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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

MEMOIR 369

GEOLOGY OF THE LARDEAU MAP-AREA, EAST-HALF, BRITISH COLUMBIA

J. E. Reesor

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GEOLOGY OF THE LARDEAU MAP-AREA, EAST-HALF, BRITISH COLUMBIA

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PLATE I. Panorama from Mount Ethelbert at about 10,000 feet looking northwest to Snowpatch, Howser, and Bugaboo Spires, northward across the north-plunging arch of the Purcell anticlinorium, and northeast to the wooded ridge north of Bugaboo Creek and the Rocky Mountain Trench beyond. Peaks in the order of 10,000 to 11,000 feet and Templeton Lake in foreground at 6,000 feet asl.

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By

J. E. Reesor

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
CANADA

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PREFACE

The area contains the complete geological section fom Precambrian to Mesozoic. Relations are shown between major rock units of the middle and late Proterozoic and the entire Paleozoic. The report deals as well with contrasting structural provinces and contrasting levels of regional metamorphism between the Rocky Mountains and the Selkirk Mountains.

There has been active exploration for mineral deposits in this area since before the turn of the century, and the area continues to interest a broad spectrum of mineral exploration companies.

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

OTTAWA, December 21, 1970

MEMOIR 369 — Geologie des Kartenblatts Lardeau (östliche Hälfte) in Britisch-Kolumbien (Kanada)
Von J. E. Reesor

Die geologische Schichtenfolge umfasst mehr als 11 500 Meter präkambrischer und bis 5 500 Meter paläozoischer Schichten. Die Gesteine, ihre Verformung und Metamorphose werden beschrieben. Zahlreiche kleine Silber-Blei-Zink-Lager sind in diesem Gebiet abgebaut worden.

МЕМУАР 369 — Геология картографированной местности Лардо (восточная часть), Британская Колумбия, Канада
Дж. Э. Рисор

Геологическая последовательность составляет свыше 38 000 футов (11 500 м) докембрийских и до 18 000 футов (5 500 м) палеозойских пластов. Описываются эти породы и их деформации и метаморфизм. В районе разрабатывались многочисленные, но небольшие по размеру, залежи серебряно-свинцово-цинковых руд.

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GEOLOGY OF THE LARDEAU MAP-AREA, EAST-HALF, BRITISH COLUMBIA

Abstract

Lardeau map-area, east-half, encompasses about 3,100 square miles in the central culmination of the Purcell Mountains, as well as segments of Brisco and Vermilion Ranges of the Rocky Mountains, and a small part of the Selkirk Mountains near Kootenay Lake.

The Precambrian history of this area is recorded by more than 30,000 feet of Purcell strata, unconformably overlain by as much as 8,000 feet of Windermere strata, all deposited during a time span about twice that of the Paleozoic. The Purcell rocks are uniformly fine grained and reflect deposition in a shallow-water environment in which subsidence maintained equilibrium with deposition over long periods. The Windermere reflects rapid deposition of coarse to fine clastics derived from a nearby emergent area to the east and southeast. These two sequences are separated by the East Kootenay orogenic event at the end of Purcell time, and this event is assigned a minimum age of about 800 m.y.

The Paleozoic history is characterized by deposition of sediments in two contrasting environments. In the northeast, Paleozoic successions though dominantly carbonate contain some shales and quartz sands. Total thickness ranges from a few tens of feet to about 6,000 feet or more. Lithological variations and individual formational thicknesses are much modified by the Windermere High, in central-eastern Purcell Mountains, that remained a positive area from Early Cambrian to at least Devonian time. It underwent active denudation during the Early Cambrian, but no evidence of active denudation is found in succeeding formations. In the southwest, the Paleozoic rocks are characterized by a much greater thickness of sediment, as much as 18,000 feet of fine-grained clastics and volcanics, with minor quartz sand and carbonate mainly confined to the Lower Cambrian. Faunal evidence is lacking in this succession and formation-by-formation correlation with the northeast zone is not yet possible.

Evidence beyond the confines of this map-area point to a pre-Milford (pre-Mississippian) deformation. A boulder-to-pebble conglomerate exists in some localities at the base of the Milford, yet Milford and later Kaslo Group sediments and volcanics continue the eugeosynclinal succession characteristic of pre-Milford sedimentation.

