift. The intensity of folding decreases rapidly northeast from the fault. The southwestern limb of the inner syncline is overturned and dips 65 degrees southwest near the fault, whereas a quarter of a mile northeast of the fault the southwestern limb of the outer syncline dips 45 degrees northeast. Massive, soft sandstones and interbedded, thinner bedded shales of Paleocene age are chiefly involved in the folding. The plunge of the minor folds is gently northwest. Considering that the intensity of folding

decreases rapidly northeast of the fault, that the Stolberg anticilinal axis lies 3 miles to the northeast, and that at least one small-scale fault is present in that interval, it is concluded that the plunge of these minor folds is not necessarily an indication of the plunge of the Stolberg anticline. Examples will be given later to demonstrate the non-uniformity of plunge directions in minor folds.

Directly northwest of No. 2 fault, several quartzite cobbles in massive sandstone are sheared in the manner of minute hinge faults, so that in one cobble 100 millimetres long the sheared halves are displaced nearly 2 millimetres on one side, and not at all on the opposite side. These quartzite cobbles seem to demonstrate a great confining pressure during their deformation. Many remain intact even after a displacement in the hinge-shear of nearly 3 per cent of the diameter of the cobble on one side and no visible displacement on the other.

Minor folds and drag-folds are abundant in Mountain Park and Luscar strata of Jock Creek in the west-central part of Alexo map-area. The folds in Luscar beds are too minute and numerous to be shown on the map. Most of them are asymmetrical, with a steeper northeast limb; a few have the reverse asymmetry. Minor slips or small, southwest-dipping thrust faults are associated with the folds in many places. The exposed rocks are chiefly carbonaceous, interbedded sandstone and shale, and bear coal seams in a few places. Although the Luscar is only 900 feet thick and is much folded, it is the only formation along Jock Creek for 3 miles across strike. The contact on both northeast and southwest sides of this belt of Luscar rocks is with the Mountain Park formation, so that, actually, the numerous crumples and drag-folds constitute an anticlinorium (*See* Map 884A). The directions of the plunges of the minor folds are not systematic, but are both to the northwest and southeast, so that they cannot be used to determine the plunges of major structures across strike or along strike. The highly folded section of Luscar rocks in Jock Creek reflects the type of deformation of incompetent rocks, in contrast with the gently folded section of competent Fernie and Rundle rocks in North Saskatchewan River Valley to the north, and the warped section of competent Bighorn rocks along strike to the southeast.

CHEVRON FOLDS

Minor folds with sharp bends at their axes (chevron folds) occur in the Blackstone, Luscar, and Fernie formations, where these have been closely crumpled and drag-folded, as in Jock Creek and Dizzy Creek Valleys of Alexo map-area. Both symmetrical and asymmetrical types were seen, but normally they are asymmetrical. Minor, symmetrical chevron folds, with crest to crest widths of less than 10 feet and dips on limbs of from 40 to 50 degrees, occur in Blackstone shales on lower Dizzy Creek. The shales in the folds are thin bedded and soft, and contain thin limestone bands or concretions disposed along the bedding planes. An asymmetrical chevron anticline is exposed in bedded Fernie limestone about a mile southeast of the Blackstone occurrences. The northeast limb dips 75 degrees. Asymmetrical, chevron-type folds occur in the minor folds and drag-folds along Jock Creek within the carbonaceous shales and sandstones of the Luscar formation. The folds dip steeply northeast, and are

50 feet or less from crest to crest. Chevron folds were seen at too few places to warrant speculation as to their origin. Where observed, they are small; they occur in well-bedded, generally incompetent, strata; and they are associated with disharmonic, minor folds.

SUMMARY AND CONCLUSIONS

The general structure of the northeastern or outer Foothills belt for a length of more than 100 miles consists essentially of northwest-trending, low-dipping, broad folds. These are intersected by occasional large-throw, southwest-dipping thrust faults trending parallel with the bedding structures. The age of the associated rocks is Upper Cretaceous and Paleocene. Two belts of collinear, discontinuous, outlier ranges of Palæozoic rocks occur northeast of the first range of the Rocky Mountains at intervals of about 10 miles. The outlier ranges are represented generally by asymmetrical anticlines, faulted on the steep or overturned northeastern limb. Brazeau Range in Alexo map-area and Ram River anticline in Saunders map-area are two such outlier ranges in the outer Foothills. The axes of the anticlines composing the outlier ranges coincide closely with the topographic highs of the ranges. The first range is composed of linear, strike-faulted ridges, thrust northeastward along southwest-dipping, low-angle faults. Dip-slopes on the southwest and steep scarps on the northeast are typical. The first range, as well as the outlier ranges to the northeast, partly override, or are adjacent to, large basins of the youngest rocks in the area. Rocks as old as Cambrian are exposed in the first range and inner Palæozoic outliers, and rocks as old as Devonian are exposed in the outer Palæozoic outliers.

Alexo and Saunders map-areas are cut diagonally by a northwest-trending thrust fault that divides the areas into two general structural and stratigraphic units: a broadly folded, relatively little faulted, northeastern half, underlain by Upper Cretaceous and Paleocene rocks, and a moderately to closely folded and faulted southwestern half, comprising Upper Devonian to lower Upper Cretaceous rocks. The extreme northeastern part of Saunders map-area is believed to be part of the west flank of the 'Alberta Syncline'.

Folds in the map-areas vary in magnitude from minute drags to broad structures more than 8 miles across. Types of folds include various degrees of open and closed, symmetrical and asymmetrical anticlines and synclines; and overturned, recumbent, chevron, and minor folds. Examples of open, symmetrical folds are the Stolberg anticline, the Ram River anticline and syncline, the warped folds of Bighorn rocks southwest of Brazeau Range, and the Philip Creek syncline. Examples of asymmetrical folds include the Brazeau Range, Tawadina Creek, and Weaver anticlines, and the Ancona syncline. Overturned and recumbent folds occur on Ram and North Saskatchewan Rivers, southwest of a large thrust fault, and on the northeast flank of Brazeau Range anticline. Chevron folds occur in the incompetent Blackstone and Luscar strata, and minor folds and drag-folds are best developed in the incompetent strata of the Blackstone, Mountain Park, and Luscar formations.

The asymmetrical fold, with gentle to moderate southwest dips and steep to vertical northeast dips, is considered the normal type of fold of

the Foothills belt of west-central Alberta. Numerous minor folds in the map-areas conform to this asymmetry. Such anticlines, especially if of considerable size, are commonly faulted on the northeastern limb by a low-angle, large-displacement thrust fault whose plane dips southwest. Brazeau Range and Tawadina Creek anticlines represent, wholly or in part, the typical, faulted, asymmetrical anticline.

Departures from the above type of asymmetrical structures do occur, and are explained by disruptions or modifications of the normal development. Thus, Stolberg anticline and Ancona syncline, being farthest removed from the presumed active stress, are broad, gentle-dipping structures, and do not conform to the usual type of Foothills fold. In addition, Stolberg anticline is symmetrical, and the Ancona syncline has reverse asymmetry from folds typical of the Foothills. The development of these folds into broad, normally asymmetrical structures was apparently modified by the large-throw thrust fault on the southwestern flank of the Stolberg anticline, and by a similar type of fault on the northeastern flank of the Ancona syncline (*See* Figure 2). Vertical dips and minor folds were formed on the footwall side of Fault No. 2, and the dips on the southwestern limb of Stolberg anticline were generally steepened, so that a symmetrical structure resulted. The normally low southwest dips of the northeastern limb of the Ancona syncline were increased because of proximity to the large thrust fault on the northeast, so that the typical asymmetry was reversed.

The larger symmetrical structures, as Stolberg anticline, Ram River anticline, and Ram River syncline, do not show the thrust faults on their northeastern sides as do the large, asymmetrical anticlines. In the case of the Ram River anticline and syncline, a subsidiary, typically asymmetrical, faulted anticline is adjacent to the syncline on its northeastern flank in Tay River map-area (Henderson, 1944). The Weaver anticline is a prominent fold of small, reverse asymmetry; the northeastern limb is free from faults. Considering its size this anticline is unique in Alexo and Saunders map-areas, and no reason is apparent for the atypical development (*See* Structure-section E-F, Map 884A).

Overturned and recumbent folds and drag-folds in the map-areas are predominantly of the normal asymmetry.

The plunges of the Stolberg anticline and Ancona syncline are not determinable within the map-areas. The larger structures of the southwestern half of Alexo and Saunders map-areas show one or more reversals of plunge along strike. Minor folds in the Luscar formation show reversals in direction of plunge within short distances across strike, so that they cannot be used as infallible indicators of regional plunge, or of plunge in associated major structures. The cause of the anomalous plunges in the minor folds may be the presence of small-throw hinge faults that impart non-uniform directions of plunge to the associated minor folds.

Indications of structure at depth are derived from oil-well information; from visible structures in deeply incised valleys; by comparison with structures in progressively older formations along strike as revealed by plunging folds; and by comparison with structures of older beds as revealed in folds across strike. It was concluded that the existence of a basement control is not readily demonstrated, but that a lithological control of structure is apparent. The competent, Upper Palæozoic rocks deformed, in general,

as broad, simple structures, whereas the overlying incompetent Luscar, Mountain Park, and Blackstone formations underwent much minor folding and drag-folding. Hence, despite extensive minor folding in these younger rocks at the surface, the underlying Upper Palæozoic formations are, apparently, folded into a broad, simple fold or folds. This statement does not exclude the possibility of large-throw thrust faults in the Palæozoic rocks at depth, but indicates only the conformation of the folds.

The Bighorn rocks are closely folded northeast of Brazeau Range, gently warped southwest of this range, and are southwest-dipping and slice-faulted in the extreme southwestern part of Alexo map-area. The variation in the accommodation of Bighorn strata to deformation, across Alexo and Saunders map-areas, may be due to the difference in confining pressures existent in the formation during deformative stresses, and to the increasing thickness and competency of the formation toward the southwest.

In general, both folds and faults appear to be the result of one diastrophism, or, if more than one, then the later stresses acted from the same direction, presumably from the southwest. The coincidence of the strike of a large fault with the strike of adjacent folds in the hanging-wall indicates that thrust faulting is merely a later stage of folding; the plastic limit of the beds was exceeded, and strike faulting replaced folding. In many places folds were developed in the foot-wall of a large fault (Fault No. 2, Figure 2) by dragging during the fault movement. The strike of these folds also appears to conform with the strike of the associated fault. But the strike of folds on the foot-wall side of the fault, which are farther removed from the fault, may or may not conform with the strike of the fault. Any coincidence of trends is believed to be due to the regularity of the general regional structure rather than to a genetic relationship between the large fault and these farther-removed folds.

The intensity of folding, as denoted by the closeness and frequency of the folds, increases markedly from the broad, gently dipping Ancona and Stolberg structures on the northeast to the numerous minor folds and faults on the southwest, indicating that the structures developed progressively from southwest to northeast. Although folding of strata in most places preceded faulting, nevertheless, thrust faulting preceded some folding in the vicinities of both Philip Creek and Dizzy Creek of Alexo map-area. This reversal in the general order of deformation has resulted in folded thrust faults, intimately associated with folded beds. These folded faults are discussed in detail under a separate heading.

CULMINATIONS AND DEPRESSIONS

GENERAL STATEMENT

The term culmination has been defined as the high-lying part or "culmination" in the lengthwise direction of folds or complex folds, whereas a depression is the low-lying part or "depression" in the lengthwise direction of these structures (Rutten, 1929). Billings (1942, p. 49) represents culminations and depressions by lines essentially at right angles to the trend of folds; the folds plunge away from culminations towards the depressions. Staub (1916) shows transverse culmination and depression zones

on a small-scale tectonic map of the southeastern Alps. Kober (1923, p. 38), indicates culmination and depression axes on a tectonic map of part of the Alps, and describes the occurrence of culmination and depression axes in the nappes and massifs of the Helvetian Alps.

Culmination and depression axes are shown on the accompanying structural map of Alexo and Saunders map-areas (Figure 2), as determined by plotting all known plunges of both major and minor folds. The locations of the axes are only approximate in some places due to scarcity of outcrops. The data were plotted in order to determine whether such information could be used in interpreting certain structural problems, as for example, whether a favourable oil structure could be defined in a drift-covered area by a study of culminations and depressions in neighbouring areas of outcrop. The conclusions arrived at from a study of the data are for a relatively small area, and do not necessarily apply in other areas.

MAJOR CULMINATIONS AND DEPRESSIONS

A well-defined major culmination axis trends southwest from the east-central part of Alexo map-area at nearly right angles to the structures, and is indicated for a distance of 8 miles in Figure 2. The culmination axis traverses the highest part of Brazeau Range. To the southeast, the Brazeau Range anticline plunges southeast in places at angles as great as 20 degrees, and, on the other side, at much gentler angles to the northwest. At its northeast end, the culmination axis is, apparently, terminated by the branch of No. 2 fault. To the southwest, it has been followed to the area of warped Bighorn strata. The surface rocks along the axis of culmination range from those of Devonian age, in Brazeau Range, to those of the Upper Cretaceous Bighorn formation in North Ram River Valley.

The major depression axis in Alexo and Saunders map-areas lies southeast of the culmination axis described above. It crosses the structural trend through an area of general low relief, and has been mapped for about 8 miles southwest from Tawadina Creek anticline to the south edge of Alexo map-area. At the anticline, the axis trends at right angles to that of the folds, but toward the southwest the axis trends more westerly. The result is that, whereas the depression axis on Tawadina Creek anticline is 6 miles distant from the culmination axis described above, in the southwestern part the interval between them is less than 3 miles. The northeastern extension of the depression axis from Tawadina Creek anticline was not observed. Formations exposed along the axis range from lower Luscar, on Tawadina Creek anticline, to Bighorn on the southwest.

A second major culmination, whose axis crosses Brazeau Range about 3 miles northwest of The Gap of North Saskatchewan River, exposes Palæozoic rocks at their highest elevation in this range. The calculated Devonian-Mississippian contact at the intersection of the culmination axis and the axis of the Brazeau Range anticline is at an elevation of about 7,500 feet. This figure contrasts with the elevation of 7,000 feet for the same contact in the first major culmination described. The second culmination axis is not traceable for any great distance southwest or northeast. The strata plunge moderately to the southeast and northwest from the culmination.

MINOR CULMINATIONS AND DEPRESSIONS

The axes of several minor culminations and depressions are indicated in Figure 2. One such culmination axis crosses the Brazeau Range anticline about 6 miles northwest of The Gap. There the projected Devonian-Mississippian contact is at an elevation of about 6,600 feet. The position of a minor depression axis to the southeast is not definite, and has been placed midway between the two culminations. A second minor depression occurs about 1½ miles northwest of The Gap. There the calculated Devonian-Mississippian contact is at 6,400 feet. This figure represents a southeasterly plunge of 1,100 feet from the major culmination to the northwest. The rise between this minor depression and the first major culmination described (southeast of The Gap) is about 600 feet.

Minor culminations and depressions occur in the western and southwestern parts of Saunders map-area, but are mappable for only short distances along their axes. The axis of the most southerly culmination in the area crosses Tawadina Creek anticline, exposing Rundle rocks. It appears to trend southward, and to cross the Ram River anticline in Fall Creek map-area. The culmination of Tawadina Creek anticline is directly opposite a depression in Ram River anticline to the southwest. Ram River syncline, situated between the above anticlines, is apparently a structural unit of the Ram River anticline rather than of the Tawadina Creek anticline; the change in plunge occurs in Ram River Valley between Tawadina Creek anticline and Ram River syncline. The reason for the anomalous, southerly trend of the culmination axis is not apparent. The existence of hinge or pivotal faults would account for the reversal of plunges in a relatively small distance across strike; but no faulting was observed. The culmination of Tawadina Creek anticline is situated relatively near a large thrust fault (Fault No. 2, Figure 2). This suggests that the culmination may be a local reflection of the attitude of the fault surface at shallow depth, and that the culmination was, therefore, not apparent in anticlines and synclines to the southwest where the fault surface is much deeper. This suggestion is supported by evidence that although the reversal of plunge, between Tawadina Creek anticline and Ram River syncline, takes place over a relatively small distance across strike, yet this change appears gradational rather than abrupt.

Local depressions occur in the Bighorn warped mesas southwest of Brazeau Range. Reversals in plunge occur within short intervals across strike in the minor folds of Jock Creek Valley. No pattern was recognized, and apparently the reversals are due to the presence of small-throw faults seen in the field, and to irregular drag-folds of incompetent beds.

A longitudinal section is shown along the axis of the Brazeau Range anticline (*See* Figure 2), in which the Devonian-Mississippian contact, projected where necessary, is the horizon datum. The section shows that the Brazeau Range consists of a series of undulations along strike, both large and small. The major culmination north of The Gap is terminated on the northeast by the subsidiary fault southwest of Fault No. 3. This fault loses its identity south of The Gap. The position of The Gap of North Saskatchewan River does not appear related to a culmination or depression as the river flows directly across a northwest-plunging fold.

Evidence of the plunge of structures in the northeast half of the area was too scanty to warrant the plotting of culmination and depression axes. The abrupt terminations of the culmination and depression axes in a northeasterly direction, in the vicinity of Brazeau Range and the associated thrust faults, indicate that the southwestern half of the area is a structural unit distinct from the northeastern half of the area. The folds in the southwestern half of the area plunge moderately, in contrast with the gentle plunges for the structures in the northeastern half of the area. The termination of the culmination and depression axes appears to be the result of hinge faults, pivotal faults, or faults of varying throw along the strike.

DEDUCTIONS

Several deductions can be made from the plotting of culmination and depression axes:

(1) The axes of most culminations and depressions trend at nearly right angles to the trend of the structures. An exception to this appears to be a culmination axis that extends from the southern part of Tawadina Creek anticline southeasterly to beyond the Saunders map-area.

(2) The direction of plunge of minor folds may indicate the direction of plunge of major folds. This rule has limited application in Alexo and Saunders map-areas, but applies to some minor folds in competent rocks, such as those in Upper Palæozoic rocks in subsidiary folds of the Brazeau Range anticline. Minor folds in the incompetent Lower Cretaceous rocks show no systematic order in plunge directions. The reversals in plunge over small lateral distances are probably due to the presence of minor, hinge faults, and to the haphazard crumpling and folding of the soft, thin-bedded shales and sandstones.

(3) The mapping of culmination and depression axes is difficult in areas of much slice-faulting, as in the southwestern part of Alexo map-area.

(4) The mapping of culmination and depression axes brings out the fact that unduations, both great and small, occur at intervals along the strikes of fold-axes. Mead (1920, pp. 521-23) has demonstrated that plunging folds, similar to those in Alexo and Saunders map-areas, may be developed by pure shortening or compression, and by shear or rotational stress. Additional data from faults and joints will be considered towards determining the type of deformative stress in this area.

(5) The termination of culmination and depression axes by faults, as shown in the northeast part of Brazeau Range, indicates the presence of two major structural units in general bordered by Faults Nos. 2 and 3 (*See* Figure 2). One of these units is represented by the area of broad gentle folds northeast of the above-mentioned faults, whereas the second unit includes Brazeau Range and the area to the southwest.

The corollary follows that the plotting of culmination and depression axes may prove useful in the confirmation or discovery of faults, especially in areas of limited outcrops of thick formations.

(6) In the southwestern structural unit of Alexo and Saunders map-areas, major culmination and depression axes extend for distances of 6 to 8 miles, exposing beds ranging in age from Devonian to early Upper Cretaceous (Bighorn). The persistence of these axes across beds of variable competencies suggests that culminations and depressions may be regional

structural features controlled by competent rocks at depth. Folds, on the other hand, reacted to stress very differently, depending on whether the folds were in competent Upper Palæozoic or in the overlying, incompetent Mesozoic beds.

(7) The applicability of culmination and depression axes toward the location of favourable oil structures was not established in Alexo and Saunders map-areas, but is believed to be feasible in areas where there is a better distribution of plunge information.

JOINTS

GENERAL STATEMENT

The following is a summary of a study of joints in Saunders map-area and parts of bordering areas to the east and west (Figure 3). No regional application of the results may be justified, as the area studied is only a small part of the entire Foothills belt.

The strike, dip, spacing, and quality of joints were recorded at about 300 stations, and as the joints commonly occur in two intersecting sets, a total of about 600 readings were made. These readings are not evenly distributed, as rock exposures are concentrated in the larger streams, higher ridges, and on Brazeau Range. The attitudes of joints were recorded in rocks ranging in age from Devonian to Upper Cretaceous or Paleocene. However, due to the small areal extent of the exposed formations, no more than 20 stations were occupied for observation of joints on any one formation, with the exception of the combined Luscar and Mountain Park formations and those of Upper Cretaceous or Paleocene age. Joint readings were taken at about 80 stations in Luscar and Mountain Park rocks, and at about 110 stations in Upper Cretaceous or Paleocene rocks. The joint attitudes in the latter are considered in greater detail because of the relatively large number of readings, the large areal extent of those rocks, the low and uniform bedding attitudes, and the similarity of lithology throughout the areas underlain by those rocks. More than 400 separate joint attitudes are plotted on Figure 3, which includes Saunders map-area and parts of adjacent map-areas. The remainder of the joints measured are either too closely spaced to plot or lie outside the boundaries of Figure 3.

Strike and dip readings of joints were made with a Brunton compass. Generally one reading was recorded, representing the average or persistent attitude.

PATTERN OF JOINTS

Most of the joints fall into two definite sets, one set parallel with the strike of the general structure, and the other approximately at right angles to it. These are conveniently denoted as 'strike joints' and 'dip joints', respectively. In places a third set is apparent. The relation of the joint sets or joint system to the major structures is shown in Figure 3.

QUALITY OF JOINTS

The quality of joints was described by use of comparative terms ranging from 'poor' to 'very good', depending on the regularity and extent of the attitude. Thus, if strikes and dips of a joint set at an exposure were con-

stant and if the set were developed for several feet, that set would be classified as 'very good'. Joint sets showing irregular, curved, or subparallel partings would be classified as 'poor'.

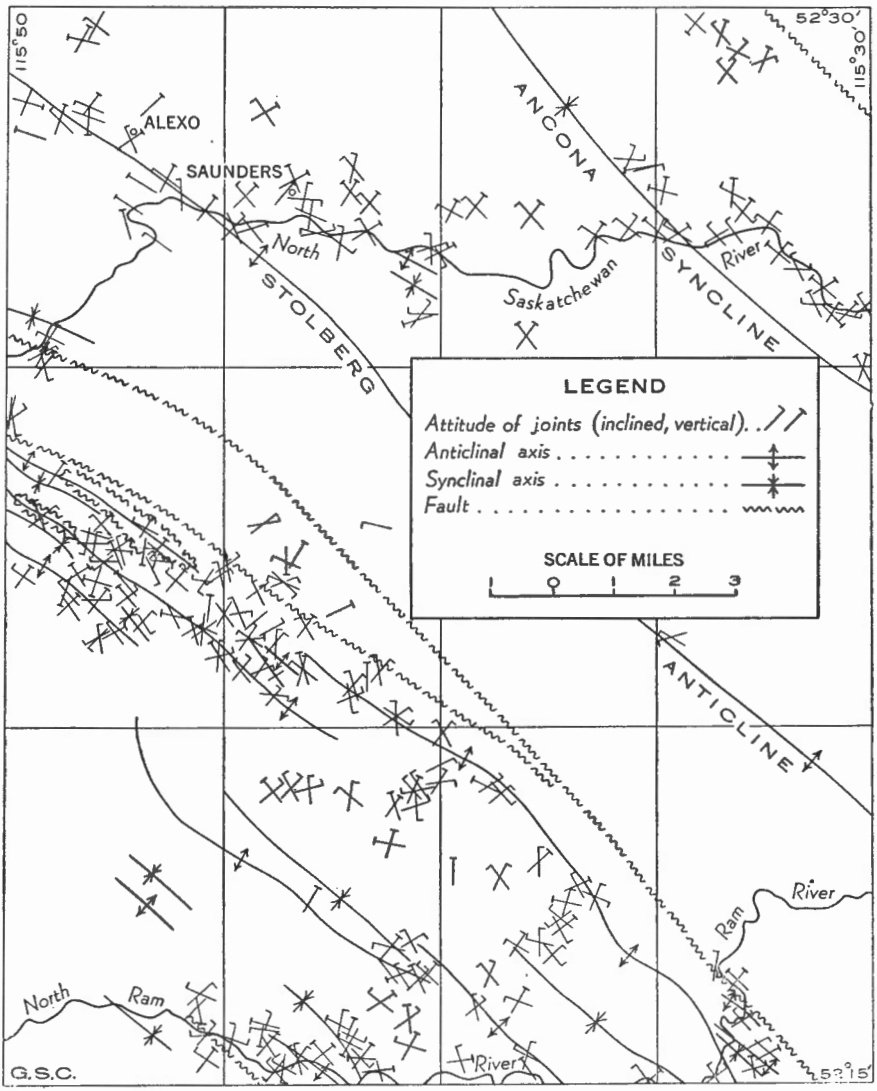


Figure 3. Joints and major structures in Saunders map-area and part of Alexo map-area.

The following results were obtained from a summary of the field notes:

(1) The quality of a joint appears related to the lithology and the location of the exposure. Thus, in an outcrop of interbedded, massive sandstone and shale, well-developed joints may transect the massive sandstone, but be absent or poorly developed in the shale. However, lithologically similar rocks of the same formation, but in different parts of the area, may

show a great variation in quality of the joint sets. This observation applies to limestones of the Upper Palæozoic as well as to sandstones of Upper Cretaceous or Paleocene age.

(2) In general, if one joint set is well developed, the associated intersecting set is also; whereas, if one set is poorly developed, so also is the associated set. This generality was derived from a statistical count of 60 joint sets picked at random from rocks of all ages. The tabulated results follow.

Relation between Quality of Joints and Type of Joints

Quality of joints	Number of strike joints	Number of dip joints
Very good	4	4
Good	39	48
Fair	12	4
Poor	5	4
Total	60	60

The table indicates that the quality allotted to dip joints is slightly higher than that allotted to strike joints. Plate V shows well-developed strike and dip joints in Luscar sandstone on lower Fall Creek.

A good agreement in trends of joints was indicated for the northeastern part of the area where dips are uniformly low, and probably more consistent results would have been obtained if more painstaking methods had been used.

In places the joints are typical of those developed under tension, such as in the axial regions of folds. The following evidence, however, suggests that some joint sets are shear joints: (1) in many places both sets are clean-cut and trend regularly; (2) the joint planes cut across both pebbles and matrix in Lower Cretaceous conglomerates; a short distance south of Alexo map-area the surfaces of such joints are slickensided.

SPACING OF JOINTS

The space between individual joints in a set was recorded in the field as a rough average figure, if the spaces were regular, or by limiting ranges if spaces were irregular. Lithology appears the controlling factor in the spacing of joints. Those in coal, shale, and sandy shale are much closer than those in massive sandstone and massive limestone; the joints or cleats of observed coal seams are in the order of fractions of an inch, whereas contiguous massive sandstone may show joints separated by as much as 4 or 6 feet. A similar increase in the spacing of joints crossing from interbedded shale to overlying sandstone was observed in the Luscar formation. The mean spacing for 34 strike joints in Mountain Park and Luscar rocks is 13 inches; and for 46 dip joints the mean spacing is 17 inches. Because of the great variability in spacing even in a single outcrop, the figures are useful mainly to indicate the general order of magnitude of the spacing.

The somewhat higher figure for the dip set than for the strike set may have significance, as a similar tendency is exhibited in the spacing in some Upper Cretaceous or Paleocene rocks.

DIP OF JOINTS

The dips of the joints are mainly steep to vertical, but may be as low as 10 or 15 degrees. The dips of the strike joints are more variable than those of the dip set, and seem roughly normal to the dip of associated beds. The dip joints appear more generally steep to vertical, with no definite pattern of dip values. Typical strike and dip joints are tabulated below in the order of increasing dip of the associated beds.

The following table demonstrates the general complementary relation of the dip of strike joints to the dip of beds. The dips of the dip joints are steep to vertical, showing no apparent variation with change in dip of beds.

Comparison of Attitude of Strike and Dip Joint Sets with Attitude of Beds

Azimuth and dip of beds (Degrees)	Azimuth and dip of strike joints (Degrees)	Azimuth and dip of dip joints (Degrees)
345 - 5 SW	330 - 84 NE.	265 - 83 N.
325 - 9 NE	320 - vertical	230 - 73 NW.
308 - 18 SW	325 - 72 NE.	215 - vertical
327 - 40 SW	327 - 47 NE.	220 - 85 SE.
320 - 77 NE	302 - 24 SW.	230 - 80 NW.
316 - 86 NE	345 - 7 SW.	230 - 78 SE.
321 - 83 SW.[1]	290 - 15 NE.	230 - 69 SE.

[1] Overturned beds.

Strike and Dip Joints Divided on Basis of Angle of Dip

Dip of joints (Degrees)	Strike joints (Percentage)	Dip joints (Percentage)
85 - 90	30	51
80 - 85	11	11
75 - 80	11	9
Less than 75	48	29

The above table gives the generalized dips of 282 strike joints and 300 dip joints. It indicates that about half of the dip joints are within 6 degrees of vertical, whereas less than a third of the strike joints fall in this range. About half the strike joints dip less than 75 degrees in contrast with less than a third of the dip joints. As this table includes all the joint attitudes recorded, the data should be indicative of general tendencies throughout some 300 square miles. The relatively large number of strike joints dipping less steeply than 75 degrees is a reflection of the complementary relation of dip of beds with dip of strike joints, as brought out in the preceding table, and the relatively large number of steep dip

joints shown confirms the tendencies of dip joints to be vertical, as indicated in that table. A critical examination of dip joints at the axes of the plunging Tawadina Creek and Ram River anticlines shows that those joints lie approximately at right angles to the crests of the folds, and that they are normal to the pitch of the folds, in a manner true of 'transverse joints' as described by Hills (1941, p. 96). Although field evidence of dip joints at the crests of folds is scarce, the association of steeply dipping dip joints with, in general, low-plunging folds through the area, suggests the complementary relation between dip of joints and plunge of folds.

JOINTS IN UPPER CRETACEOUS AND PALEOCENE ROCKS

About 200 joint attitudes, from about 120 locations, were recorded in the Upper Cretaceous and Paleocene rocks northeast of Fault No. 2 (Figure 2).

The mean strike of the southwest-dipping beds of this area is north 48 degrees west, whereas the mean dip is 12 degrees. The mean attitude of associated strike joints is: strike, north 52 degrees west; dip, 78 degrees northeast. The mean attitude of associated dip joints is: strike, north 40 degrees east; dip, vertical. The northeast-dipping beds in the area of Figure 3 have an average strike of north 47 degrees west, and an average dip of 15 degrees. The mean attitude of the associated strike joints is: strike, north 53 degrees west; dip, 76 degrees southwest. The mean attitude of the dip joints is: strike, north 48 degrees east; dip, vertical.

The following table is a statistical presentation indicating the complementary relationship between the dip of strike joints and the dip of the associated beds. The dip joints generally have steeper dips than the strike joints, and, moreover, tend to verticality regardless of the dip of the associated beds.

Strike and Dip Joints Divided on Basis of Direction of Dip

Direction of dip of beds	Percentage of strike joints		Percentage of dip joints	
	Dips are southwest	Dips are northeast	Dips are northwest (steep)	Dips are southeast (steep)
Northeast	77	14	48	45
Southwest	19	82	48	47
Horizontal	4	4	2	6
Other directions	..	..	2	2

JOINTS AND VEINS

In many places the joints are lined or veined with calcite, generally less than a quarter of an inch thick. These joints are more common in the Palæozoic shales and limestones, but are noted in Blackstone shale as well as in Luscar and Upper Cretaceous or Paleocene sandstones. Narrow calcite veins occur in joints at two places in Alexo map-area near the axes of anticlines. The joints are in Upper Palæozoic shaly limestone, and appear to be tension joints or feather joints. Closely spaced fractures on

the axes of tight anticlines, and parallel with the trend of the anticlines, are common in the map-areas. The tension, vein-filled joints noted above may represent fracture cleavage produced during folding.

Intersecting sets of calcite-filled joints in the Blackstone shale of Dizzy Creek Valley show subsequent fracturing by unveined joints of slightly different attitudes. Calcite-lined joints in the Upper Cretaceous or Paleocene beds a short distance northeast of the large thrust fault crossing Ram River show strong slickensiding. Joints filled with calcite occur to depths of at least 4,000 feet, as shown by diamond-drill borings a short distance southeast, in Tay River map-area.

JOINTS AND FAULTS

The relative age relationships of joints and faults is demonstrated in a few places. The slickensiding of the calcite-veined joints a short distance northeast of Fault No. 2 (Figure 2) indicates that joints were formed and lined with calcite before or between faulting movements. A thrust fault with a throw of 23 feet illustrates the relations of the joints in foot-wall beds to those of hanging-wall beds. The fault has displaced massive sandstones and a 12-foot coal seam on North Ram River. Both hanging-wall and foot-wall beds dip gently southwestward. However, the joint sets of a massive sandstone bed in the hanging-wall have been rotated between 20 and 25 degrees around a vertical axis from the joint sets in the same sandstone bed of the foot-wall. Added to this, the calcite-filled joints or fractures in the vicinity of the fault have been slickensided. These data indicate that the joints had formed prior to the faulting.

SUMMARY

A survey was made of the attitudes of about 600 joints over an area of 300 square miles, and attitudes of about 200 joints recorded in the northeastern two-thirds of the map-areas were analysed in more detail. The following is a summary of the results:

(1) A joint system composed of two, intersecting, steeply dipping sets is present throughout the map-areas, and in places a third set is apparent. One set, referred to as 'strike joints', is parallel with the general strike of the beds; the other set, the 'dip joints', is approximately at right angles to the general strike. The joint pattern appears more regular in the low-dipping beds of the northeastern part than in the moderate- and high-dipping beds of the southwestern part.

(2) The strike and dip joints are generally equally persistent and regular in attitude. The quality of joints in rocks of the same formation and of similar lithology varies throughout the map-areas.

(3) Both tensional and compressional varieties of joints are indicated in the field.

(4) Lithology appeared the decisive factor in the spacing of dip and strike joints. The spacing between joints in shale and coal may be in the order of fractions of an inch; the spacings in massive sandstone are as much as 6 feet. The general order in magnitude of joint spacing in Luscar and Mountain Park formations is about 1½ feet.

(5) The dips of strike joints appear more variable than those of the dip joints, although each set may range from steep to vertical. Strike joints appear to dip approximately normal to the dip of the associated beds. The dip of the dip joints at the crest of a fold may be nearly normal to the plunge of the fold. In other words, the data indicate that both strike and dip joints are approximately perpendicular to the bedding plane.

(6) In many places the joints are lined or filled with calcite veinlets. Veined joints may show subsequent fracturing by unveined joints. Tension joints near the crests of folds may be fracture cleavage developed during folding.

(7) Field evidence from a few places indicates that the joints were formed previous to the faults or during fault movements.

FAULTS

GENERAL STATEMENT

The major faults of Alexo and Saunders map-areas are southwest-dipping thrusts. Imbricate structure is well developed in Bighorn rocks of the southwest corner of Alexo map-area. Minor faults are usually southwest-dipping thrusts, but in a few places small gravity faults and northeast-dipping thrusts do occur. Folded thrust faults, which originally dipped southwest, appear in two parts of Alexo map-area.

MAJOR THRUST FAULTS

Fault No. 1. This major thrust fault (*See* Figure 2) has been mapped in the extreme northeast corner of Saunders map-area. It is not exposed in the area, but evidence of it was observed in a railway cut about 8 miles to the east. There, coal-bearing beds of the foot-wall, dipping moderately southwest, are in contact with clay shales and sandstones of the hanging-wall or northeast side that dip at low angles to the north. Slickensiding is strongly developed in the rocks on both sides of the fault, which has thrust older beds on the southwest into contact with younger rocks on the northeast. The position of the surface trace of this No. 1 fault is taken from the map by Allan and Rutherford (1923), who show it as a southwest-dipping thrust fault extending from about 10 miles southeast to about 35 miles northwest of Saunders map-area. MacKay (1943a) has mapped the fault an additional 50 miles or more northwest. The only structural evidence for the presence of the fault in the Saunders map-area is the steepening of dips in coal-bearing strata near upper Jackfish Creek. The hanging-wall beds contain the coal series of Saunders and Alexo area, but the amount of throw of the fault is not determinable because the stratigraphic position of the foot-wall beds is not known.

Fault No. 2. This fault (*See* Figure 2 and Maps 884A, 885A) is a northwest-trending thrust fault that crosses Alexo and Saunders map-areas diagonally and extends for several miles northwest and southeast. It parallels nearby minor folds, but is subparallel with major folds, such as the Stolberg anticline. The fault is exposed only on Ram River. It traverses drift-covered areas through most of its length, but its surface trace is delimited fairly well by scattered exposures on both sides. Though

the fault has no definite topographic expression, its displacement is about twice as great as the displacement of the fault that produced the prominent northeast facing scarp of Brazeau Range north of North Saskatchewan River (*See* Plate I).

The surface trace of Fault No. 2 is mainly concealed in North Saskatchewan River Valley, but upper Blackstone shales lie a stone's throw southwest from massive sandstones and conglomerates of Paleocene age. Because of this fault only the lower part of the Brazeau formation is exposed in these map-areas. The calculated stratigraphic throw of the fault on North Saskatchewan River is 7,000 to 8,000 feet. Small, compressed folds are present in Lower and Upper Cretaceous beds in the river valley between Fault No. 2 and The Gap. Folds with vertical to overturned limbs occur in the foot-wall beds near the fault, but less than half a mile northeast of the fault the dips decrease to less than 30 degrees.

Fault No. 2 is well exposed on Ram River, in the southeastern part of Saunders map-area. Lower Luscar rocks on the southwest are in contact with those of Palæocene age on the northeast. The fault contact is a zone rather than a plane, as the overturned beds of the hanging-wall are sheared against a zone of strongly contorted foot-wall beds. The fault dips about 45 degrees southwest at the surface, but the angle of dip is believed to become much less at depth, more in agreement with the dip of the axial plane of the recumbent fold directly southwest of the fault. This fold is an overturned to recumbent anticline, modified by drag-folds and minor shears. Steeply dipping, asymmetrical folds, progressively less compressed, continue southwest from the fault for about a mile. The beds of the foot-wall dip regularly southwest from the axis of the Stolberg anticline to within a thousand feet of the fault, a distance of about 3½ miles. About 500 feet northeast of the fault the sandstone beds are strongly sheared and slickensided; calcite veinlets filling joints are also slickensided. About 200 feet northeast of the fault, beds believed to be of Paleocene age become strongly sheared and folded. Much crushed coal occurs in the fault zone, and assuming it to be of Paleocene age, the stratigraphic throw of the fault is calculated to be in the neighbourhood of 10,000 feet. The maximum throw of the fault is thought to occur in Tay River map-area, 3 or 4 miles southeast of Ram River, where Jurassic rocks in the hanging-wall are in contact with rocks of Paleocene age in the foot-wall (Henderson, 1944). The throw of the fault definitely decreases from this place southeastward, and the fault ends about 20 miles southeast of the Ram River fault outcrop.

The dip of No. 2 fault at depth is indicated by Ram River No. 1 well drilled in Tawadina Creek Valley, less than a mile southwest of the surface trace of the fault. At 1,235 feet the drill passed from Devonian dolomite into strongly slickensided, steeply dipping sandstones of Paleocene age. This evidence indicates that the fault has an average southwest dip of 12 degrees, in contrast with a surface dip of 45 degrees on Ram River, about 3 miles to the southeast. Thus the dip of the fault surface must decrease at depth. The structural section (*See* Map 885A) indicates that the fault is a low-angle fault, with a warped or gently folded surface. Such folding is required to account for the low depth to the fault at the oil well, assuming that thrust faults cut through successively older beds down dip. The

presence of a known folded fault 8 miles northeast along strike lends added weight in favour of a folded or warped fault surface. Folded faults are discussed later in this report.

Fault No. 3. This fault underlies the northeast-facing scarp of Brazeau Range north of North Saskatchewan River (*See* Map 884A and Figure 2). It continues northwest for some tens of miles, but fades out a short distance south of the river, where it is replaced by *en échelon* folds (*See* Figure 1). North of the river the trends of the No. 2 and No. 3 faults are not quite parallel. Mesozoic rocks form both hanging- and foot-wall sections throughout most of the fault's length in Alexo map-area. To the northwest, Luscar rocks in the hanging-wall are in contact with Brazeau and Wapiabi rocks in the foot-wall, representing a stratigraphic throw of about 4,000 feet. The throw decreases to the southeast, and amounts to only a few hundred feet in The Gap. The throw of the fault reaches a maximum of about 5,000 feet in Wawa Creek map-area, about 4 miles northwest of the northwestern corner of Alexo map-area (MacKay, 1943b). The prominence of the northeast-facing scarp of Brazeau Range bears a direct relation to the variations in the throw of the fault. North of the river, where the throw is large, the scarp is well shown; south of the river, where the throw decreases and folding replaces faulting, the scarp loses its identity.

At the surface, Fault No. 3 and the subsidiary fault to the southwest dip steeply to the southwest, as indicated by the small deviation from the true strike of the faults where the surface traces traverse an area of high relief, such as The Gap. Some information on the attitude of Fault No. 3 at greater depth is indicated in Shunda No. 1 well, drilled 1¼ miles southwest of the surface trace of the fault in Brazeau map-area. A fault (presumably Fault No. 3) was encountered at 2,415 feet, and the well passed from beds of Cambrian (?) age above to sandstones of the Blairmore (?) group below. Thus the fault has an average dip southwest of about 20 degrees.