Although considerable deposition of Mesozoic volcanics and sediments took place in the region immediately to the west and southwest, Mesozoic history in Lardeau map-area is characterized by a culminating, regionally important orogeny, with associated regional metamorphism and emplacement of two distinct granitoid sequences. Metamorphism increased gradually from

northeast to southwest from a shale–argillite–slate sequence to lower greenschist rocks in a broad belt across the Purcell divide. Southwest there is a steep rise of regional metamorphism through biotite, garnet, staurolite, and finally to staurolite–kyanite-bearing assemblages in pelitic rocks.

Deformation, both folding and faulting, culminated in the mid-Mesozoic. Folds are steep and upright in the Brisco Range, characteristically overturned eastward in the eastern Purcell anticlinorium, steep and isoclinal in the western Purcell. In the higher grade metamorphic zone of the southwest part of the map-area, folding is very complex, characterized by an early phase of isoclinal folding and a later phase that co-axially refolded the early structures. Important reverse faults are found along the Rocky Mountain Trench and across the central-eastern Purcell cutting across the Mount Forster syncline and the Purcell boundary syncline on Steamboat Mountain.

Granitoid intrusions consist of early mesocratic quartz diorite and granodiorite, syn- to late-kinematic, and leucocratic quartz monzonites that are post-kinematic. They superimpose a structural and a metamorphic aureole on early regional structures and metamorphism.

Résumé

La région couverte par la coupure de carte de Lardeau, moitié est, comprend environ 3,100 milles carrés dans la partie centrale des chaînons Purcell, ainsi que des segments des chaînes Brisco et Vermilion des montagnes Rocheuses, et une petite partie des monts Selkirk, près du lac Kootenay.

L'histoire du Précambrien de cette région est attestée par les couches de Purcell, de plus de 30,000 pieds, recouvertes en discordance par les couches de Windermere, épaisses jusqu'à 8,000 pieds, le tout accumulé sur une période de temps approximativement égale à deux fois la durée du Paléozoïque. Les roches de Purcell, d'un grain uniformément fin, reflètent des conditions de sédimentation en eaux peu profondes, dans lesquelles subsidence et sédimentation se sont compensées mutuellement pendant de longues périodes. Le Windermere reflète une sédimentation rapide de matériaux clastiques, de grossier à fin, provenant d'une région en émersion, située à l'est et au sud-est. Ces deux successions se trouvent séparées par le mouvement orogénique de l'East-Kootenay, à la fin de l'étage de Purcell et on leur attribue un minimum d'environ 800 millions d'années.

L'histoire du Paléozoïque est caractérisée par le dépôt de sédiments dans deux conditions de milieu opposées. Au nord-est, les successions du Paléozoïque, bien que composées surtout de carbonates, comprennent quelques schistes et sables quartzeux. L'épaisseur varie de quelques dizaines de pieds à environ 6,000 pieds ou plus. Les variations lithologiques et les épaisseurs des différentes formations se trouvent modifiées considérablement par la présence de la zone surélevée de Windermere, dans les chaînons Purcell du centre-est, qui est restée une région émergée bien établie depuis le début du Cambrien jusqu'à la fin du Dévonien. Cette zone a été l'objet d'une érosion intense pendant le début du Cambrien, mais il n'existe aucune preuve d'intense érosion dans les formations postérieures.

Dans le sud-ouest, les roches du Paléozoïque sont caractérisées par une bien plus grande épaisseur de sédiments, ceux-ci comprennent jusqu'à 18,000 pieds de matériaux clastiques et volcaniques à grain fin, ainsi que des sables quartzeux et des carbonates en petite quantité sis seulement dans le Cambrien inférieur. On manque de preuves de l'existence d'une faune dans cette succession et la corrélation, formation par formation, avec la zone du nord-est n'est pas encore possible.

Hors des limites de cette carte, des preuves indiquent l'existence d'une déformation antérieure au Milford (antérieur au Mississippien). Un conglo-

mérat, allant de bloc au caillou, existe, par endroits, à la base du Milford, cependant les matériaux sédimentaires et volcaniques du Milford et du groupe postérieur de Kaslo continuent la succession eugéosynclinal caractéristique de la sédimentation antérieure au Milford.

Bien qu'un immense dépôt de matériaux volcaniques et sédimentaires ait eu lieu au Mésozoïque, dans la région immédiatement à l'ouest et au sud-ouest, l'histoire du Mésozoïque dans la région couverte par la coupure de carte de Lardeau est caractérisée par une orogenèse de surrection, importante à l'échelle régionale, associée à un certain métamorphisme régional et à la mise en place de deux séries granitiques distinctes.