Fault No. 4. This is a southwest-dipping thrust fault, lying between Philip and Lynch Creeks (*See* Map 884A and Figure 2). It parallels the general structural trend, and extends for several miles both northwest and southeast of Alexo map-area (*See* Figure 1). In the northwestern and southeastern extremities of Alexo map-area, the fault thrusts Mountain Park beds over Blackstone shales, and in the central part of the map-area Blackstone beds in the hanging-wall are in contact with higher Blackstone beds in the foot-wall. The throw of the fault amounts to a few hundred feet. A moderately steep dip to the southwest is indicated by the course of the fault trace through an area of varying relief.

Fault No. 5. This is a southwest-dipping thrust fault that trends northwest across the extreme southwest corner of Alexo map-area. It extends for more than 20 miles into Brazeau map-area to the northwest (MacKay, 1941a) and across most of Cripple Creek map-area to the southeast (Erdman, 1946). In Alexo map-area, Luscar or Mountain Park rocks are thrust northeastward against upper beds of the Wapiabi, representing a stratigraphic throw of nearly 4,000 feet. This throw persists for about 10 miles northwest, where subsidiary faults and folds replace the major fault. The throw of the fault is less to the southeast, and is distributed among several, minor, associated faults. These subsidiary faults

become a part of the main fault again 3 miles southeast of the southwest corner of Alexo map-area, from where a single major fault continues southeast with as great or greater throw than in Alexo map-area. Fault No. 5 appears to be the southeastern continuation of a major fault on the northeast side of Bighorn Range. The interval southwest from it to the first range of the Rocky Mountains is relatively free of faults and minor folds for a distance of several miles to the northwest and southeast (*See* Figure 1). It is, apparently, the first major thrust northeast of the faults associated with the first range.

MINOR THRUST FAULTS

Minor thrust faults are those with throws of from a few feet to a thousand feet. The most important, in terms of throw, is a subsidiary fault in Saunders map-area that branches from Fault No. 2 near its intersection with Rough Creek (*See* Maps 884A, 885A, and Figure 2). The fault trends northwest across part of Saunders map-area into Alexo map-area to within a mile of North Saskatchewan River. The trend of the fault is parallel with that of the structures southwest, but oblique to the trend of the structures northeast. The throw is not determinable, but is in the order of a thousand feet or less. To the northwest, Luscar rocks in the hanging-wall of the fault are thrust over Mountain Park rocks on the northeast, whereas to the southeast, Mountain Park rocks in the hanging-wall are in contact with younger Mountain Park and Blackstone beds in the foot-wall. The fault extends largely through a drift-covered area, so that its position as mapped is only approximate. It is known, however, that the fault dips southwest; that it is a thrust fault; that its maximum throw is near the central part of its length; and that it passes into minor folds to the northwest. The fault apparently joins the main thrust fault (Fault No. 2) to the southeast.

Another, minor, southwest-dipping thrust fault occurs in the southwest corner of Saunders map-area, where rocks of the Mountain Park formation on the southwest are in contact with those of the Blackstone on the northeast. Most of the fault, which is about 3 miles long, is exposed to the southeast in Fall Creek map-area (Henderson, 1945). Its throw is in the order of a thousand feet, but decreases rapidly to the southeast and northwest. The fault is replaced by folds in Fall Creek map-area, and, apparently, ends in the incompetent upper Mountain Park beds of Alexo map-area.

Numerous, small-throw, southwest-dipping, thrust faults are scattered throughout Alexo and Saunders map-areas. A few minor faults were observed in the interbedded sandstones and shales of Upper Cretaceous and Paleocene age in the northeastern part of Alexo map-area. These are generally in low to moderately dipping beds and are inclined more steeply than these beds. Although few minor faults were observed in exposures of the Upper Cretaceous or Paleocene rocks, the workings of the coal mines at Alexo and Saunders indicate that more are present. The number of faults, as well as their magnitudes, decreases southeast from Wawa Creek map-area into Alexo map-area with the broadening of the major folds.

Minor thrust faults are common west of Brazeau Range in Blackstone, Mountain Park, and Luscar formations. The faults are southwest-dipping, small-throw thrusts, and are commonly closely associated with drag-folds

and minor folds. Observed dips range from 44 to 60 degrees southwest, and are everywhere at steeper angles than the associated beds. The throw of the faults is generally indeterminable, but is believed small; throws as little as 2 feet were noted. The faults cut the strata in various relations to the folds: some cut across the southwest-dipping limbs, others across the axis of anticlinal drag-folds, and still others across the over-turned northeast limbs of the folds. In one place thrust faulting produced a drag syncline in the foot-wall beds. The strike of the minor thrust faults is parallel with that of the beds, and apparently the faults represent a late stage in the diastrophism that was responsible for the close folding of the beds. The incompetent nature of the shales and sandstones west of Brazeau Range has permitted the formation of small, compressed folds preceding rupture by the small thrust faults. This association of minor faulting with folding is in contrast with that in the Upper Cretaceous and Paleocene beds previously described.

Small-scale thrust faults are rare in the exposed Palæozoic rocks. Two such faults, dipping southwest and of less than 50 feet throw, occur on the southwestern limbs of an anticline southeast of Dizzy Creek. The surface rocks at the faults are interbedded shaly limestones and massive limestones of Upper Devonian age. The competent Upper Palæozoic rocks appear to have accommodated themselves to stresses by large-scale folds and faults rather than by minor deformations.

Southwest-dipping faults are predominant in the two map-areas, yet a few northeast-dipping thrusts are present. A small thrust fault, striking northwest, and dipping 33 degrees northeast, was observed in the coal mine at Alexo. The associated coal-bearing beds dip less than 10 degrees northeast. The throw of the fault is less than a foot. A few minor, northeast-dipping faults occur in Alexo map-area west of Brazeau Range. A steep, northeast-dipping fault, associated with drag-folds, appears in the coaly zone of the Luscar formation. In the southeastern part of Alexo map-area, low, east-dipping Blackstone beds are thrust relatively westward over steeply west-dipping and overturned Blackstone shales. Associated drag-folds are strongly developed on the west side. A northeast-dipping thrust fault of several feet throw transects massive Devonian limestones on the northeast limb of an anticline in upper Lundine Creek. The small-throw, northeast-dipping thrust faults were observed at widely spaced intervals, both geographically and stratigraphically. Their occurrence does not appear to follow any pattern, except that the throw is small.

NORMAL FAULTS

Normal or gravity faults are rare in Alexo and Saunders map-areas, and the few that do occur are of small displacement. A minor, northeast-dipping, strike fault of 5 to 6 feet throw disturbs the strata in the coal mine at Alexo. The fault is interesting in that, although it is normal, the attitude of the beds against the fault plane suggests that final stresses were compressional.

Normal faults or fractures of about 2-inch displacement occur in rocks of Paleocene age in Deep Creek, about 1,000 feet northeast of Fault No. 2. The faults are on the south limb of an asymmetrical, overturned, minor anticline. The faults trend about north 60 degrees west and dip about 70

degrees southwest, whereas the associated beds strike nearly east, and dip about 60 degrees south. As the anticline is closely compressed, these small-scale faults may represent fracture cleavage such as was observed at the crests of several anticlines in the area.

IMBRICATE STRUCTURE

A zone of slice-faulting, or imbricate structure, in Bighorn and Blackstone formations in the southwestern part of Alexo map-area extends diagonally across most of that part of the area. The faults are southwest-dipping, small-throw thrusts, repeating mainly lower Bighorn and upper Blackstone formations at the surface. These faults are not identifiable in the heavily bush-covered Brazeau map-area to the northwest, but continue southeast from Alexo map-area, across Cripple Creek map-area, and across the greater part of Fall Creek map-area.

As the Bighorn is divisible into three diagnostic members, small-throw faults that affect this formation are readily recognized in the field. They are reflected by numerous, small, poorly defined, subparallel ridges, formed mainly by the lower sandstone member. The transition zone from the warped, broad Bighorn area on the northeast, to the slice-faulted Bighorn on the southwest, occurs in the vicinity of Lynch Creek. There a gently folded anticline in Bighorn strata has its southwestern limb broken by a slice-fault. The dip of the fault plane is 40 degrees southwest, and the stratigraphic throw is about 50 feet. Beds of the southwestern limb dip 20 degrees southwest; the dip of the northeastern limb is more gentle. The formations farther southwest are predominantly southwest-dipping. A small thrust in this fault zone is exposed on Ram River, where upper Blackstone shales in the hanging-wall are in contact with lower Bighorn sandstones of the foot-wall. The stratigraphic throw of the fault is about 25 feet. A smaller thrust fault and an associated, asymmetrical drag-fold are present in the upper Blackstone beds less than 100 feet southwest of the fault. The drag-fold and subsidiary thrust fault do not deform the overlying Bighorn sandstone.

The average dip of one of the slice-faults, as derived from observations for a distance of several hundred feet along strike, is less than 30 degrees southwest. The dip of the beds in the adjacent Bighorn of the hanging-wall is 20 degrees southwest. The subparallel, zigzag trend of formation contacts and fault traces across an area of moderate relief indicates that both faults and beds dip at low angles. The dip of the slice-faults is not known to any great depth; the sudden steepening of the dip of beds in some places, in proximity to a fault, suggests that the faults may be steeper near the surface than at depth. No folding of the faults subsequent to faulting is demonstrated. Some of the slice-faults are of the hinge-type, with throws decreasing to the northwest, as shown in Bighorn rocks in the extreme southwest part of Alexo map-area.

The relation of the large thrust fault in the southwest corner of Alexo map-area (Fault No. 5, Figure 2) to this zone of imbricate structure is not clear. In Cripple Creek map-area several of the slice-faults trend into the major fault, but whether these are branch or subsidiary faults, or whether Fault No. 5 has overridden these slices is not known. Perhaps significantly, slice-faulting occurs mainly in Bighorn and contiguous strata; no slice-

faulting is apparent within 3 miles northwest or southeast along strike, where the plunge has exposed gentle and regularly dipping Wapiabi and Brazeau strata (MacKay, 1941a). The indications are that the imbricate structure of this zone is peculiar to Bighorn and immediately adjacent formations, and that it is not common to the overlying strata. The structure at depth is indicated by the totally different manner of deformation of Blackstone and older, weak formations a short distance northeast, in contrast with that of the Bighorn formation. Added to this indirect evidence is the observation, described above, of the non-deformation of Bighorn beds by a drag-fold in the contiguous Blackstone formation.

SUMMARY

Most faults in the map-areas are southwest-dipping strike thrusts. A few, small, normal faults and northeast-dipping thrusts are present. A major westward-dipping thrust fault lies several miles northeast of Saunders map-area, and represents the farthest east major break of the outer Foothills. Folded thrust faults, which originally dipped southwest, underlie parts of Alexo map-area.

The major fault (No. 2, Figure 2) traverses the map-areas diagonally in a northwesterly direction, and thrusts Lower Cretaceous and Upper Cretaceous strata from the southwest against Paleocene strata on the northeast. The stratigraphic throw of the fault ranges from about 7,500 feet on North Saskatchewan River to about 10,000 feet on Ram River. The exposed fault on Ram River dips about 45 degrees southwest, but the average dip for a mile below surface, as shown by drilling in the vicinity of Tawadina Creek, is 12 degrees southwest.

A southwest-dipping thrust fault of indeterminate throw is present in the extreme northeast part of Saunders map-area. The fault has elevated the coal-bearing beds of the hanging-wall side, and increased the dips.

A thrust fault lies at the northeastern base of Brazeau Range, north of North Saskatchewan River. The stratigraphic throw of the fault is approximately 4,000 feet in the northwestern part of Alexo map-area, but fades out south of North Saskatchewan River, where the fault is replaced by folds.

A thrust fault, with a throw of about 4,000 feet, cuts across the extreme southwestern corner of Alexo map-area, and thrusts Lower Cretaceous rocks into contact with those of Upper Cretaceous age. The northwestern extension of the fault, beyond the map-area, appears to be a major fault of Bighorn Range. It is the first major fault northeast of those associated with the first range of the Rocky Mountains.

Minor thrust faults occur in Blackstone, Mountain Park, and Luscar formations, chiefly in the southwestern part of the area. Small thrusts are commonly associated with drag-folds and minor folds. Observed dips of minor faults range between 44 and 60 degrees southwest. Faults everywhere dip more steeply than beds, though the angle between fault and bedding plane may be as little as 12 degrees.

Northeast-dipping thrust faults are uncommon, and have throws of less than 10 feet. Normal faults or fractures showing minor displacements were observed near the axis of a steep, minor anticline, and appear to represent fracture cleavage developed during folding.

Imbricate structure is prevalent in Blackstone, Bighorn, and Wapiabi beds in the southwestern part of Alexo map-area; the throws are generally less than 200 feet. The dip of a representative fault is 30 degrees southwest, or about 10 degrees greater than the dip of the truncated beds. The slice faulting is apparently peculiar to the Bighorn and immediately adjacent rocks, and is believed to end in the adjacent shales in the form of drag-folds.

The trend of all faults in the area is predominantly parallel with the trend of the folds. The main thrust fault (No. 2) is believed to have formed during a later stage of the same stresses that folded the beds in the hanging-wall. Near where the fault crosses Ram River the increasing intensity of the folds suggests that faulting occurred when the plastic limit of beds in the folds was exceeded. Faulting was thus later than folding in hanging-wall beds, but is believed contemporaneous with minor folding in the adjacent foot-wall strata. The relative age of faulting to folding above does not apply to folded thrust faults.

FOLDED THRUST FAULTS

GENERAL STATEMENT

The term 'folded fault' implies warping or folding of the fault plane or fault surface, following shearing. The term 'warped fault' may be synonymous with 'folded fault', except in degree of deformation. Stresses causing folded faults may be vertical, tangential, or a combination of both. Folded faults may show added complexity if modified by subsequent shearing, giving rise to faulted folded faults. This type of structure has been described by Keith (1907, pp. 8-9) in the Southern Appalachians of Tennessee-North Carolina; by Bailey Willis (1912, p. 4) in the Alps; and by Hake, Willis, and Addison (1942, pp. 319-20) in the Foothills of Alberta.

A recently published article on Foothills Structures (Link, 1949) includes a discussion of folded thrust faults in the Foothills of Alberta.

HISTORICAL SKETCH

The concept of folded faults is not new. A folded fault was produced experimentally and described by Cadell (1889, p. 346). He placed soft clay below brittle strata in a pressure box, and when pressure was applied, both plastic and brittle beds bowed and faulted. Limbs of the folds dipping away from the direction of source of pressure bowed forward toward verticality when additional pressure was applied; and the faults originally dipping toward the source of stress now dipped in the opposite direction as well. When the experiment was repeated with sand in lieu of the pressure block, folded faults were again obtained, and in addition the folded mass slid bodily forward on a low-angle sole-fault.

Folded faults were mapped by Hayes (1894) in the Southern Appalachians as early as 1892. Keith (1901) mapped folded faults in Maynardville area, Tennessee. He also shows four or five superincumbent, synclinally folded fault plates in Roan Mountain area of Tennessee and North Carolina (1907). Peach, Horn, Gunn, and others (1907, pp. 463-594), in their classic work on the North-West Highlands of Scotland, depict and describe

several large-throw, low-angle, warped or folded thrust faults. In the 1890s or later, Alpine geologists, chiefly Schardt (1893, pp. 707-09) and Lugeon (1901, pp. 723-822) evolved the modern nappe theory to explain the large foreign masses resting on younger sediments. Superimposed nappes occur in places, and the thrust fault plates of many of these have been folded by subsequent movements.

Several low-angle overthrusts, of large horizontal displacement, such as the Darby, Absaroka, Bannock, Lombard, and Lewis overthrusts, occur on the eastern side of the central and northern Rocky Mountains of Wyoming, Idaho, Montana, and southern Alberta. The fault surfaces have a general westward dip, but are warped in part, and may be classified as warped or gently folded thrusts.

Detailed studies of folded faults in Alberta are comparatively recent, although early geologists have denoted the existence of this type of structure. In 1886, McConnell (1887, p. 34) noted low-angle thrust faults in the eastern range of the Rocky Mountains, near the 51st parallel; he remarked that the undulation in the fault plane must indicate a period of disturbance subsequent to that in which the main faulting was produced. Bailey Willis (1902, pp. 332-33) and, later, Daly (1912, p. 89) noted the occurrence of secondary warps in the Lewis overthrust fault near the 49th parallel. In the same general area, Hume (1933, p. 9) described a fault plate of older Precambrian rocks resting on younger Precambrian formations and separated by a fault whose surface was folded subsequent to faulting. These folded faults are in the eastern Rocky Mountains.

Folded faults were recognized in the Foothills east of the Rocky Mountains by Hake, Willis, and Addison in 1929, and reported in 1934 at the annual meeting of the Cordilleran section of the Geological Society of America (1935, p. 324). A detailed publication of the discovery was made in 1942 (pp. 291-334). These authors mapped folded faults in Mesozoic strata within a belt 20 miles long by 5 miles wide, lying about 35 to 55 miles northwest of Alexo map-area. They describe a superimposed sequence of seven, and probably nine, faults, which are folded, both anticlinally and synclinally. They postulate the existence of an incompetent series above a competent series, within an asymmetrical syncline, where beds are subjected to compression parallel with the beds, combined with rotational stress. The faults were not believed to displace the Palæozoic rocks, but to be confined to the weak Upper Cretaceous sediments.

Sanderson (1939, pp. 429-42) published a report of the geology of Brazeau area, which overlapped the ground worked by Hake, Willis, and Addison. From 1939 to 1942, MacKay (1943a, 1943b) in mapping the series of map-areas extending from Pembina River, on the northwest, to beyond North Saskatchewan River, on the southeast, confirmed the southeastward extension of the belt of folded faults discovered by Hake, Willis, and Addison. The approximate dimensions of this belt are about 15 miles by 50 miles. The folded faults occur generally in Upper Cretaceous formations, and are especially well developed in the vicinity of Pembina, Cardinal, and Brazeau Rivers. The interpretation of the structure in this area is facilitated by the presence of the resistant and distinctive Bighorn formation lying between two thick series of marine shales. MacKay's maps show the folded faults mainly in Mesozoic formations, but the structural sections show the faults passing downward into Palæozoic rocks.

Hume (1941, pp. 87-92) described a folded fault in the Foothills of southern Alberta, at about the 50th parallel. The exposed extent of the fault plate is about 1½ by 2½ miles. Lower Cretaceous and Jurassic rocks have been thrust northeast over upper Lower Cretaceous rocks, and the fault plate was subsequently folded into an anticline and syncline. Hume believes that other folded faults occur in the western part of the same area, where Palæozoic rocks have been thrust over Cretaceous rocks. Hage (1942, pp. 67-78) described two folded faults in the inner Foothills of southern Alberta, in an area near that described by Hume. The faults bring rocks ranging in age from Upper Palæozoic to Lower Cretaceous into contact with rocks of Upper Cretaceous age. Folding and faulting of the outer Foothills were considered to have occurred prior to the thrust faulting of strata of the western part. Subsequent vertical uplift along the axis of the south-plunging anticlinal nose of Moose Mountain, folded the thrust faults, and produced some small normal faults.

Crombie (1944) mapped a synclinally folded fault plate in Alexo map-area, in the vicinity of Philip Creek, southwest of Brazeau Range, and commenced the mapping of a folded fault in the vicinity of Dizzy Creek, to the east of Brazeau Range. The mapping of the Dizzy Creek folded fault was completed by the writer in 1944, and is referred to in detail on the following pages. Henderson (1945) showed that the broad, synclinal Philip Creek fault plate in Alexo map-area, southwest of Brazeau Range, is recurrent along strike to the southeast in Fall Creek map-area. This folded fault was not recognized by the writer in Cripple Creek map-area, immediately south of Alexo area.

FOLDED FAULT OF PHILIP CREEK

The Philip Creek folded fault occurs in the vicinity of Philip Creek, southwest of Brazeau Range in Alexo map-area. The fault surface has been folded to much the same degree as have the beds of the associated syncline. Figure 4 is a large-scale map showing the folded fault and the associated shale. The fault has thrust lower Bighorn sandstone upon Wapiabi and Bighorn beds. The area enclosed by the fault at the surface is ½ mile wide by 2½ miles long, but was formerly much more extensive. Areally the folded fault lies between the low plateau area of gently folded Bighorn sandstone on the northeast and the area of imbricate fault structure in upper Blackstone, Bighorn, and lower Wapiabi beds on the southwest (*See* Map 884A). Traced northwestward along the synclinal axis, the Wapiabi and Bighorn strata underlying the fault give place progressively to beds of the Blackstone and Mountain Park formations. This is in part due to lower elevations in this direction, and in part to the regional southeasterly plunge of the synclinal structure. Blackstone shales underlie the valley of North Ram River southeast of the fault plate; and these are overlain by the Bighorn and Wapiabi formations at the south border of the map-area (*See* Map 884A). No other folded faults were observed along strike of the Philip Creek folded fault in Alexo map-area.

The position of the folded fault is closely delimited in the field by the distinctive horizons in the Bighorn formation, but the actual fault is not exposed. The strata in both foot-wall and hanging-wall of the fault dip moderately to steeply, as shown on Map 884A. The angle of the fault

plane with the bedding is small, as indicated by structure-section A-B, Figure 4. The stratigraphic throw of the fault on the northeastern limb of the syncline is about 600 feet, but is only about 300 feet on the southwestern limb. This marked decrease in throw in a distance of about half a mile southwest appears due to the smaller angle of incidence displayed by the overthrust rocks to the fault plane than by the rocks below the fault. A similar relation was observed in folded faults by Hake, Willis, and Addison, who explained the reduction of the angle of incidence by bedding-plane slippage.

Although only a small fault plate remains today, the folded fault formerly underlay a large area. The western part of the gently folded Bighorn rocks of the low-plateau area southwest of Brazeau Range represents a well-developed stage of erosion of the rocks below the fault. All evidence of the fault plane and overlying strata has been removed by erosion. The fault cuts progressively younger rocks to the northeast, so it formerly cut across the Bighorn rocks and entered the Wapiabi formation. However, faulting may have been replaced in the Wapiabi by drag-folding and crumpling. That the folded fault formerly extended over a larger area is indicated by the occurrence of two residual thin plates of Bighorn, about 10 and 14 miles southeast along strike in the Fall Creek map-area and a westerly dipping fault in the southeast part of Alexo map-area. These faults separate synclinally folded Bighorn strata above from younger Bighorn below (Henderson, 1945). The faults are not necessarily remnants of the formerly extensive Philip Creek folded fault plate, but the association of the same formations, the similar order of magnitude of throw, a similar type of synclinal folding, and the relative proximity of the Philip Creek and Tay River map-area folded faults, are all strong evidence for their correlation. The original southwestern extension of the Philip Creek folded fault may be traced for some distance. The first outcrop of Bighorn strata southwest of Fault No. 4 (Figure 2) must correspond with the Bighorn of the foot-wall of the Philip Creek folded fault (map and structure-section, Figure 4). This indicates that the fault is a very low-angle, or bedding-plane fault for a distance of more than a mile. Because of the small throw of this fault, which was shown to decrease toward the southwest, and because of the recognized inability of Blackstone shale to transmit thrusts, the southwestern extension of the folded fault is probably replaced by drag-folds in the incompetent Blackstone shale. Possibly the other small thrust faults southwest of Lynch Creek (Figure 4) formerly extended northeastward, and were synclinally folded with the Philip Creek fault in the manner of the several fault plates in the area of Brazeau, Cardinal, and Pembina Rivers, or similar, on a miniature scale, to the superposed several nappes of the Prealps of France and Switzerland (Hake, *et al.*, 1942; Bailey, 1935, pp. 57-89).

FOLDED FAULT OF DIZZY CREEK

General Remarks. The folded fault of Dizzy Creek was discovered when the writer was with Dr. Crombie late in the field season of 1943, and its mapping was completed by the writer in 1944.

The Dizzy Creek folded fault lies in Alexo map-area, on the northeastern side of Brazeau Range. It is exposed in three places: as a small window in Dizzy Creek Valley, about 1½ miles up creek from the mouth;

as a large, elongated window, southeast along strike from the small window; and as a narrow, elongated window about half a mile south of the small window (Map 884A and Figure 2). The three exposures of the folded fault, and sections across the fault, are shown in Figure 5. In the description to follow, the separate fault exposures are denoted 'Luscar window', 'Rundle window', and 'Banff window', respectively, named after the oldest formations appearing below the fault.

Luscar Window. The window of the folded fault exposed in Dizzy Creek is less than 300 feet across. There the gently, northwest-dipping sandstone and shale of the Luscar formation are surrounded by Rundle and Fernie limestones and cherty limestone. Erosion in the very bottom of the creek bed has proceeded only far enough to expose a small window of Luscar, the presence of which was the first indication of unusual or complicated structures in this part of the map-area. The dips of overthrust rocks surrounding the Luscar window are steep to overturned; Fernie rocks north of the window are strongly contorted. The axis of the folded fault lies a small distance northeast of, and is parallel with, the axis of an asymmetrical anticline. Thus, the crestal line of an anticlinally folded fault lies up the original dip of the fault from the axis of the associated anticline; whereas the crestal line of a synclinally folded fault lies down the original dip of the fault from the associated syncline. The Dizzy Creek folded fault illustrates the former type, and the Philip Creek folded fault illustrates the latter type.

The stratigraphic throw of the folded fault at the Luscar window is between 1,150 and 1,200 feet. The folded fault plunges northwest at a low angle, and does not reappear on the surface in this direction. It disappears to the southeast, despite its northwest plunge, because of the gentleness of the plunge and the relatively great relief, but reappears as the Rundle window about ⅔ mile southeast of Dizzy Creek, and extends to the southeast as an elongated window, more than 2 miles long.

Rundle Window. This is the largest of the three windows. Its existence is due to the uplift of the fault plate by anticlinal folding, followed by later erosion of the crestal area. Rocks ranging in age from those of Rundle to Luscar formations underlie the area enclosed by the trace of the folded fault. The overthrust rocks of the fault comprise strata of Rundle and Fernie formations. The southwestern limb of the associated anticline dips generally less than 30 degrees, both in the foot- and hanging-wall beds. The dips on the northeastern limb, within the window, are steeply northeast and the dips on the same limb, but northeast of the folded fault plane, also dip steeply to the northeast. The southwest-dipping plane of the fault is exposed in two or three places, where diagnostic horizons on both foot-wall and hanging-wall were recognized. At one place the southwest-dipping Cadomin conglomerate of the foot-wall is in contact with massive Rundle limestone of the hanging-wall. The beds in each formation dip about 30 degrees southwest. The Cadomin conglomerate is there strongly slickensided, closely sheared, and coloured brownish red with a coating of iron oxide. The northeast-dipping plane of the folded fault is not exposed, but the existence of the fault is indicated by the repetition of normal, northeasterly dipping Cadomin conglomerate across the strike on the northeastern limb of the fold, as shown in Figure 5 near the northeastern extremity of

structure-section G-H. Only a few of the outcrop data are given in the figure, but Map 884A includes all recorded rock attitudes. Although the actual fault trace was not observed in the field, excellent rock exposures fix its location within narrow limits. This mapping proved that the northeast-dipping fault shown in structure-section G-H (Figure 5) is the same as the southwest-dipping fault that is well exposed in a few places. The crestal line of the folded fault plane is presumably offset northeast from the axis of the associated anticline, but this could not be established in the field.

The throw of the fault apparently decreases gradually from the northwest to the southeast, as well as from the southwest to the northeast. The stratigraphic throw along the northeast-dipping part of the folded fault decreases from 800 feet near the northwest extremity of the fault plate to less than 600 feet at the southeast end. The stratigraphic throw along the southwest-dipping part of the same fault decreases from 1,150 feet in the northwest to about 900 feet in the southeast.

The folded fault is exposed as a complete window because the 'anticlinal fault surface' plunges both to the northwest and southeast from a culmination. The culmination of the folded fault surface coincides closely with the culmination of the associated anticline, whose culmination axis is shown in Figure 2. The extrapolated culmination of the 'anticlinal fault plane' is at an elevation of about 6,000 feet, and remains near this level for about a mile northwest, from where the folded fault plane plunges northwest at about 16 degrees. This degree of plunge is such that the fault surface is buried for more than half a mile, and reappears on Dizzy Creek as the small Luscar window. The altitude of the axis of the folded fault northwest of Lundine Creek, where it plunges southeast below the surface, is about 5,600 feet above sea-level. Because the fault surface remains below ground level in this direction, its rate of plunge must be at least 15 degrees southeast for a minimum distance of 3,000 feet.

Banff Window. A folded fault plate is again exposed about half a mile south of the Luscar window, where its trace has the form of an extenuated, asymmetrical hour-glass, extending for more than a mile southeast of Dizzy Creek. The fault has been brought to the surface by the first main anticline northeast of the Brazeau Range anticline (*See* Figure 2). The rocks below the fault on Dizzy Creek range from lower Rundle to Banff, whereas the southwest-dipping rocks of the overthrust mass are Upper Devonian, and the northeast-dipping rocks mainly Upper Devonian.

The Banff window affords the best exposure of the folded fault. Plate VI illustrates a critical part of this folded fault, looking northwest along strike. From the picture, the main anticline can be seen to be composed of beds in a normal stratigraphic sequence, from Rundle and Banff above to Upper Devonian strata below, the latter being more broadly folded because of their massive character. The truncation of the southwestern limb was first interpreted as a talus-covered slope, or a local lithological facies in the Devonian rocks. However, this interpretation was rendered untenable by the discovery of diagnostic Banff fossils in the thin-bedded limestone that directly underlies the white massive bed that crosses Dizzy Creek near the lower left-hand part of the picture. This massive bed forms a vertical gate across Dizzy Creek, and a short distance northwest of the creek forms an anticline that is truncated directly to the left or southwest

of the crest. The same massive bed of limestone, truncated high up on the southwestern limb of an anticline, was observed in the creek valley about a mile southeast of Dizzy Creek, but at a considerably higher altitude. Along it Upper Devonian strata in the hanging-wall are in contact with lower Rundle and upper Banff strata in the foot-wall, which are folded into an anticline that plunges northwest. The southwest-dipping fault is fairly well exposed in Dizzy Creek (Plate VI), but nowhere is a northeast-dipping fault observable. However, a careful examination in the field proved that neither the Rundle nor the Banff strata on the ridge west of Dizzy Creek are cut by any fault, and the most logical explanation is that the northeasterly continuation of the fault trace, as determined and delimited by good control exposures on Dizzy Creek, must form an anticlinal fold that is concealed in the small, rubble-covered gully directly north of the vertical, massive Rundle wall (*See* Plate VI).

The anticline associated with the folded fault is asymmetrical. In Dizzy Creek the beds of the southwest limb dip about 30 degrees. The beds of the northeast limb, in the foot-wall rocks, dip from 50 to 60 degrees north, whereas the overthrust rocks are vertical to overturned southwest. The axis of the anticline in the fault plane is presumably offset a short distance to the north of the axis of the anticline in the underlying and overlying strata, as indicated in Plate VI. The offsets cannot be demonstrated as the position of the axis of the folded fault surface is not known precisely.

The stratigraphic throw of the fault at the Banff window is about 1,350 feet. The average plunge of the folded fault surface, as well as of the associated anticline, is 12 degrees northwest for a distance of half a mile along strike. This plunge buries the fault surface, and it does not reappear to the northwest. The folded fault is exposed for more than a mile southeast of Dizzy Creek, where it plunges southeast below the surface. A southwest-dipping thrust fault appears on the overturned northeast limb of the anticline, less than a mile southeast from where the folded fault plunges below the surface. The stratigraphic throw of the thrust fault along structure-section G-H (Figure 5) is approximately 500 feet.

The original rupturing that resulted in the present fault of the Banff window apparently preceded folding (Structure-sections A-B and C-D, Figure 5). A more detailed description and interpretation is given in a later discussion of the folded faults.

Relation of the Separate Windows. The occurrence of several, superimposed folded faults, about 60 miles northwest of the Dizzy Creek area, shown by a series of structure-sections in the intervening belt mapped by MacKay (1941c and 1941d), necessitates a critical examination of the separate folded faults of Dizzy Creek to ascertain if these are component parts of one large folded fault, as has been assumed to this point of the discussion, or whether they are separate and superimposed. The evidence that the folded faults exposed at the Luscar and Rundle windows are parts of the same fault is summarized: (1) a similar order in magnitude of throws is indicated at the Luscar window and the northwest part of the Rundle window; (2) foot-wall and hanging-wall beds in the Luscar window and in the northwest part of the Rundle window closely coincide stratigraphically; (3) the two windows are along strike, and are associated with a common anticline (Figure 5); (4) the fault traces of the Luscar and

Rundle windows are separated by an interval of little more than half a mile; and (5) the plunge of all observed folds a short distance south of the Luscar window is northwest. The projection of the plunge between the Rundle window and the Luscar window is in harmony with the interpretation that the two windows are parts of a larger unit.

The evidence that the fault exposed in the Luscar-Rundle windows and that exposed in the Banff windows is the same folded fault is clearly demonstrable in the valley of Dizzy Creek:

(1) The typical thrust faults of the Foothills dip southwest, generally at steeper angles than the beds, so that the faults cut progressively older beds to the southwest. This principle is believed to hold also for the folded faults before folding. Applying the test in Dizzy Creek, Luscar beds in the foot-wall of the Luscar window are in contact with Rundle rocks in the hanging-wall, whereas in the Banff window Rundle and Banff rocks in the foot-wall are in contact with lower Banff and Upper Devonian rock in the hanging-wall. Thus, if the general principle functions here, then the faults of Luscar and Banff windows are parts of a larger, partly concealed, folded fault.

(2) Both faults are exposed near anticlinal axes, and concealed near synclinal axes, as would be expected were they component parts of the same larger folded fault.

(3) The similarity in magnitude of throw of the Luscar and Banff window faults strongly indicates a common relation to a larger fault.

(4) The throw of the fault in the Banff window is somewhat greater than the throw of the fault in the Luscar window. This increase in throw toward the southwest conforms with the direction of increase in throw of the Rundle window fault, and is to be expected if Luscar, Rundle, and Banff window faults are correlative.

(5) Structure-sections A-B and C-D, Figure 5, were constructed by extrapolating available surface information to depth. A stratigraphic throw of about 1,200 feet and a net displacement along the fault plane of about 3,500 feet were used to construct the faults to depth. These figures are the approximate average displacements of the faults in the separate windows. These give an angle of about 20 degrees between the dip of the fault and the dip of the beds. The sections show that except for minor irregularities the two distinct faults at the surface combine easily and logically into one extensive folded fault.

Extension of the Folded Fault. The northwest plunge buries the exposed, anticlinally folded fault or faults a short distance northwest of Dizzy Creek, and they do not reappear at the surface in that direction. Presumably, the folded fault continues northwest below the surface in the same strata that are thus deformed in Dizzy Creek Valley.

The folded fault or faults are believed to extend below the surface southwestward, in Dizzy Creek, for less than a mile. The lowest observed stratigraphic occurrence of the folded fault is in the Banff window on Dizzy Creek, where Devonian rocks, lying about 800 feet below the Banff-Devonian contact, are faulted against middle Banff rock. This horizon of the Devonian is near the upper limit of observed massive, competent Devonian rock. Minor highly compressed folds appear within half a

mile south of the Banff window, and these folds are believed to represent the change from faulting in the competent Devonian and younger rocks to folding in the incompetent Devonian shale below.

The fault plane of the Rundle window cannot be traced southeast from where it plunges below the surface. The throw of the fault decreases at a moderate rate from northwest to southeast, and if this decrease in throw continues the folded fault will fade out a few miles southeast of the last observed exposure. Possible folding of the fault plane is indicated for the large thrust fault (Fault No. 2, Figure 2) about 8 miles southeast of the Rundle window, where the fault contact between Upper Devonian in the hanging-wall and Paleocene of the foot-wall was encountered in Ram River No. 1 well at abnormally shallow depths.

The folded fault of the Banff window on Dizzy Creek persists for a mile southeast of Dizzy Creek, where it plunges below the surface. This fault has reacted very differently to stresses than has the Rundle window fault to the northeast, which plunges southeast from a culmination coincidently with the plunge of its associated anticline. The Banff window fault is replaced less than a mile southeast of its southeastern exposure by a well-developed thrust fault that transects the overturned northeastern limb of the Banff window anticline. The greatest throw of the thrust fault (500 feet) appears directly across from the southeastern part of the Rundle window and the southwest-dipping fault of this window is believed to extend through competent rocks on both hanging- and foot-walls, and to become part of the thrust fault as shown in sections E-F and G-H, Figure 5. The folded fault is not mapped as being offset by the thrust fault and continuing southwest in the hanging-wall beds of the thrust fault. A minor thrust fault was observed on the southwestern limb of the main anticline; this fault, unless it is a bedding-plane fault, is of too small a throw to represent the offset continuation to the southwest of the folded fault. Possibly the main thrust fault, with associated compressed folding, and minor thrusting on the hanging-wall side, has replaced the southwest limb of the Banff window folded fault. The rocks of the competent Upper Palæozoic in the vicinity of the Rundle window may have deformed first by faulting and then by folding, whereas the rocks of the incompetent Devonian in the vicinity of the thrust fault apparently reacted by folding first and faulting later. The mechanism of folding of fault planes in competent strata appears applicable in overthrust rocks ranging from those at least 1,000 feet below the top of the Devonian to lower beds of the Luscar formation. The equivalent rocks below the fault range respectively from Banff to upper Luscar formations.

The northeastern extension of the folded fault is neither known nor indicated in the figures. Normally, the fault should cut progressively younger beds in this direction, thus passing from the competent rock of the Upper Devonian into the incompetent sandstones and shales of the Luscar, Mountain Park, and Blackstone formations. If the folded fault continues to traverse beds to the northeast, and provided a large syncline is present, then the folded fault trace would reappear at the surface northeast of the Luscar and Rundle windows. However, several complications are evident: (1) no large syncline was observed through the beds of which the folded fault could again work its way to the surface; (2) the branch of the large thrust fault (Fault No. 2, Figure 2) lies less than half a mile

northeast of the folded fault, and should truncate the northeastern dipping folded fault at depth; (3) were the offset folded fault to continue northeast of the branch fault, it would be replaced by the numerous, minor, compressed folds in Blackstone shale, which make their appearance there; this replacement is all the more plausible because of the known decrease in throw of the folded fault toward the northeast.

Evolution of Dizzy Creek Folded Fault. The writer's conception of the evolution of the folded fault of Dizzy Creek area is as follows:

(1) In the first stage, the horizontal or homoclinal beds of Dizzy Creek area were deformed during an episode or cycle of the Laramide orogeny. The competent rocks, ranging in age from those of Upper Devonian to late Lower Cretaceous (Luscar), were under such confining pressures that they responded mainly by faulting. Possibly during this stage the older Devonian rocks southeast of the Banff window of Dizzy Creek, being less competent and, perhaps, under greater confining pressure, deformed chiefly by folding. The sandstones and shales of the Luscar, Mountain Park, and Blackstone formations northeast of the Dizzy Creek folded fault area, although under less static load, were sufficiently incompetent to react chiefly by folding.

(2) In the second stage, stresses in the competent rocks were relieved chiefly by folding. This may have been a logical outcome of tilting of the previously faulted blocks; or may have resulted from increased confining pressures due to piling up of hanging-wall beds on foot-wall beds. During this stage the incompetent Devonian rocks southeast of the Banff window on Dizzy Creek were either folded and then thrust-faulted, or, if they were folded during the first stage, were now thrust-faulted.

(3) Folding of the rocks southwest of Fault No. 2 (Figure 2) is believed to have occurred while, and after, the Dizzy Creek fault was being folded, and to have been replaced finally by the rupturing that produced Fault No. 2 and its branch fault. The significant part played by these faults was in elevating the mass in which the folded fault occurred, so that erosion could produce the present-day exposures.

SIGNIFICANCE OF FOLDED FAULTS

Folded faults have been recognized in increasing numbers in recent years, mainly in Mesozoic formations of the Foothills belt of Alberta. The Dizzy Creek folded fault, although of small extent, excellently illustrates moderate to steep folding of a fault, and involves both Mesozoic and Palæozoic rocks.

The Dizzy Creek folded fault was recognized because of the diagnostic lithology and fossil content of the strata involved. The writer believes that folded faults are more widespread in the Foothills than has been indicated, as they may occur below the surface in drift-covered parts; or the faults may occur within thick, featureless formations such as those of Upper Cretaceous or Paleocene age.

The occurrence of folded faults in Mesozoic and Palæozoic rocks of the Foothills belt of the Rocky Mountains is interesting in the light of possible oil structures. Folded faults may offer, theoretically at least, a new type of reservoir bed for oil—a catchment zone at or near the crest of anticlinally folded faults in fault gouge or breccia. But the main interest

in regard to folded faults and oil accumulation is the duplication of possible producing beds—analogous to the two superimposed anticlines in the Banff formation as illustrated in Plate VI. Porous strata of the Rundle or Upper Devonian could thus be repeated by folded faults. Erosion in the Dizzy Creek area fortuitously exposed anticlinally folded faults. Field mapping may not reveal folded faults below the surface, but seismic survey may indicate their presence.

SUMMARY OF CONCLUSIONS

Three folded faults are exposed in Dizzy Creek area and affect rocks ranging in age from Upper Devonian to Lower Cretaceous. The exposed, anticlinally folded fault surfaces are believed to join below the surface with synclinally folded parts to form one folded fault. The stratigraphic throw of this composite fault is about 1,350 feet in its northwestern exposure, and decreases to the northeast and southeast. Both north and south of its three exposures the fault appears to be dissipated by folding in incompetent beds.

The dips of the folded fault and contiguous beds are moderate to steep. The similarity of dips in the hanging- and foot-wall beds in many parts of Dizzy Creek area indicates that very little folding, if any, preceded the faulting. This feature would preclude the application of the strut fault to explain folded faults, as suggested by Bailey and Robin Willis (1934, p. 230).

The marked asymmetry of the anticlinal fault surface of Dizzy Creek is typical of the asymmetry of folded strata in the Foothills, and suggests that tangential stresses were dominant in folding the fault. As part explanation of folded faults northwest of Dizzy Creek area, Hake, Willis, and Addison (1942, p. 331) postulate compression parallel with the beds, combined with rotational stress. This contrasts with Hage's (1942, pp. 77-78) interpretation of folded faults in the southern Alberta foothills, where the postulated force, subsequent to thrust faulting, is thought to have been essentially one of vertical uplift.