Le degré de métamorphisme augmente graduellement du nord-est au sud-ouest et l'on passe d'une succession schiste-argilite-ardoise à des roches formées de schistes cristallins plus profonds, suivant une large zone, de part et d'autre de la ligne de crête des chaînons Purcell. Au sud-ouest, on constate un brusque accroissement du métamorphisme régional avec l'apparition de biotite, de grenat, de staurolite, et finalement d'assemblages minéralogiques comprenant de la staurolite et de la cyanite dans des roches pélitiques.

La déformation, aussi bien par plissement que par failles, a eu son intensité maximale au milieu du Mésozoïque. Les plis sont escarpés et droits dans la chaîne Brisco, couchés d'une façon caractéristique vers l'est dans l'anticlinorium de la zone est de Purcell, et escarpés et isoclinaux dans la zone ouest de Purcell. Dans la zone la plus métamorphisée de la partie sud-ouest de la région couverte par la carte, le plissement est très complexe et se caractérise par une première phase de plissement isoclinal suivie d'une deuxième phase qui a replissé les structures précédentes suivant le même axe.

On trouve d'importantes failles inverses le long du sillon des Rocheuses et de part et d'autre de la coupe de la zone centre-est de Purcell qui passe par le synclinal du mont Forster et par le synclinal de la limite de la zone de Purcell, dans le mont Steamboat.

Les intrusions granitiques comprennent, au début, de la diorite quartzifère et de la granodiorite mésocrates, formées pendant le mouvement tectonique et vers la fin de ce dernier, ainsi que des monzonites quartzifères leucocrates, formées après le mouvement tectonique. Ces intrusions superposent une auréole structurale et métamorphique aux structures et au métamorphisme régionaux primitifs.

Chapter I

INTRODUCTION

Location and Accessibility

Lardeau map-area, east-half, consists of approximately 3,100 square miles of mountainous terrain in the east Kootenay district of British Columbia. It is bounded by 50° and 51°N and by 116° and 117°W. The area includes a part of the Vermilion and Brisco Ranges of the Rocky Mountains, the entire central part of the Purcell Mountains, and the very eastern slopes of the Selkirk Mountains west of upper Kootenay Lake (Fig. 1).

The fringes of this area are accessible by main highway along the valley of Columbia River and by dirt roads that extend part way up most of the main streams flowing eastward from the Purcell Divide. The settlements of Lardeau, Argenta, and Johnsons Landing at Kootenay Lake and the west side of Duncan Lake are also accessible by dirt road.

Where the road ends along any of the major creeks of the eastern Purcell Mountains the problems of travel and working rapidly increase, due in part to heavily timbered valley sides and bottoms, and in part to high, serrate mountain ridges above. Although horses were successfully used during the 1953 season on Findlay and Dutch Creeks, they are limited to travel within the bottoms of major stream valleys, and even during this season, much of the work was done by back-packing to small camps at, or near treeline at about 7,500 feet elevation. During the following seasons all the region not accessible by jeep on dirt logging or mining roads was worked by back-packing from airdropped supply sites (Reesor, 1955). Camps were established at 7,500- to 8,000-foot elevations by dropping supplies in 100- to 150-pound packs by parachute from a Pacific Western Airways Beaver aircraft, based at Nelson, B.C. Geological mapping was then carried out by back-packing from airdrop to airdrop. This method allowed a greater flexibility than the use of horses, and further, allowed geological work to be concentrated at or above timberline without the daily long climb through thick-timbered or burned hillsides from the valley bottoms.

Under present-day conditions helicopters would be used for transport with good landings above timberline almost anywhere. Landing spots in creek bottoms are rare, however, and in general landings on the long timbered slopes between the valley bottoms and timberline at 7,500 feet are impossible.