The main factors upon which the folded fault of Dizzy Creek appears dependent are dominantly lateral stresses acting on competent rocks under appropriate confining pressures. Where incompetent beds are involved the relatively small throw of the fault may explain its apparent small lateral extent.

SUMMARY OF STRUCTURAL HISTORY

The exposed rocks of Alexo and Saunders map-areas are entirely sedimentary, and comprise an aggregate thickness of more than 13,000 feet of limestones and dolomites (mainly Palæozoic) and sandstones and shales (mainly Mesozoic). The oldest rocks exposed are of Middle (?) and Upper Devonian age and the youngest consolidated rocks were formed in early Tertiary time. Although minor intervals of erosion are apparent in the stratigraphic section, those of principal significance are represented by the Rundle-Fernie contact and by the great unconformity between the Pleistocene drift and the variety of older consolidated rocks below. The Rundle-Fernie contact marks a period of erosion, or of sedimentation and erosion, ranging from late Mississippian or early Pennsylvanian to Jurassic time. The apparent conformity of the contact, however, suggests that any

diastrophism during this interval was regional or epeirogenic in character. The strong angular unconformity between rocks of the Tertiary or earlier periods and those of Pleistocene age indicates that the Rocky Mountain or Laramide orogeny was active in post-Paskapoo (Paleocene) time, but did not involve the more recent Pleistocene deposits. The orogeny resulted in the production of the highly folded and faulted consolidated formations of the map-areas. Close folds in the brittle sandstones of Paleocene age suggest that the exposed surface of today lay beneath at least a few thousand feet of younger Tertiary sediments at the time of the Laramide orogeny, sediments that were eroded prior to the deposition of glacial drifts.

Field data on the types and attitudes of folds and joints supplement and combine harmoniously with the stratigraphic data in explanation of present regional structures. The northwesterly trend of folds and faults indicates a maximum shortening in a northeasterly direction. The intensity of the deformative stresses has been shown to be gradationally greater toward the southwest, thus indicating that the stresses acted from that direction. The parallel, plunging, continuous folds in the area are similar to those obtained by Mead (1920, pp. 522-523) in experiments involving either non-rotational or rotational stress in the plane of the surface. Most of the faults in the Alexo and Saunders map-areas are strike thrusts, dipping southwest at angles generally less than 45 degrees. Thus, it may be assumed that horizontal compressive stresses operated in vertical planes perpendicular to the trend of the structures, and that these stresses developed rotational strains that lowered the angles of shearing from the theoretical 45 degrees to as little as 12 degrees or less (as noted in the field).

The development of typical asymmetrical folds with southwest-dipping axial planes could have resulted from the same type of stresses. Furthermore, the attitudes of the folded faults in the area may be reconciled with such stresses in conjunction with special conditions of rock competency and load, as demonstrated experimentally by Cadell (1889, pp. 337-357).

The joints in the rocks of Alexo and Saunders map-areas constitute two sets, each set approximately perpendicular to the bedding planes. One set (the strike set) trends parallel with the general strike of the structures, and the other set (the dip set) lies at right angles to the trend of the general structure. The strike set may have been formed by tension parallel with the trend of the folds and perpendicular to the bedding when the rocks were subjected to deformation. The dip set may have developed by tension in the rocks when they were deformed into an arcuate pattern (areally) or as a result of tension across the axes of folds where these fold axes assumed plunges in one or both directions.

Thus the stratigraphic succession and the data from folds, faults, and joints in Alexo and Saunders map-areas indicate two main periods of structural activity that affected the immediate area as well as the general Foothills belt for perhaps hundreds of miles along strike. The older diastrophism was epeirogenic in character and resulted in the hiatus between early mid-Carboniferous and Jurassic times. The younger (and major) diastrophism appears to have acted from the southwest through horizontal compressional stresses. It ended in post-Paskapoo (Paleocene) pre-Pleistocene time, and resulted in the complexity of structures that are present in the Foothills belt of the Rocky Mountains of west-central Alberta.

CHAPTER IV

ECONOMIC GEOLOGY

OIL AND GAS

Porous zones are known to be present in the Upper Palæozoic rocks of the map-areas. The Upper Devonian rocks of Alexo map-area (Crombie, 1944, p. 4) include more than 400 feet of dense to porous, saccharoidal dolomite. The upper part of this zone was drilled in Ram River No. 1 well in Saunders map-area. The porous section, where observed in surface exposures and cored samples, shows no indications of oil.

Surface exposures of Rundle rocks in both Alexo and Saunders map-areas include porous limestones and dolomites both in the lower and upper massive members of the formation. On lower Ram River and on Tawadina Creek the lower member consists in part of a coarse, granular limestone, some interstices of which are filled with a dry, black residue of hydrocarbons. Pores, vugs, fractures, and shell cavities are common within the upper 200 feet of the upper massive member of the Rundle in parts of Alexo, Saunders, and Wawa Creek map-areas, and a dry, black residue occurs in these voids in many places. In parts of Alexo map-area a few feet of limestone at the top of the Rundle is black as a result of permeation by such material. Rocks at the Rundle-Fernie contact may exude a petroliferous odour on percussion.

Samples of the dry, black residue of hydrocarbons found in cavities about 200 feet below the top of the Rundle formation were submitted to the Division of Fuels, Bureau of Mines, Ottawa, for analysis. Sample No. 1 weighed about 9 grammes, and sample No. 2 more than 200 grammes. Results of the analyses are as follows:

—	Sample No. 1	Sample No. 2 (as received)
	Per cent	Per cent
Moisture	0·9	1·8
Ash	23·9	9·8
Volatile matter	23·3	20·0
Fixed carbon	51·9	68·4
Carbon	.....	72·9
Hydrogen	.....	3·6
Sulphur	6·6	7·8
Nitrogen	.....	0·7
Oxygen	.....	5·2
B.T.U./lb., gross	9,050	12,090

The report accompanying the analysis of sample No. 1 states that the low B.T.U. value precludes classification of the material as bitumen. When heated in a test tube, only a light deposit of oil or tar formed on the walls of the tube. No smell of oil or tar was noticed, and the residue

was not coherent, as would be expected with a bituminous material. The material did not yield any extractable oil as a result of treatment with solvents.

The material is black, brittle, and amorphous, coaly in appearance, of dull to bright lustre, and exhibits conchoidal fracture. A previous liquid phase for the dry, black residue of hydrocarbons is indicated from the following: (1) its dissemination in fine pores; (2) its presence in re-entrant angles of calcite that line vugs and fractures; (3) the presence of small bubbles on some fractured surfaces of the residue; and (4) its mode of filling whorls of gastropods.

Double-ended quartz crystals occur in the cavities that contain the residue, and some crystals enclose black specks that may be the dry residue of hydrocarbons trapped in the process of crystal growth.

It is not known when the liquid hydrocarbon was introduced nor when it thickened and hardened to its present consistency. The Rundle rocks were exposed to erosion before the Fernie sediments were laid down; diastrophism during the Laramide revolution resulted in folding, fracturing, and faulting of the rocks; later erosion of the uplifted rocks has exposed the Palæozoic formations. Although no dry residue was noted within rocks of the Fernie formation, nevertheless, the concentration of the bituminous material in the rocks at the Rundle-Fernie contact indicates a liquid phase for the residue in post-Fernie time. The occurrence of the residue in veinlets and fractures within the upper Rundle further suggests that a liquid condition obtained during or after the Laramide orogeny. Euhedral quartz crystals line many residue-filled vugs in the Rundle rocks. The presence of black specks of apparently dry residue within some of the clear quartz crystals may indicate that the more volatile constituents of the hydrocarbon matter escaped before the Rundle rocks were exposed to post-Laramide surface weathering. But the presence of dry, black hydrocarbon at depth in both Rundle and Devonian rocks, as shown by wells drilled in nearby areas, indicates that surface weathering is not a requisite in the loss of volatile constituents from an apparently previous liquid material.

Ram River No. 1 well, in SW. ¼ sec. 26, tp. 38, rge. 12, W. 5th mer., is the only exploratory well drilled within the map-areas. Thirteen other wells have been drilled to the northwest and southeast, within 25 miles of some part of the map-areas. The locations of some of them are shown in Figure 1. Because data from surrounding wells are pertinent toward a better understanding of subsurface conditions within the map-areas, an abridged history of the wells is included. Most of the information is from the Petroleum and Natural Gas Conservation Board of Alberta. Imperial Oil Limited, Calgary, and the Shell Oil Company of Canada, Limited, Calgary, kindly permitted the writer the use of their data on Imperial Shell Stolberg No. 1 well. A tabulated list of the wells and their locations, from the northwest to southeast, is given in the following table.

Home Brazeau No. 1 well is in unsurveyed territory about 25 miles northwest from the northwest cornor of Alexo map-area, at an elevation of 4,454 feet. The well was started in December 1937, and abandoned in November 1940 at 8,728 feet. The summary log is as follows: surface rocks, Blackstone; "grit", 6,390 feet; Blackstone to Blairmore (Mountain Park), 6,400 feet; coal, 6,604, 7,070, 7,135 feet; brown limestone (lower Blairmore?), 7,545 feet; conglomerate (base of Blairmore?), 8,170-8,200 feet;

Fernie, 8,500? feet; fault to Blairmore(?), about 8,550 feet; carbonaceous shale (Luscar?), 8,670 feet. Gas at 6,645 feet lifted the tools. The section from 8,480 to 8,500 feet produced gas at the rate of 9,000 to 10,000 Mcf. a day, and some naphtha.

Name	Location				
	L.s.d	Sec.	Tp.	Rge.	Mer.
Home Brazeau No. 1.....about	16	7	43	17	W.5th
[1]Home Brazeau Syndicate No. 1.....about	5	17	43	17	W.5th
Arrow Brazeau No. 1.....	5	9	41	15	W.5th
Imperial Nordegg No. 1.....	12	13	40	16	W.5th
Brazeau Collieries No. 1.....	.....	.....	40	15	W.5th
Shunda Oils No. 1.....	15	36	40	15	W.5th
[1]Imperial Shell Stolberg No. 1.....about	3	22	41	14	W.5th
Ram River No. 1.....about	6	26	38	12	W.5th
Ram River No. 2.....	8	2	37	11	W.5th
Ram River No. 3.....	12	1	37	11	W.5th
Clear Oils No. 1.....about	8	2	35	10	W.5th
Ram River No. 4.....about	9	36	34	10	W.5th
Altoba and Canyon No. 1.....about	5	31	34	9	W.5th

Home Brazeau Syndicate No. 1 well is located about ½ mile northeast from Home Brazeau No. 1 well, at an elevation of 4,475 feet. The well was started in March 1945, and completed in February 1946 at 11,689 feet. The summary log is as follows: Bighorn to Blackstone, about 150 feet; Jumpingpound equivalent 4,960 feet; "grit", 5,210 feet; Blackstone to Mountain Park, 5,220 feet; fault, Mountain Park to Blackstone, 5,440 feet; "Jumpingpound equivalent", 6,860 feet; "grit", 7,040 feet; fault in Blackstone, 7,070 feet; "grit", 7,310 feet; Blackstone to Mountain Park, 7,330 feet; Mountain Park to Luscar, 7,560 feet; Luscar to Cadomin, 8,850 feet; Cadomin to Nikanassin, 8,967 feet; Nikanassin to Fernie, 9,070 feet; Fernie to Rundle, 9,498 feet; fault, Rundle to Fernie, 9,595 feet; Fernie to Cadomin, 9,680 feet; Cadomin to Luscar, 9,690 feet; Cadomin repeated, 10,763 feet; Nikanassin, 10,880 feet; Fernie, 10,980 feet ('Brown sand'); Rundle, 11,351 feet; fault to Luscar, 11,595 feet. Drill stem tests of the first Rundle sheet from 9,524 to 9,682 feet resulted in strong gas flows to the surface in 5 and 6 minutes, and the recovery of 1,068 feet and 2,170 feet of gassified fluid. Gas flow was estimated at 500 to 1,000 Mcf. a day. The well was tested on separator after two acidization treatments totalling 4,000 gallons, applied to the Rundle above 9,654 feet. Tests during approximately a month gave a maximum of 7,500 Mcf. and a minimum of 4,730 Mcf. a day. The maximum amount of oil obtained was 3½ barrels a day, with 3 barrels of water. The oil was clear and of about 50 degrees A.P.I. gravity.

Arrow Brazeau No. 1 well lies in the southern part of Wawa Creek map-area, about 5 miles west of the northwest corner of Alexo map-area. Structurally, it is located about ¾ mile southwest from the axial trace of Brazeau Range anticline. The well was started in May 1945 and suspended drilling in September 1946 at 2,265 feet. The summary log is as follows:

[1] Locations based on surface and seismograph surveys. The other wells are believed to be located on the basis of surface structures.

surface rocks, Banff; Banff and Exshaw to Devonian limestone, 280 feet (writer's interpretation); siltstone and silty lime, 1,065 to 1,185 feet; 'Blackface Mountain shale', 2,095 feet. Porous dolomite occurs in the upper part of the Devonian, and saccharoidal, brown dolomite, showing good intercrystalline and vug porosity is common from about 700 feet down to the top of the silt zone at 1,065 feet. The section is comparable to the massive, saccharoidal dolomite that overlies the thin bed of sandstone in the upper 600 feet of the Devonian in Alexo map-area. Some of the limestone and dolomite also show some porosity between depths of 1,200 and 1,345 feet.

Imperial Nordegg No. 1 well is located in Brazeau map-area, about 7 miles west of Alexo map-area. The ground elevation is 4,434 feet. The well was started in July 1943, and completed in October 1943 at a depth of 2,803 feet. The well started and finished in the Luscar formation and was abandoned.

Brazeau Collieries in tp. 40, rge. 15, W. 5th mer., is reported in the Summary Report of the Geological Survey of Canada for 1916 as two diamond-drill test holes, one of which was drilled to 1,200 feet. Apparently more than 1,000 feet of Blairmore group was cored.

Shunda Oils No. 1 is located in Brazeau map-area, about 1 mile west from the northwest corner of Alexo map-area. Its elevation is 4,341 feet. The well was started in June 1944, completed in May 1947 at a depth of 2,429 feet, and abandoned in January 1948. The location is less than ½ mile southwest from the surface axial trace of Brazeau Range anticline. The summary log is as follows: surface rocks, Devonian; 'Blackface Mountain shale', 960 feet; Minnewanka (Devonian) to Ghost River (Cambrian?), 1,615 feet; fault to Blairmore or younger beds, 2,415 feet. Traces of porosity and oil staining were observed in brown to buff dolomite from 100 to 150 feet. A slight oil stain was noted in limestone at depths of 1,100 and 1,180 feet, and both limestone and dolomite show some porosity at depths of 1,290, 1,420, 1,505, and 1,565 feet.

The Imperial Shell Stolberg No. 1 well, in l.s.d. 3, sec. 22, tp. 41, rge. 14, W. 5th mer., about 4 miles northwest of the north margin of Alexo map-area, was drilled at or near the crest of the Stolberg anticline. The elevation is about 4,650 feet. The well commenced drilling in March 1945, and completed drilling in August 1946 at 13,747 feet. It was abandoned in October 1946 after testing. The well commenced in rocks of the Brazeau formation and was completed in Banff strata. The summary log is as follows: Brazeau to Wapiabi, 4,020 feet; fault, Wapiabi to Brazeau, 4,630 feet; Brazeau to Wapiabi, 4,850 feet; Wapiabi to Bighorn, 6,690 feet; Bighorn to Blackstone, 7,240 feet; "grit", 9,580 feet; Blackstone to Mountain Park, 9,640 feet; Mountain Park to Luscar, 10,160 feet; Luscar to Cadomin, 11,635 feet; Cadomin to Nikanassin, 11,645 feet; Nikanassin to Fernie (top of 'Brown sand'), 11,725 feet; Fernie to Rundle, 12,218 feet; fault, Rundle to Fernie, 12,475 feet; Fernie to Rundle, 12,826 feet; fault in Rundle, 13,094 feet; fault, Rundle to Fernie, 13,102 feet; Fernie to Rundle, 13,118 feet; and Rundle to Banff, 13,675 feet. The bottom of the hole at 13,747 feet is in dark grey, dense, silty dolomite of the Banff formation. The Rundle formation shows little or no porosity in the Stolberg well, but 'pyrobitumen' was found disseminated or streaked through the limestone in places. The section of sandstone from 9,750 to 9,800 feet in

the Mountain Park formation was placed on separator test and produced 2 to 9 barrels of 56 degrees A.P.I. oil, 2 barrels of water, and gas at the rate of 620 to 800 Mcf. a day. However, no oil or gas was produced in commercial quantities from any formation.

Ram River No. 1 well is in the southern part of Saunders map-area. The well is on the west limb and near the northwest-plunging nose of a closed anticline. Surface rocks are those of the lower Rundle. Drilling was commenced in October 1938 and the well was abandoned in July 1939 at a depth of 1,346 feet. The following is the writer's summarized log: Rundle to Banff, 170 feet; Banff to Exshaw, 912 feet; Exshaw to Minnewanka (Devonian), 918 feet; and fault, Minnewanka (saccharoidal dolomite) to Paleocene rocks, 1,235 feet. The large fault encountered at 1,235 feet is Fault No. 2 (*See* Figure 2). Porous, saccharoidal dolomite and limestone of Upper Devonian age are common from 1,050 to 1,235 feet. Dry residue of hydrocarbons occurs in limestone at 970 feet. Gas showings were reported at depths of 300, 368, and 417 feet, and a trace of oil at 1,285 feet.

Ram River No. 2 well is in Tay River map-area about 8 miles southeast of the southeast corner of Saunders map-area. Its elevation is 4,568 feet. It was drilled near the crest of an anticline that exposes Upper Devonian rocks. Drilling commenced in May 1940 and the depth in June 1942 was 4,340 feet. A summary log published by the Petroleum and Natural Gas Conservation Board of Alberta follows: 'Blackface Mountain shale', 1,811 feet; 'Blackface Mountain shale' to Ghost River, 4,130 feet; Ghost River to Cambro-Ordovician, 4,185 feet; and conglomerate, 4,190 feet. Porous, saccharoidal dolomite occurs from 20 to 220 feet. The well produced a little oil and gas during tests. Gas shows were reported at 4,170 feet, and oil shows at 3,011 to 3,019 feet, and 3,060 feet (in fractures). Oil and gas shows were encountered at 4,240 and 4,298 to 4,325 feet.

Ram River No. 3 well is located about ¼ mile northeast of Ram River No. 2 well, at an elevation of about 4,565 feet. Drilling commenced in March 1944 and the well was drilled to 5,745 feet, but due to crooked hole it was redrilled from 2,574 feet, and in December 1948 was standing at a depth of 5,753 feet. The well lies a short distance northeast of the surface crest of an anticline, and surface rocks are Devonian in age. 'Blackface Mountain shale' was reported at 2,689 feet, and Ghost River (?) at 4,890 feet. According to Henderson (Descriptive Notes, Map 840A), a porous, saccharoidal dolomite similar to that found in Ram River No. 2 well between depths of 20 and 220 feet is present in Ram River No. 3 well from 820 to 960 feet, and duplicated between 5,510 and 5,637 feet. Gas showings were reported at 814, 1,745, and 4,365 feet, and oil showings from 1,745 feet and possibly lower.

Clear Oils No. 1, Ram River No. 4, and Altoba and Canyon No. 1 wells are all located in the valley of Clearwater River, about 20 miles southeast of the southeast corner of Saunders map-area. Each of the wells started in the Banff formation and encountered comparable sections, although the Altoba well is the deepest and was the only one of the three to reach pre-Devonian beds. The Exshaw shale was encountered in this well from 259 to 262 feet, and the 'Blackface Mountain shale' top is at 2,066 feet. The writer's interpretation from core study places the top of the Ghost River (pre-Minnewanka) at 2,725 feet. The glauconitic and oolitic limestones

from 2,844 to 3,035 feet appear comparable to similar rocks in the upper part of the Upper Cambrian section of Cripple Creek map-area. Porous, saccharoidal dolomite, similar to the saccharoidal dolomite of Alexo map-area, is present from 472 to 932 feet. Anhydrite is present in the lower part. Porous dolomites were encountered from 1,196 to 1,216, 1,234 to 1,284, 2,435 to 2,452, and, in parts of the section of dolomite, from 2,517 to 2,647 feet. Gas flows were reported from the Altoba well at 1,196, 1,644 to 1,648, 1,723 to 1,725, 1,838, 1,938, 2,377, and 2,712 feet (700 Mcf.). Oil of 39 degrees A.P.I. was reported from a depth of 1,196 feet.

A study of surface outcrops in Alexo and Saunders map-areas, and of subsurface rocks in wells drilled both northwest and southeast of the map-areas, indicates the presence of porous rocks of Palæozoic age ranging through much of the Devonian and through parts of the Missisippian strata. Rocks of Lower Cretaceous age are also porous in part. Surface rocks in the map-areas afford ample evidence of porosity through a 400-foot zone of saccharoidal dolomite of Upper Devonian age. Both the lower and upper members of the Rundle formation show porosity and black residue of hydrocarbons in places. Subsurface information from neighbouring wells suggests that the thickest and most uniform porous rocks are the saccharoidal dolomites mentioned above. Dolomites below the 'Blackface Mountain shale' may also show good porosity. Oil and/or gas flows have been obtained from beds as old as those below the Ghost River (in Ram River No. 2 well) to those as young as Mountain Park (in Imperial Shell Stolberg No. 1 well) or younger. Therefore, because Alexo and Saunders map-areas are in the same inner Foothills belt as the wells studied above, and are underlain by comparable strata, it follows that the porous strata in Alexo and Saunders map-areas should provide reservoir beds for gas and oil under suitable conditions of depth of burial and structure.

A study of the structures in the map-areas and at depth near the map-areas, as interpreted from well information, makes it evident that unbroken surface anticlines may be thrust-faulted at depth so that possible oil structures may be difficult or impossible to delineate from surface mapping alone. Geophysical methods, probably reflection and refraction seismic surveys, appear to be a requisite for accurately locating structures at depth. The degree of magnitude of the anticlines should be sufficient in this area to permit satisfactory results from either reflection or refraction methods. The principal obstacle to geophysical work is the lack of roads and access within the map-areas.

The writer believes that the Rundle outlier on North Saskatchewan River on the west side of Alexo map-area (*See* Map 884A), and the Weaver anticline (*See* Figure 2), which exposes rocks as old as Mountain Park, offer the most attractive structures for oil exploration of rock of Palæozoic age. The Stolberg anticline in Saunders map-area is much broader and gentler on the surface near Ram River than at the Imperial Shell Stolberg No. 1 well, and should warrant further surface and seismic exploration.

The greater depths to possible producing horizons and the less accessibility to and within the Foothills belt will discourage oil exploration there so long as the Plains continue to produce increasing amounts of high quality oil from relatively shallow depths. That tendency may be in part offset by the presence of more pronounced structures in the Foothills belt, which should be delineated more readily by seismograph than on the Plains.

COAL

Production of coal in Alexo and Saunders map-areas is by Alexo Coal Company, Limited, at Alexo, and by Bighorn and Saunders Creek Collieries, Limited, at Saunders. Saunders Alberta Collieries, Limited, of West Saunders, about a mile west of Saunders, was abandoned in 1926, and the Jack Fish Lake Coal mine, northeast of Ancona, was abandoned in 1941. Abandoned adits or test pits in Alexo map-area occur on Taunton Creek and in a creek about 1½ miles northeast of Stolberg; in Saunders map-area they are to be found on Saunders Creek and on a southern tributary of Jackfish Lake, which lies north of the map-area.

The coal mines at Alexo and Saunders are situated about a mile east of the Stolberg anticline. The strata strike 30 to 45 degrees west of north and dip from 5 to 10 degrees northeast. The coal seam being mined is 4½ to 5 feet thick. Coal also occurs on the west limb of the Stolberg anticline, and on the east limb of the Ancona syncline. Dips are, in general, uniform and less than 25 degrees. Little evidence of faulting is present north of North Saskatchewan River, but faulting increases progressively toward the west.

Outcrops of Luscar coal occur wholly southwest of the main fault (Fault No. 2, Figure 2). In Alexo map-area, on the southwest flank of Brazeau Range, is a 10-foot seam that was exposed in places for at least 5 miles along strike. Smaller seams were observed in the folded rocks in Jock Creek Valley. Northeast of Brazeau Range, in Alexo map-area, the coal seams are faulted, and dips are steep to overturned. In Saunders map-area the Luscar coal dips at low to moderate angles. Outcrops of coal on Ram River are associated with, or occur near, thrust faults and small folds.

A tabulated list of coal outcrops 1 foot or more in thickness is given below for Alexo map-area northeast of Brazeau Range, and for all of Saunders map-area. One seam may be represented by several outcrops. Outcrops of Luscar coal are so indicated in the list, all others are of Paleocene age.

Location					Dip	Thickness
L.s.d.	Sec.	Tp.	Rge.		Degrees	Feet
Alexo map-area, north of North Saskatchewan River						
15	23	40	13	Taunton Creek	3–4 NE.	4·8 (upper seam) 4·0 (lower seam)
16	33	40	13	Creek northeast of Stolberg	10 NE.	1·0 (?)
1	4	41	13	Creek northeast of Stolberg	14 NE.	3·6
3	2	41	14	Upper Shunda Creek	SW.	Rubble
7	30	40	13	South tributary of Shunda	SW.	3+
6	15	40	13	Saskatchewan River above Shunda	9(?) SW.	1+
3	15	40	13	Saskatchewan River above Shunda	10 SW.	3+
4	15	40	13	Saskatchewan River above Shunda	15 SW.	2+
16	9	40	13	Saskatchewan River above Shunda	30 SW.	1
16	36	39	14	Saskatchewan River east of The Gap	Overturned	10 (?) (Luscar)

Location					Dip	Thickness
L.s.d.	Sec.	Tp.	Rge.		Degrees	Feet
				Alexo map-area, south of North Saskatchewan River		
3	15	40	13	Saskatchewan River above Shunda	8 SW.	
3	15	40	13	Creek south of Saskatchewan River	12 SW.	5·5
9	10	40	13	Creek south of Saskatchewan River	17 SW.	2·0+
12	33	39	13	Dizzy Creek	90	— (Luscar)
				Saunders map-area, north of North Saskatchewan River		
5	6	41	11	Tributary of Jackfish Lake	26 SW.	1·5
7	6	41	11	Tributary of Jackfish Lake	28 SW.	6·9 (includes parting)
16	31	40	11	Tributary of Jackfish Lake	31 SW.	3·0 (upper) 0·3 (middle) 1·6 (lower)
11	19	40	12	Saunders Creek	15 NE.	9·2 (?)
12	19	40	12	Saunders Creek	17 NE.	2·0
13(?)	19	40	12	Saunders Creek	7 NE.	2·6
13	17	40	12	Saskatchewan River below Slippery Creek	8 NE.	1·0 (upper) 1·0 (middle) 2·0 (lower)
				Saunders map-area, south of North Saskatchewan River		
15	18	40	12	Saskatchewan River below Saunders	—	Much rubble
11	32	39	12	Upper Trout Creek area	17 NE. (?)	2·0 (?)
16	30	39	12	Upper Trout Creek area	29 SW.	1·0 (?)
6	29	39	12	Upper Trout Creek area	18 SW.	1·0 (?)
8	18	38	11	Ram River, at fault	Steep	3·0 (?) (age unknown)
14	36	38	13	Upper Rough Creek	10 SW.	1·0 (?) (Luscar)
7	22	38	12	Upper Tawadina Creek	30 SW.	4·0 (Luscar)
8	22	38	12	Upper Tawadina Creek	17 SW.	1·0+ (Luscar)
14	8	38	11	Fall Creek	50 SW.	2·0 (?) (Luscar)
8	8	38	12	North Ram River	23 E.	2·0 (?) (Luscar)
8	7	38	12	North Ram River	13 SW.	12·6 (Luscar)
10	12	38	13	North Ram River	15 N.	12·3 (Luscar)
8	12	38	13	North Ram River	10 SW.	4·0+ (Luscar)
13	12	38	13	Tributary of North Ram River	?	4·0+ (Luscar)

An examination of the tabulated list of coal outcrops, in conjunction with the maps, indicates a large reserve of the younger coal north of North Saskatchewan River, on both limbs of the Ancona syncline. In general the dips are low, but partings or impurities in some seams may deter exploitation. At least one seam of commercial thickness and low dip occurs on the west limb of the Stolberg anticline. It outcrops on both sides of North Saskatchewan River, and on the north side underlies a 40-foot cliff of massive, gritty sandstone. Minor faults were observed in the vicinity of the coal outcrops.

Lower Cretaceous (Luscar) coal that outcrops in the Alexo map-area, east of Brazeau Range, is not favourable for exploitation due to steep dips, associated faulting, and relative inaccessibility. Commercial thicknesses of Luscar coal are exposed in Saunders map-area, especially on North Ram

River. One seam exposed on North Ram River is more than 10 feet thick and has a 15-foot roof of shaly sandstone overlain by 40 feet of massive sandstone. Until the more readily accessible younger coal deposits north of North Saskatchewan River are depleted the Luscar coal will remain as reserve. The rank of this coal is believed to conform with that mined at Nordegg, which, according to American Society of Testing Materials rank (D388-38) is Bituminous-Low volatile (Bureau of Mines, Coal Mines in Canada, 1945, p. 9).

The classification of the younger coal, which is mined at Alexo and Saunders, is Bituminous-High volatile C (ibid., p. 9). The typical analysis of coal from the Saunders area[1] is given below (Stansfield and Lang, 1944, p. 159):

	Per cent
Moisture	9·7
Ash	6·8
Volatile matter	33·2
Fixed carbon	50·3
Sulphur	0·4
B.T.U. per lb., gross	11,550
Fuel ratio (FC/VM)	1·50

The following are the analyses of coal samples of Paleocene age from two localities, collected by the writer, as reported on by the Bureau of Mines, Division of Fuels, Ottawa. Locality No. 1 (l.s.d. 3, sec. 15, tp. 40, rge. 13) is in Alexo map-area, south of North Saskatchewan River, on the first creek above the mouth of Shunda Creek. The sample was taken across the cleaned surface of a seam that measures 5·8 feet at point of sampling. Locality No. 2 (l.s.d. 7, sec. 6, tp. 41, rge. 11) is in Saunders map-area, 2,500 feet up creek (west) from Jack Fish Lake Coal Mine buildings. The sample was taken across the cleaned face of the upper 4·4 feet of a coal outcrop whose section at the point of sampling is: 4·4 feet coal, 0·8 feet mudstone, and 1·7 feet coal.

Analyses of Coal Samples from Outcrops in Creeks

	Locality No. 1		Locality No. 2	
	As received	Dry	As received	Dry
	Per cent	Per cent	Per cent	Per cent
Moisture	15·1		23·1	
Ash	8·0	9·4	6·6	8·5
Volatile matter	30·0	35·4	27·8	36·2
Fixed carbon	46·9	55·2	42·5	55·3
Sulphur	0·4	0·5	0·4	0·5
B.T.U. per lb., gross	9,870	11,640	8,430	10,960
Caking properties	Non-agglomerating		Non-agglomerating	

Analyses of coal samples from fresh faces in mines should not be expected to agree with analyses of coal exposed in outcrops, as it is not practicable to collect field samples below the zone of weathering.

[1] Saunders area here refers to one of the coal districts into which Alberta has been divided by the Research Council of Alberta.

The following estimates of coal reserves for Alexo and Saunders map-areas assume:

(a) 100 per cent recovery
(b) coal seams 3 feet or more in thickness
(c) coal seams within 2,000 feet of the surface
(d) dip of coal seams less than 35 degrees
(e) areas of intense folding and faulting not considered
(f) conversion factor from cubic feet to tons, 0·043 for coal of Luscar age; and 0·042 for coal of Paleocene age

Table Showing Estimated Coal Reserves for Alexo and Saunders Map-areas

	Coal of Luscar age	Coal of Paleocene age	Total
	Tons	Tons	Tons
Alexo map-area	65,000,000	76,000,000	141,000,000
Saunders map-area	45,000,000	110,000,000	155,000,000
Total	110,000,000	186,000,000	296,000,000

The combined production of coal from Alexo and Saunders in 1945 was 59,926 tons[1].

[1] Crawford, John: Chief Inspector of Mines, Edmonton, Alberta, November 30, 1946 (personal communication).

APPENDIX

PALÆONTOLOGY

GENERAL STATEMENT

The collections of fossil fauna and flora made during the field seasons of 1943 and 1944 were submitted for identification to the Palæontological Division of the Geological Survey of Canada, Ottawa, and in the case of Cenozoic invertebrate fauna were transmitted to Dr. L. S. Russell of the University of Toronto. Fossil names as determined have been classified by the writer, and are shown in the following tabulated lists together with the locality numbers of the Geological Survey.

	Collection numbers												
	11204	11211	11208	11212	11205	11203	11279	11271	11277	11206	11192	11201	11207
	increasing age →												
ANTHOZOA													
Cyathophyllum-like coral	×												
Diphyphyllum-like coral	×												
Synaptophyllum sp.								×					
BRACHIOPODA													
Athyris sp. B shape like *A. angelecoides* Merriam but having fine spines		×		×									
Atrypa reticularis var. A	×	×		×	×	×				×			
A. spinoza Hall var.									×				
A. n.sp.	×												
A. n.sp. cf. *A. missouriensis* Miller	×	×		×	×	×	×	×	×				
Camarotoechia sp. A						×							
C. sp. B						×							
C. sp. C			×										
Hypothyridina ? n.sp.								×					
Leiorhynchus n.sp. A		×		×		×		×					
L. n.sp. A var.				×		×							
Linguloid—pustulose												×	
Martinia n.sp.		×		×	×	×							
Pugnax sp.						×							
Spirifer jasperensis Warren													×
PELECYPODA													
Paracyclas n.sp. cf. *P. elliptica* Hall, wide form								×					
GASTROPODA													
Murchisonia sp.						×							×
Gastropods (minute) undtd.											×		
CEPHALOPODA													
Manticoceras cordiforme Miller									×				
PISCES													
Fish spines ?													×

UPPER DEVONIAN

(All collections within upper 200 feet of Devonian section)

	Collection numbers																		
	11273	11193	11195	11275	11200	11276	11198	12343	11216	11214	11199	11213	11194	11190	11197	11218	11215	11223	11220
Bryozoa																			
Bryozoa, small branching, undtd.														×					
Brachiopoda																			
Athyris parvula Whiteaves															×				
A. sp. A						×													×
A. sp. B shape like *A. angelecoides* Merriam but with fine spines			×	×		×	×	×	×	×		×	×	×	×	×	×	×	×
A. sp. C																			×
A. sp. D (young?)												×							
Camarotoechia nordeggi Kindle	×			×		×													
C. cf. *nordeggi* Kindle					×					×		×	×		×	×			
C. cf. *banffensis* Warren					×														
C. sp. D							×												
C. sp.—poor																		×	
Cyrtia standleyensis Shimer						×													
Cyrtina n.sp.										×									
Leiorhynchus cascadensis Warren		×								×									
L. n.sp. B				×						×									×
Platyrachella sp.				×															
Productella coloradensis Kindle				×														×	
P. sp. cf. *P. girtyi* Shimer						×													
P. sp. cf. *P. spinulicostata* Hall			×				×			×	×	×	×						
P. sp. A		×					×												
P. sp. B															×				
P. sp.—poor						×										×			
Rhipidomella sp.																			×
Schizophoria iowensis (Hall)					location uncertain														

UPPER DEVONIAN—*con.*

(All collections within upper 200 feet of Devonian section)—*con.*

	Collection numbers																		
	11273	11193	11195	11275	11200	11276	11198	12343	11216	11214	11199	11213	11194	11190	11197	11218	11215	11223	11220
BRACHIOPODA—*conc.*																			
S. striatula Sch.		×				×		×											
S. cf. *striatula* Sch.							×					×		×	×	×		×	×
S. striatula cf. *australis* Kindle									×	×			×						
S. sp. A (young?)	×		×	×			×	×	×	×					×	×	×	×	×
S. sp. B			×													×			
S. sp. C close to *S. iowensis* (Hall)																			×
Schuchertella sp. close to *S. girtyi* Shimer							×	×		×			×						
S. sp.—poor														×				×	
Spirifer whitneyi Hall (*Cyrtospirifer whitneyi* (Hall))				×		×			×	×	×					×			
S. cf. *whitneyi* Hall (young? and poor)			×				×					×							
S. whitneyi var.			×					×	×	×			×		×	×		×	×
S. whitneyi cf. *monticola* Haynes												×	×	×		×	×	×	
S. whitneyi animasensis Girty									×										
S. whitneyi cf. *animasensis* Girty			×									×							
S. cf. *argentarius* Meek																		×	
S. cf. *hungerfordi* Hall																	×		
S. sp. close to *S. hungerfordi* Hall										×		×						×	
S. sp. close to *S. raymondi*										×									
S. sp. close to *S. utahensis*																		×	
S. sp. A													×						
S. sp. B														×					
S. sp. C			×																
S. sp. D (minute)																		×	
S. sp.						×				×									

PELECYPODA																			
Aviculopecten sp.						×													
? *A.* sp.																			×
cf. *Macrodon* sp.																			×
Pectenid pelecypod																		×	
GASTROPODA																			
Diaphorostoma sp.										×									
Euomphalus cf. *inops* Hall										×									×
E. sp. A				×			×					×			?				
Loxonema sp.							×												
cf. *Mourlonia* sp.				×															
Straparollus sp.							×												
CEPHALOPODA																			
? *Agoniatites* sp.																		×	
Michelinoceras ? sp. A			×															×	
M.? sp. cf. *M.*? *accelerans* Raymond																		×	
cf. *Offleyoceras* sp.			×																
cf. *Orinoceras* sp.																			×
Orthoceras sp.																			×
Orthoceratids unidentifiable			×							×				×					

MISSISSIPPIAN (Banff formation)

	Collection numbers																
	16282	16283	16284	16285	16286	16287	16288	16290	16291	16292	15389	15390	15391	15392	15394	15395	15396
ANTHOZOA																	
Lophophyllum profundum (E. and H.)			×				×										
cf. *L. profundum* (E. and H.)									×								
Syringopora aculeata Girty							×										
S. pennsylvanica Shimer			×														
S. surcularia Girty			×										×				×
Cup corals—undtd.					×		×		×								
BLASTOIDEA																	
Pentremites cf. *conoideus* Hall											×						
CRINOIDEA																	
cf. *Platycrinus* sp.			×														
Crinoid plate sp. A								×									
Crinoid disks						×											
Crinoid undtd.			×														
BRYOZOA																	
Fenestella, sp. A and sp. B		×															
F. sp. undtd.						×						×					
Bryozoa undtd.			×					×						×			
BRACHIOPODA																	
Ambocoelia sp.								×									
Athyris sp. close to *A. lamellosa* (Leveille)						×											
Brachythyris sp. A						×											
B. sp. B						×									×		
Camarophorella cf. *missouriensis* (Winchell)	×																
Camarotoechia cf. *allani* Warren	×		×		×												
C. sp. A and sp. B			×		×	×								×		×	
Chonetes cf. *illinoisensis* Worthen			×														
C. sp. close to *C. illinoisensis* Worthen										×							

Cleiothyridina hirsuta (Hall)										×						
C. cf. *hirsuta* (Hall)								×								
C. lata Shimer			×	×	×	×								×	×	×
C. parvirostris Meek and Worthen	×															
C. sp. *A*	×															
C. sp.											×					
Composita athabaskensis Warren	×		×				×									
C. sp. cf. *C. athabaskensis* Warren														×		
C. humilis (Girty)			×						×							
C. cf. *subtilita* (Hall)			×													
C. sp. cf. *C. subtilita* (Hall)						×										
C. cf. *ozarkana* Mather						×										
C. sp					×											
Dielasma sp.	×		×													
Echinoconchus—poor			×				×									
Leptaena analoga (Phillips)			×													
Martinia sp.		×				×										
Moorefieldella sp. close to *M. parva* Warren			×													
cf. *Moorefieldella* sp.	×				×											
Productella cf. *pyxidata* Hall	×															
P. sp.			×													×
Productus arcuatus Hall					×		×	×						×		
P. arcuatus var.			×													
P. fernglenensis Weller			×													
P. minnewankensis Shimer									×							
P. sp. A										×						
P. sp. B			×				×									
P. sp. C			×													
Productid—new							×									
Reticularia pseudolineata (Hall)									×							
R. sp.			×						×							×
Rhipidomella cf. *pulchella* Herrick								×								
R. n.sp.						×										
Rhynchopora sp. A	×															
R. sp. B							×									
R. sp. C							×									
cf. *R. pustulosa* (White)								×								
R. sp.					×											
Schizophoria—fragment										×						
S. sp.—poor			×													

MISSISSIPPIAN (Banff formation)—*conc.*

	Collection numbers																
	16282	16283	16284	16285	16286	16287	16288	16290	16291	16292	15389	15390	15391	15392	15394	15395	15396
BRACHIOPODA—*conc.*																	
Spirifer albapinensis Hall and Whitfield			×	×					×								
S. cf. *albertensis* Warren																×	
S. cascadensis Warren									×								
S. cf. *cascadensis* Warren			×														
S. cf. *centronatus* Winchell			×														
S. rutherfordi Warren					×						×						
S. sp. cf. *S. centronatus* but finer striæ			×													×	
S. sp. close to *S. marionensis* Shumard				×					×								
S. n.sp. aff. *S. subrotundus* Weller			×		×	×											
S. sp. A				×		×								×	×		×
S. sp. B															×		
S. sp. C			×														
S. sp.											×						
Spiriferina sp.								×			×						
? *S.* sp.—poor						×								×			
Squamularia depressiplicata Shimer		×	×		×												
Spirorbus sp.			×														
cf. *Strophalosia*						×											
GASTROPODA																	
Bellerophon sp.			×														
Gastropod—undtd			×														
TRILOBITA																	
Proetus cf. *peroccidens* Hall and Whitfield						×											
P. sp. cf. *P. occidens* Hall and Whitfield			×														
P. sp. A.— pygidium		×															
PISCES																	
Fish plate			×														

MISSISSIPPIAN (Rundle formation)

	16293	11057
ANTHOZOA		
cf. *Diphyphyllum astraeiforme* Warren (has form but not structure)	×	
Neozaphrentis sp.		×
BRACHIOPODA		
Composita humilis Girty	×	
C. cf. *athabaskensis* Warren	×	
Productella cf. *concentrica* (Hall)	×	
P. sp. close to *P. pyxidata* Hall	×	
P. n.sp.	×	
Spirifer banffensis Warren	×	
S. cf. *centronatus* Winchell	×	
S. sp.	×	

JURASSIC AND LOWER CRETACEOUS

(Fernie group and Nikanassin and Luscar formations)

	Locality numbers																
	14303	14304	14305	14299	14279	14301	14302	14298	14284	14277	14297	14283	14275	14269	14278	14280	14272
	(Luscar)						(Nikanassin or Fernie)					(Fernie)					
	increasing age →																
BRACHIOPODS																	
Rhynchonella n.sp.														×			
PELECYPODA																	
Anomia ? sp.										×							
Arctica												×					
Echinotis sp.													×				
Lima n.sp. cf. *L. terquemi* Tate														×			
cf. *L. succinta* Schloth														×			
Modiolus									×								
Ostrea n.sp. cf. *O. bristovi* Etheridge														×			
O. sp.									×								
Oxytoma n.sp. ? cf. *O. cygnipes* Phillips and *longicostata* (Strickland)														×			
Pecten											×						
P. (*Camptonectes*)									×								
Pleuromya											×						
Sphaerium n.sp. (cf. *S. onestae?*)	×		×														
S.? sp.				×													
Tancredia ? sp.							×	×									
Trigonia (*costatae* group)											×						
T. (*Vaugonia*) n.sp.					×									×			
Unionids					×												
GASTROPODA																	
Campeloma sp.		×															
C. (or *Viviparus?*)		×				×											
C.? sp.	×																
Melania cf. *multorbis* Russell	×					×											
BELEMNOIDEA																	
Belemnoids, gen. and sp. not determined												×			×		×
PISCES																	
Fish? vertebræ, etc.																×	

UPPER CRETACEOUS

(Blackstone, Bighorn, and Wapiabi formations)

	Locality numbers																
	14288	14287	14267	?	14286	14285	14292	14291	14289	14290	?	14264	14266	14261	14262	14263	14265
	(Wapiabi)					(Bighorn)						(Blackstone)					
	increasing age →																
PELECYPODA																	
Anomia subquadrata ?			×														
A. cf. *subquadrata*	×																
Brachidontes multilinigera								×									
Cardium pauperculum						×											
Inoceramus capulus (corpulentus)							×				×					×	
I. labiatus												×	×	×	×		
I. leylandensis									×								
I. leylandensis var. *bighornensis*									×								
I. sp.										×							
Oxytoma nebrascensis ?		×															
Pholadomya				×													
GASTROPODA—a gastropod			×														
CEPHALOPODA																	
Baculites cf. *aquilaensis* Reeside		×															
B. cf. *gracilis*												×					
B. sp.	×																
Scaphites ventricosus			×		×												
Watinoceras sp.												×					
W.? sp.															×		
PISCES																	
Fish scales, vertebræ, etc.																	×

PALEOCENE (Flora)

	Locality numbers									
	3366	3367	3368	3369	3370	3371	3372	3373	3374	3375
ANGIOSPERMS										
Paliurus colombi Heer	×			×						
Paranymphaea crassifolia (Newberry)			×							
Trochodendroides arctica (Heer)	×	×		×						
Vitis sp.	×									
CONIFERS										
Cryptomerites sp.			×						×	×
Thuites interruptus (Newberry)									×	×
Elatocladus nordenskioldi (Heer)		×			×				×	
E. olriki (Heer)									×	×
EQUISETALES										
Equisetites arcticus? (Heer)				×						
MISCELLANEOUS										
Unidentifiable fossil wood						×				
Unidentifiable leaf							×	×		

PALEOCENE (Fauna)

	Locality numbers															
	12337	12345	12347	12351	12350	12341	12346	12338	12334	12340	12335	12344	12342	12339	12348	12349
PELECYPODA																
Plesselliptio ("Unio") priscus (Meek and Hayden)											×					
Rhabdotophorus ("Unio") senectus (White)											×		×			
Sphaerium cf. *aequale* Russell						×		×								
S. formosum (Meek and Hayden)								×								
S. cf. *heskethense* Warren	×															
S.? sp.										×						
Unionid, genus undeterminable	×						×					×				
GASTROPODA																
Grangerella mcleodensis (Russell)		×														
Hydrobia sp.					×					×						
Limnaea sp.										×						
Lioplacodes? sp.	×											×				
Oreohelix? rotundata Russell			×													
O. thurstoni (Russell)									×						×	×
O. sp.						×				×						
O.? sp.				×												
Physa sp.		×			×		×							×		
Valvata? bicincta Whiteaves					×											
V. subumbilicata (Meek and Hayden)								×								
Viviparus planolatere (Russell)														×		
V. cf. *leai* (Meek and Hayden)			×													
V. retusus (Meek and Hayden)					×						×					
V. sp.	×											×				
PISCES																
Fish scales	×															

COLLECTION LOCALITIES

Locality number[1]	Description of locality
3366.	Alexo map-area; 2,800 feet up North Saskatchewan River from mouth of Shunda Creek.
3367.	Saunders map-area; on Rough Creek, 2,600 feet, in a straight line, above its junction with Meadows Creek.
3368.	Alexo map-area; 600 feet up a tributary of Shunda Creek opposite Stolberg.
3369.	Saunders map-area; on Canadian National railway at west border of area.
3370.	Saunders map-area; 4,750 feet up a creek above Jack Fish Lake mine buildings on northeast border of area.
3371.	Saunders map-area; tree trunk along Canadian National railway, 8,850 feet west of Ancona station.
3372.	East of Saunders map-area; 3¼ miles (straight line) down Ram River from mouth of Makwa Creek.
3373.	Saunders map-area; about 4,600 feet west of mine buildings of Jack Fish Lake mine on a creek on northeast border of area.
3374.	Alexo map-area; about 1,000 feet up a small tributary of North Saskatchewan River at sharp bend in river southwest of Shunda Ranger station.
3375.	Alexo map-area; near same locality as 3374.
11057.	Saunders map-area; at elevation 4,950 feet on Lundine Creek.
11190.	Alexo map-area; at elevation 5,900 feet on southwest slope of same 6,000-foot peak as in locality 11194.
11192.	Alexo map-area; at elevation 5,100 feet, in small creek flowing east from 6,783-foot mountain 3 miles NW. of 'The Gap' of North Saskatchewan River.
11193.	Alexo map-area; east slope of Brazeau Range; $\frac{3}{16}$ mile north of 52° 25′ latitude line at elevation 6,300 feet.
11194.	Alexo map-area; on ridge west of Dizzy Creek, at elevation 5,700 feet on NE. slope of 6,000-foot peak.
11195.	Alexo map-area; north of North Saskatchewan River gap, at elevation 4,350 feet in fourth creek east of Dutch Creek.
11197.	Alexo map-area; at elevation 5,000 feet in NW. corner of area and ⅔ mile from west border.
11198.	Alexo map-area; east side of Brazeau Range, north of North Saskatchewan River, at elevation 6,200 feet, 1 mile northwest of 6,683-foot peak in northwest corner of area.
11199.	Alexo map-area; at elevation 4,700 feet, SE. of 'The Gap', in second creek west of Dizzy Creek.
11200.	Alexo map-area; south of North Saskatchewan River gap, at elevation 4,650 feet on third creek west of Dizzy Creek.
11201.	Alexo map-area; at elevation 4,400 feet in small creek north of 'The Gap', the sixth east of Dutch Creek.
11203.	Alexo map-area; at elevation 5,390 feet on south end of 5,500-foot ridge, 1 mile SE. of 'The Gap'.
11204.	Alexo map-area; at elevation 6,030 feet at head of first creek east of Dizzy Creek.
11205.	Alexo map-area; at elevation 5,120 feet, at head of creek ¾ mile SE. of 'The Gap'.
11206.	Alexo map-area; at North Saskatchewan River gap on north side of river at elevation 4,500 feet in small creek valley, the fifth east of Dutch Creek.
11207.	Alexo map-area; in North Saskatchewan River gap, north of river, and a little east of locality 11201.
11208.	Alexo map-area; at elevation 5,000 feet at forks of creek about 1⅓ miles WNW. of 'Falls' on Dizzy Creek.
11211.	Alexo map-area; at elevation 5,900 feet, ¾ mile west of 'Falls' on Dizzy Creek.
11212.	Alexo map-area; 1½ miles north of North Saskatchewan River, 3,000 feet SE. of 6,783-foot peak.
11213.	Alexo map-area; on north side of 7,130-foot peak 1 mile west of head of Lundine Creek.
11214.	Alexo map-area; a mile northwest of North Saskatchewan River gap, at elevation 6,400 feet on east slope of Brazeau Range.

[1] Numbers provided by the Palæontological Division of the Geological Survey of Canada in lieu of original accession numbers supplied by collectors.

COLLECTION LOCALITIES—*con.*

Locality number[1]	Description of locality
11215.	Alexo map-area; $\frac{5}{8}$ mile east of west border and $\frac{15}{16}$ mile south of north border of area.
11216.	Alexo map-area; at 6,200 feet elevation on east flank of Brazeau Range near locality 11193.
11218.	Alexo map-area; east side of Brazeau Range, south of Shunda Creek, near same locality as 11198.
11220.	Alexo map-area; at elevation 5,400 feet, $\frac{1}{4}$ mile east of west border and $1\frac{1}{4}$ miles south of north border of area.
11223.	Alexo map-area; at elevation 5,850 feet nearly 1 mile east of west border and $1\frac{3}{4}$ miles south of north border of area.
11271.	Alexo map-area; elevation 6,200 feet on east slope of 6,900-foot mountain southeast of head of Dizzy Creek.
11273.	Alexo map-area; on first ridge north of Lundine Creek, $\frac{1}{3}$ mile from east border of area.
11275.	Alexo map-area; 2,600 feet due north of 7,000-foot knob at head of Lundine Creek.
11276.	Alexo map-area; on second ridge east of head of Dizzy Creek on 5,800-foot knob. A little more than 2 miles west of east border of area.
11277.	Alexo map-area; in float of Devonian rocks in upper part of second creek east of Dizzy Creek.
11279.	Alexo map-area; at elevation 6,800 feet on ridge of Brazeau Range, nearly $1\frac{3}{4}$ miles SE. of 'Falls' on Dizzy Creek.
12334.	Saunders map-area; on Trout Creek, 12,000 feet (straight line) down Trout Creek from trail crossing.
12335.	East of Saunders map-area; on North Saskatchewan River and 700 feet above mouth of Trout Creek.
12337.	Alexo map-area; Shunda Creek, 200 feet down from mouth of creek from west.
12338.	Saunders map-area; 4,000 feet down Trout Creek from trail crossing.
12339.	Saunders map-area; on Rough Creek, 6,600 feet below junction of Meadows Creek.
12340.	Saunders map-area; 6,100 feet up Trout Creek from east edge of area.
12341.	Saunders map-area; 2,300 feet up Meadows Creek from mouth.
12342.	East of Saunders map-area, at Phoenix Ferry.
12344.	Saunders map-area; 8,900 feet west of Ancona along Canadian National railway.
12345.	Alexo map-area; on south side of North Saskatchewan River, 5,200 feet down river from mouth of Dizzy Creek.
12346.	Saunders map-area; 3,600 feet down Trout Creek from trail crossing.
12347.	Saunders map-area; 1,190 feet east of Slippery Creek, on Canadian National railway.
12348.	Saunders map-area; on north bank of North Saskatchewan River on east border of area.
12349.	Saunders map-area; 9,000 feet in straight line down North Saskatchewan River on north side from mouth of Jackfish Creek.
12350.	East of Saunders map-area; 11,400 feet (straight line) down Ram River from mouth of Makwa Creek.
12351.	East of Saunders map-area; 2,500 feet down North Saskatchewan River in a straight line from mouth of Rough Creek.
14261.	Alexo map-area; Blackstone formation; north tributary of Easy Creek, $1\frac{3}{4}$ miles SW. of Gap Lake.
14262.	Alexo map-area; Blackstone formation; at elevation 5,000 feet on Easy Creek.
14263.	Alexo map-area; Blackstone formation; at elevation about 3,850 feet on Dizzy Creek.
14264.	Alexo map-area; Blackstone formation; at elevation 4,600 feet on west tributary of Gap Creek 2 miles below Gap Lake.
14265.	Alexo map-area; Blackstone formation; at elevation of about 3,950 feet on Dizzy Creek.

[1] Numbers provided by the Palæontological Division of the Geological Survey of Canada in lieu of original accession numbers supplied by collectors.

COLLECTION LOCALITIES—*con.*

Locality number[1]	Description of locality
14266.	Alexo map-area; Blackstone formation; mouth of first creek from SW. entering North Ram River east of junction of Lynch Creek.
14267.	Alexo map-area; Wapiabi formation; 280 to 380 feet upstream on upper east fork of Philip Creek east of Jock Lake.
14269.	Saunders map-area; Fernie group, arenaceous, argillaceous limestone near west border of the area on ridge south of Lundine Creek at elevation 5,600 feet.
14270.	Saunders map-area; Fernie group; at head of creek south of Lundine Creek near west border of area.
14272.	Alexo map-area; 5 feet above Fernie-Rundle contact on third creek south from Shunda Gap, on east side Brazeau Range near northwest corner of area.
14275.	Alexo map-area; Fernie group; on north rim of first ridge east of Dizzy Creek, at 5,250 feet elevation.
14276.	Alexo map-area; Fernie group; west margin of area, on first creek north of Lundine Creek; 228 feet below Cadomin-Nikanassin contact.
14277.	Saunders map-area; Nikanassin formation; Tawadina Creek, 1,300 feet up creek from Ram River No. 1 well site.
14278.	Saunders map-area; Fernie limestone; 3,150 feet (straight line) up Ram River from mouth of Fall Creek.
14279.	Saunders map-area; Luscar formation, shale member; south side of Ram River, at extreme south border of area.
14280.	Saunders map-area; on Ram River 3,500 feet up from mouth of Fall Creek.
14283.	Alexo map-area; Fernie group; 540 feet north of trail, on second creek east of Dutch Creek.
14284.	Alexo map-area; basal Nikanassin or Fernie formation; on Gap Creek west side, 930 feet down creek from Cadomin conglomerate crossing The Gap.
14285.	Alexo map-area; Bighorn formation; southwest corner of area.
14286.	Alexo map-area; Wapiabi formation; about 2 miles east and ½ mile north of southwest corner of area, on south tributary of North Ram River.
14287.	Alexo map-area; Wapiabi formation; on creek south of Deep Creek 1,300 feet up creek from North Saskatchewan River trail crossing.
14288.	Alexo map-area; near top of Wapiabi formation, on creek south of Deep Creek, 200 feet downstream from intersection with North Saskatchewan River trail; found in limestone concretions.
14289.	Alexo map-area; Bighorn formation; basal sandstone member; 3 miles WNW. of Gap Lake at elevation 5,720 feet.
14290.	Alexo map-area; Bighorn shale member(?) on creek at west border of the area, north of Ram River at about elevation 5,050 feet.
14291.	Alexo map-area; Bighorn formation; second creek valley north of Gap Lake from west; elevation 5,505 feet, on NW. side of creek.
14292.	Alexo map-area; talus of Bighorn formation; less than 50 feet below pebble-conglomerate at top of arc-shaped ridge; ¾ mile south of Rough Creek trail at elevation 5,500 feet on NW. corner of ridge.
14297.	Alexo map-area; Fernie group; second tributary of Dutch Creek from mouth and 1,200 feet up from junction with Dutch Creek.
14298.	Alexo map-area; Nikanassin formation; on 6,400-foot knob, 1½ miles northeast of Gap Lake.
14299.	Alexo map-area; Luscar formation; creek northeast of Gap Lake, 1,070 feet downstream from Cadomin conglomerate.
14300.	Alexo map-area; Luscar formation; first creek from east south of Gap Lake; elevation, 5,000 feet.
14301.	Alexo map-area; Luscar formation; Dizzy Creek near elevation 4,250 feet.
14302.	Alexo map-area; Nikanassin formation; first creek from east crossing Gap trail, south of Gap Lake.
14303.	Alexo map-area; Luscar formation; on south tributary of Jock Creek just below 'Falls' shown on Map 884A.

[1] Numbers provided by the Palæontological Division of the Geological Survey of Canada in lieu of original accession numbers supplied by collectors.

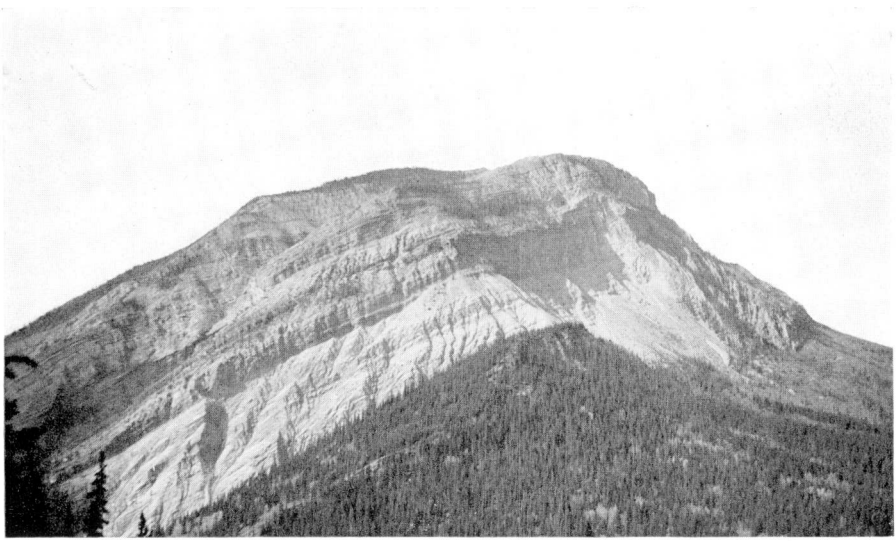
COLLECTION LOCALITIES—*con.*

Locality number[1]	Description of locality
14304.	Alexo map-area; Luscar formation; first creek crossing Gap trail north of Gap Lake.
14305.	Alexo map-area; shale member of Luscar formation; 840 feet up small creek between Gap and Jock Creeks.
15389.	Alexo map-area; about 50 feet below 7,100-foot peak west of head of Lundine Creek and 2 miles west of east border of area.
15390.	Alexo map-area; on 7,130-foot peak of Brazeau Range, 50 feet below top, and 2⅓ miles west of east border of area WNW. of head of Lundine Creek.
15391.	Alexo map-area; on ridge near top of Brazeau Range east of 7,130-foot peak WNW. of head of Lundine Creek.
15392.	Alexo map-area; 1,200 feet below falls on Dizzy Creek, at about elevation 4,450 feet.
15394.	Alexo map-area; first creek east of Dizzy Creek, at elevation 5,100 feet.
15395.	Alexo map-area; first creek east of Dizzy Creek, at elevation 5,300 feet
15396.	Alexo map-area; south side of Lundine Creek, at east border of area, at elevation 5,600 feet.
16282.	Alexo map-area; elevation 6,450 feet on ridge 1½ miles NW. of North Saskatchewan River gap.
16283.	Alexo map-area; on top of Brazeau Range, north of North Saskatchewan River near locality 16282.
16284.	Alexo map-area; in North Saskatchewan River Gap, at elevation 4,100 feet, north of North Saskatchewan River between third and fourth creeks east of Dutch Creek.
16285.	Alexo map-area; elevation 4,120 feet in creek at east end of 'The Gap' and south of North Saskatchewan River.
16286.	Alexo map-area; at elevation 7,000+ feet on summit ⅓ mile west of extreme head of Lundine Creek.
16287.	Alexo map-area; elevation 6,850 feet in saddle on ridge ½ mile west of locality 16286.
16288.	Alexo map-area; at elevation 5,800 feet on SE. ridge from high mountain NW. of 'Falls' on Dizzy Creek.
16290.	Alexo map-area; elevation 5,700 feet and $\frac{1}{16}$ mile north of locality 16288.
16291.	Alexo map-area; ⅜ mile east of west border and about 1 mile south of north border of area, at elevation 5,700 feet.
16292.	Alexo map-area; at elevation 6,400 feet on top of mountain ½ mile south of locality 16291.
16293.	Alexo map-area; at elevation 6,500 feet near top of mountain 1¼ miles NW. of 'The Gap'.

[1] Numbers provided by the Palæontological Division of the Geological Survey of Canada in lieu of original accession numbers supplied by collectors.

93685

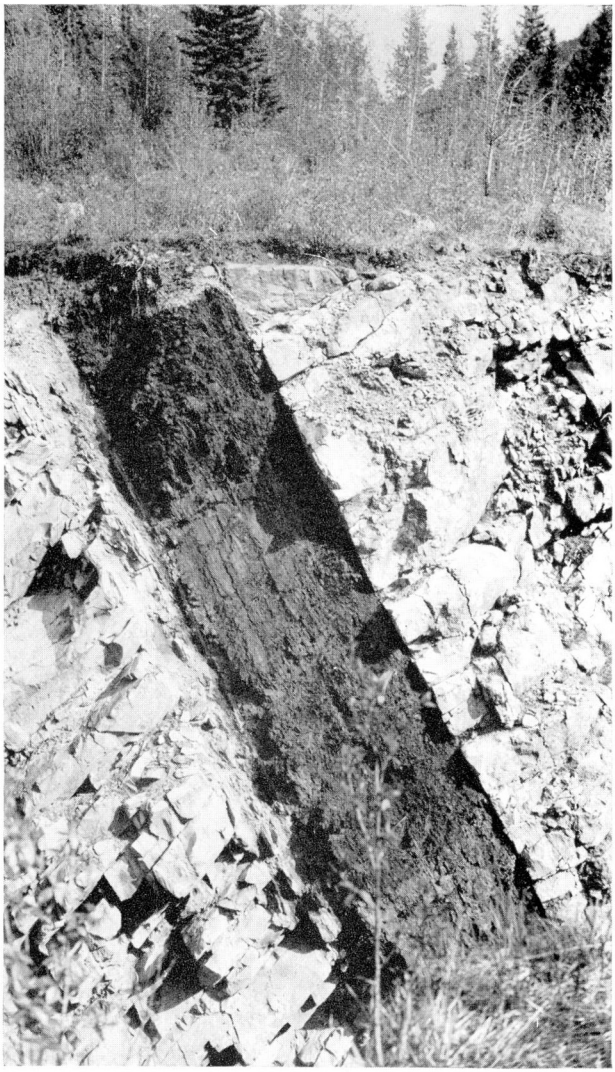
A. Looking northwest, along strike of Brazeau Range anticline, southeast of The Gap. Anticline is much gentler than in The Gap (Plate II B). The cream weathering, calcareous, Devonian shale occurs at the axis of anticline near base of picture; saccharoidal Devonian dolomite is present at the axis on the ridge. Banff shale appears on the southwestern limb above a massive cliff of Devonian beds. (Pages 3, 9, 10, 25.)



93694

B. Looking northwest along strike at Brazeau Range; north side of The Gap of North Saskatchewan River. Devonian rocks form the limbs of the asymmetrical Brazeau Range anticline. The cream weathering, calcareous shale is well defined. (Pages 3, 9, 25.)

PLATE III

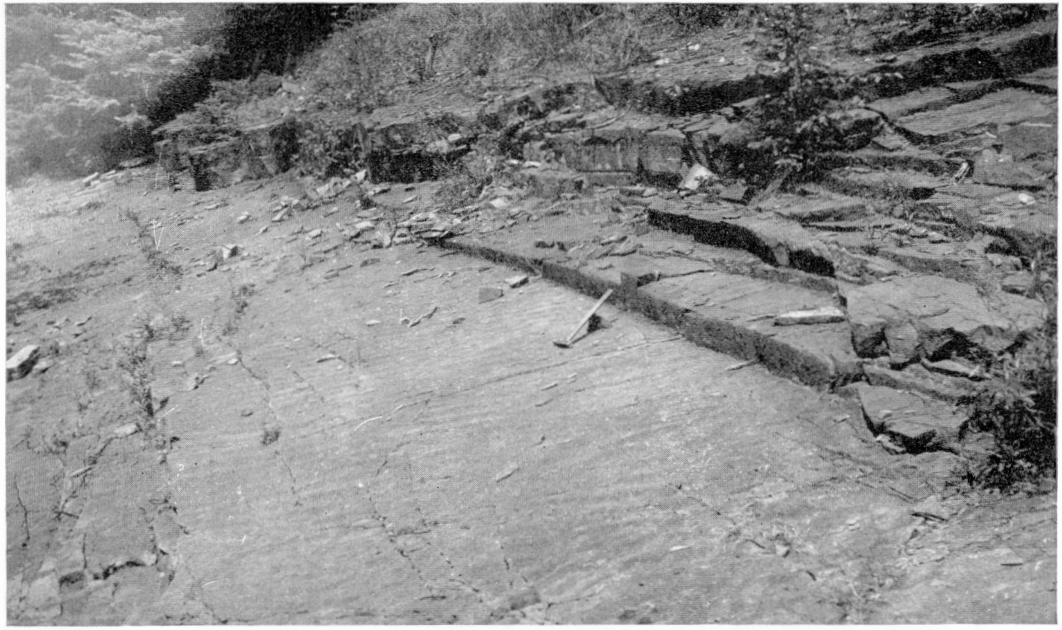


96126

Exshaw formation on railway cut a short distance west of Alexo map-area. The beds are overturned to the south-west. (Page 10.)

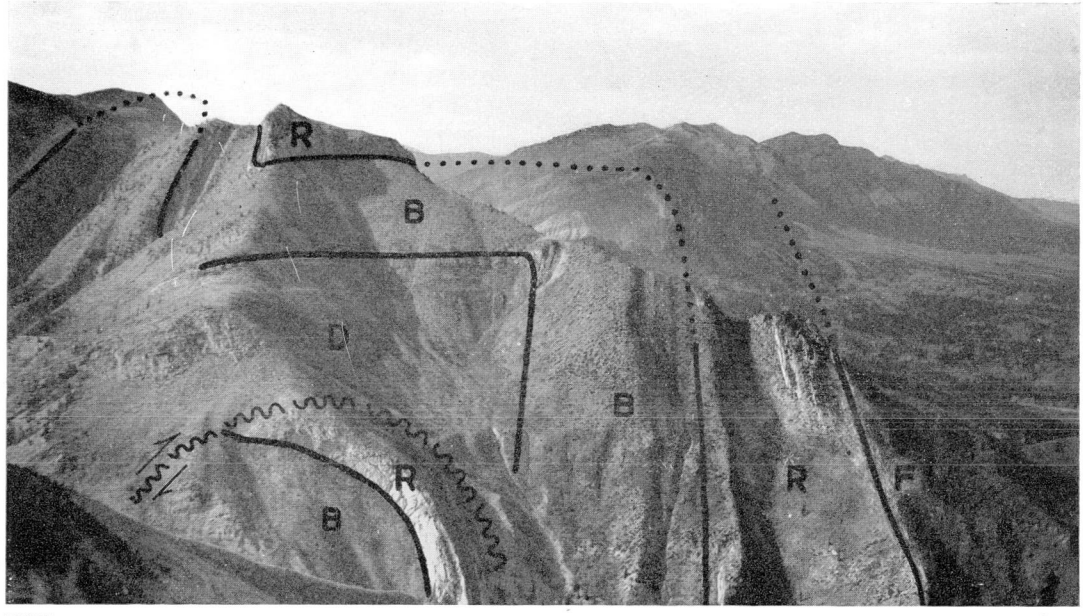
96619

The flat crest of the Stolberg anticline on North Saskatchewan River at mouth of Shunda Creek, showing soft interbedded sandstones and shales of Paleocene age. (Pages 14, 17.)



96153

Well-developed strike and dip joints in Luscar sandstone with ripple-marks, on lower Fall Creek. (Page 40.)



93697

Part of folded thrust fault in Dizzy Creek Valley, on northeastern side of Brazeau Range. Observer is looking northwest along strike of range. D-Devonian, B-Banff, R-Rundle, F-Fernie. (Pages 11, 56, 57, 61.)

INDEX

PAGE

Absaroka overthrust 52
Acidization treatments 65
Alberta, foothills of 51
  Southern foothills of 52
Alberta syncline 32
Alberta-B.C. border 1
Alexo Coal Co., Ltd. 2
  Production 69
Altoba and Canyon No. 1 well 65, 67, 68
Altoba Clearwater No. 1 well 9
American Society of Testing
    Materials 71
Ancona syncline 14, 33
Anhydrite 68
Antecedent streams 3
Anticlines, breached 3
  Eroded 15
  Steep-crested 3
Anticlinorium 31
A.P.I. gravity 65
Appalachians, southern 51
Appendix, lists of fossils in 2
Arkosic sandstones 14
Arrow Brazeau No. 1 well..... 65
Ash 63, 71
Atrypa 10
Axis, culmination 35-37, 56
  Depression 35
Baculites 13
Banff, Alta. 1
Banff area 7
Banff formation 9, 10, 56, 57,
    66, 67
Banff window 55-60
Bannock overthrust 52
Basement control 33
Bedrock 2
Bell, W. A. acknowledgment 2
Bibliography 4
Bighorn and Saunders Creek Col-
    lieries, Ltd 2, 69
Bighorn basin, previous work in .. 1
Bighorn formation 13, 34, 37, 49,
    51, 52, 65, 66
Bighorn rge. 7, 15, 47, 50
  Major fault 50
Bighorn r., map-area 15
Blackface Mountain shale 66, 68
Blackstone formation 8, 12, 29-31,
    32, 34, 46-51, 65
Blairmore gp. 12, 46, 66
Boulder clay 14
Bradshaw, F., acknowledgment ... 2
Brazeau area 52
Brazeau formation 66
  Thickness 8, 14
Brazeau map-area 15
Brazeau strata 50
Brazeau rge. 2, 3, 11, 15,
    29, 30, 32, 38, 50, 69

PAGE

Brazeau Range anticline 3, 36, 37,
    56, 65, 66
Brazeau r. 54
Brazeau Collieries No. 1 ..... 65, 66
Brazeau River anticline 36
British American Oil Co., Ltd. ... 9
Brown, J. P., acknowledgment 2
Brown, R. A. C., fossils identified by 2
Brown sand 65, 66
Bureau of Mines, anal. by 71
Cadomin conglomerate 55
Cadomin formation 8, 12, 65, 66
Calcite veinlets 45
Cambrian age 15, 32, 46, 66
Canadian Gulf Oil Co. 2
Canadian National Rly. 1
Carbon 63
Carboniferous 9
Cardinal r. 52, 54
Cardium pauperculum 13
Chamberlin, R. T., acknowledgment 2
Clark, L. M., acknowledgment 2
Clear Oils No. 1 ..... 65, 67, 68
Clearwater rge. 15, 29
Coal 69-72
  Anal. of sample 71
  Bituminous-high volatile 71
  Bituminous-low volatile 71
  Caking properties of 71
  Conversion factor 72
  Luscar age 69, 70, 72
  Mines 47, 48, 69
  Outcrops, list of 69, 70
  Paleocene age 72
  Previous work 1
  Production of 72
  Reserves, estimates of 72
    conversion factor 72
  Seams 69
Cobbles, quartzite 31
Cook, Ian M. 9
Coquina bed 11
Crestal line 56
Cretaceous 8
  Lower 8, 50
  Rocks of 30
  Upper 8, 12-14, 32, 37, 38,
    40, 42, 47, 50, 52, 60
Cripple Creek map-area 15
  Upper Cambrian section of 68
Crombie, G. P., acknowledgment .. 2
Crystals, quartz 64
Culmination axis 35-37, 56
Culminations 34-38
  Major 35
  Minor 36, 37
Currie, J. B., acknowledgment 2
Darby overthrust 52
Deep ck. 48

PAGE

Depression axis 35
Depressions 34-38
  Minor 36-37
Devonian 7, 10, 15, 32, 37, 66, 67
  Middle 9
  Thickness 9
  Upper 9
Devonian-Mississippian contact ... 36
Dizzy ck. 10, 30, 48, 53, 57
  Folded fault 53-60, 62
  Valley 11
Dolomites, porous 68
  Saccharoidal 10, 63, 66-68
Drag-folds 36, 47
Drainage 3, 4
Drift, Pleistocene, unconformity below 61
Drill stem tests 65
Dutch ck. 3
Edmonton formation 8, 14
Erratics 3
  Glacial 14
Eskers 2
Exshaw formation 9, 10, 66, 67
Faults 43-51
  Faulted folded 51
  Folded 34, 46, 51, 53, 56, 60, 62
    thrust 50, 51-62
  Gravity 44, 48
  Hinge 31
  Major 49, 50
  Minor 44, 47
  Normal 48, 49
  Slice 49
  Sole 51
  Strut 61
  Subsidiary 46, 47
  Tear 30
  Thrust 7, 32, 44
    folded 34
    minor 47, 48
    northeast dipping 48
  Warped 51
Fault No. 1 44
Fault No. 2 (thrust) ... 7, 28-30, 33, 34, 37, 43-48, 50, 51, 59, 60, 67
Fault No. 3 ..... 37, 46
Fault No. 4 ..... 46, 54
Fault No. 5 ..... 46, 49
Fauna 11, 14, 73-83, 85
Fernie formation 7, 8
Fernie gp. 11
  Rocks of 31
  Thickness 65, 66
'Flatirons' 3, 11
Flora 14, 84
Flutings 3
Fluvioglacial deposits 14
Folds 16-34
  Asymmetrical 16, 62

Folds—*Concluded*

PAGE

  Chevron 31
    asymmetrical 31
  Drag 16, 28, 29, 33, 49
    overturned 29
  En échelon 46
  Minor 28-31, 47
  Overturned 28, 29, 33
  Plunging 37
  Recumbent 28, 29, 33
  Slice 49
  Symmetrical 16
Foothills belt 1, 16, 32, 33, 38, 60, 62, 68
Foothills of Alberta 51, 52
  Outer 32
Fossils 2, 10-12, 14, 73-85
  Palæozoic invertebrate 2, 73-81
France, Prealps of 54
Fuels, Division of 63
Gap ck. 3
Gap, The, North Saskatchewan r. 3, 9, 36, 46
Gas 63-68
Gastropods 64
Geologists, alpine 52
Geophysical methods 68
George ck. 15
Ghost River formation 66-68
Glacial erratics 14
Glaciation, alpine 3
Glover, W. J., acknowledgment ... 2
Gouge, fault 60
'Grit' 65, 66
Home Brazeau No. 1 well 64-66
Home Brazeau Syndicate No. 1 ... 65
Hydrocarbons, black residue of 11, 63, 68
Hydrogen 63
Ice-sheet 3
Imbricate structures 44, 49-51
  Differential erosion 3
Imperial Nordegg No. 1 ..... 65, 66
Imperial Oil Ltd., acknowledgment 2, 64
Imperial-Shell-Stolberg No. 1 well 2, 64-66, 68
Incidence, angle of 54
Inoceramus labiatus 13
Jack Fish Lake Coal m. 69, 71
Jasper, Alta. 1
Jasper area 7
Joints 38-44, 62
  Attitudes 38
  Calcite-filled 43
  Calcite-lined 43
  Calcite-veined 43
  Dip of 38, 41-44
  Dip set 62
  Feather 42
  Pattern of 38, 43
  Quality of 38, 39
  Sets 38, 41
  Spacing of 40

PAGE

Joints—*Concluded*
Strike 38, 41-44
Strike set 62
System of 38, 43
Tension 42, 44
Transverse 42
Jones, A. G., acknowledgment 2
'Jumpingpound equivalent' 65
Jurassic rocks 8, 11, 53
Jurassic system 7
Kliske, A. E., acknowledgment 2
Knob-and-kettle topography 2
Laramide orogeny 60, 62, 64
Revolution 64
Lewis overthrust 52
Limestone, Devonian 48, 66
Fernie 31
Phosphatic 11
Limestone mt., map-area 9, 10
Limestone rge. 15, 16
Lithologic units 11, 13
Lombart overthrust 52
Lower Cretaceous formation 8, 50
Rocks of 11, 12, 53, 60
Luscar formation 7, 8, 29, 31-34, 38, 42, 50, 66
Rocks of 31, 47, 65
Luscar window 55, 58
Lynch ck. 49, 54
MacLaughlin, R., acknowledgment 2
McLearn, F. H., acknowledgment . 2
Mesozoic formations 7, 15, 38, 60
Mesozoic invertebrate fossils ... 2, 82, 83
Plant fossils 2, 84
Middle Devonian 9
Minnewanka 66, 67
Mississippian age 9-12
Moose mt., vertical uplift 53
Morainal deposits 14
Morgan, Owen, field work 2
Mountain Park formation . 7, 12, 29, 31, 38, 46, 47, 50, 65-67
Mountain Park map-area 8, 15
Muskegs 2
Naphtha 65
Nappe theory 52
Nikanassin formation 7, 8, 11, 66
Niganassin rge. 15, 65
Nitrogen 63
Nordegg, Alta. 71
Nordegg coal basin, previous work in 1
North Ram r. 4
North Saskatchewan r. 3, 4, 52
Ferry crossing 1
North-West Highlands, Scotland .. 51
Oil companies 1
Staining 66
Structures 38, 60, 63-68
Oxygen 63
Palæontological Division 72
Palæontology 73-89

PAGE

Palæozoic formations 7, 15
Rocks of 30
Palæozoic invertebrate fossils .. 2, 74-81
Paleocene 8, 14, 32, 38, 40, 42, 47, 48, 60, 67, 69
Flora 84
Sandstones 62
Strata 50
Thickness 14
Paskapoo formation 8, 14
Pembina r. 52, 54
Pennsylvanian system 7
Permian system 7
Petroleum and Natural Gas Conservation Board of Alberta ... 64
Philip ck. 3
Folded fault of 53-54
Physiography 2-4
Plastic limit 51
Plateau area, low 2, 54
Pleistocene 8, 14
Angular unconformity between rocks of Tertiary and 62
Drift, unconformity below 61
Porosity, intercrystalline 66
Vug 66
Porous zones 63
Precambrian, rocks of 52
Pressure box 51
Previous work 1
Productoids 11
Pullen, E. F., acknowledgment ... 2
Pyrobitumen 66
Quartz crystals 64
Quaternary 8
Ram r. 3
Anticline 32, 33
Syncline 33, 36
Valley 29
Ram River No. 1 well ... 1, 29, 45, 59, 63-65, 67, 68
No. 2 well 65, 67, 68
No. 3 well 65, 67
No. 4 well 65, 67
Recent 8, 14
Red Deer, Alta. 1
Relief, topographic 2
'Ribboned' cliffs 10
Roads, lumber 1
Roan mt., Tennessee and North Carolina 51
Rocks, competent 60, 61
Porous 68
Rocky Mountain formation..... 7
Rocky Mountain orogeny..... 62
Rocky mts., eastern rge. 52
First rge. 1, 15, 32, 50
Idaho 52
Major fault 50
Montana 52
Outlier rges. 32
Southern Alberta 52
Wyoming 52

PAGE

Rundle formation 9, 11, 56, 65-67
Limestone 3
Rocks of 31, 36, 63
Strata 57
Thickness 11
Rundle outlier 68
Rundle window 55-56
Rundle-Fernie contact 63, 64
Russell, L. S., acknowledgment ... 2, 72
Sandstones 42
Arkosic 14
Saunders Alta. Collieries, Ltd. ... 69
Saunders ck., previous work in 1
Scaphites ventricosus 13
Schizophoria striatula 10
Seismic surveys 61
Reflection 68
Refraction 68
Shales, Blackstone 31, 42, 46
Luscar 42
Shell Oil Co. of Canada, Ltd., acknowledgment 64
Shunda Oils No. 1 well 46, 65, 66
Slice-faulting 49
Spirifer jasperensis 10
Spirifers 11
Spirifer whitneyi 10
Spray River formation..... 7
Stinson, E. H., field work by 2
Stolberg anticline 14, 30-33, 44, 45, 66, 68, 70
Stratigraphic throw 45-47, 50, 54, 56, 57, 61
Stratigraphy 7-14
Streams, antecedent 15
Subsequent 4
Stresses, diastrophic 16
Horizontal compressive 62
Lateral 61

PAGE

Stresses, diastrophic—*Concluded*
Rotational 62
Tangential 61
Structures, asymmetrical 33
Sulphur 63, 71
Swamps 2
Switzerland, Prealps of 54
Tawadina ck., anticline 33, 36, 37
Culmination axis on 35, 36
Depression axis near 35
Tay r. 10
Tertiary 8
Test holes, diamond-drill..... 66
Thrusts (*See* Faults)
Topography 2, 3
Tornoceras cf. *uniangulare* 9, 10
Trails 1
Triassic system 7
Upper Cambrian 9
Upper Cretaceous 8, 12-14, 32, 37, 38, 40, 42, 47, 50, 52, 60
Upper Devonian 9, 15, 48, 56, 57, 59, 60, 63
Lower 9
Upper Palæozoic rocks 30, 38, 42, 48
Limestones of 40
Outlier ranges 32
Veins 42-44
Volatile matter 63, 71
Wapiabi ck. 15
Wapiabi formation 8, 66
Beds 51
Shales 3
Strata 50
Thickness 13
Watinoceras sp. 13
Weaver anticline 68
Webb, J. B., acknowledgment 2
Wilson, Alice E. 9
Fossils identified by 2
Wuest, W. E., acknowledgment ... 2