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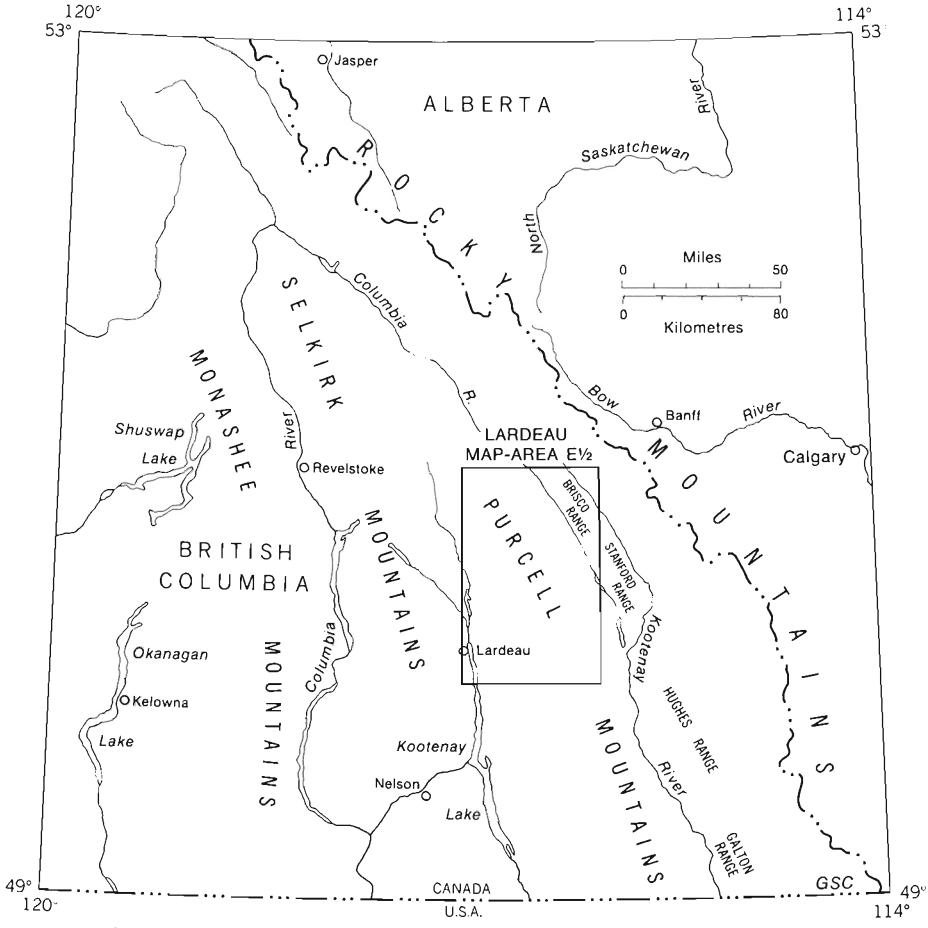


FIGURE 1. Index map showing names of physiographic divisions in the surrounding area.

Much of the area along the Purcell Divide has in the last few decades provided a readily accessible, challenging ground for mountaineering. Details of access and climbing information are available in "A Climber's Guide to the Interior Ranges of British Columbia" of the American Alpine Club (Thorington, 1955). Other information can be found in a book by J. M. Thorington (1946) and in various issues of the *Canadian Alpine Journal, American Alpine Journal,* and *Appalachia* for the years 1946–47.

Geological Work

A part of this area including the drainage basins of Toby and Horsethief Creeks was mapped by J. F. Walker between 1922 and 1924 (Walker, 1926). The western slopes of the southern Brisco Range as well as Steamboat and Jubilee Mountains were mapped as part of the Brisco–Dogtooth map-area by C. S. Evans (1933). Parts of the former area and most of the latter area were remapped during this project but

because of limited time in any one field season and difficult access, parts of the Windermere area remain as mapped by Walker (1926). A small part of the southwest corner of the map-area, around Duncan Lake and the north end of Kootenay Lake, was included in the study of the Lardeau by Walker and Bancroft (1929) (*see* Fig. 2).

The field work upon which this report is based was started in 1953 and continued through 1956. A part of the 1957 season was spent in finishing mapping in a few isolated localities and in re-examining some problem areas. In all, about 12 months were spent in the field. The field season in the high mountains above timberline is extremely short, usually six to seven weeks during July and August. Under the conditions of operation of this reconnaissance, much of this valuable time was spent travelling with a heavy pack that never lightened for as food was consumed rock samples accumulated. Furthermore it was difficult to re-examine problem localities once they had been passed, so although problems were recognized during the course of this work many were not solved.

Although there is much to be said for this time-honoured method of operation in that one does not pass too rapidly over the rocks, nevertheless it is regrettable that re-examination of some of the problem localities by helicopter has not been possible. The helicopter, among other advantages, permits full use of time in doing geology as well as enabling one to restudy problems as they arise, and to follow out structural and stratigraphic continuity quickly once established by ground examination. Nevertheless, despite the limitations imposed by the method of work adopted by necessity, sufficient information has been accumulated in this important area to warrant the following account.

Although no further work has been done by the writer in this area since 1957, there has been a much more detailed study of the complex region of northern Kootenay Lake and Duncan Lake along the western fringe of the map-area by the British Columbia Department of Mines and Petroleum Resources (Fyles, 1964). The results of this study have been used in compilation of the accompanying geological map (*in pocket*) (*see also* Fig. 2).

Acknowledgments

The writer wishes to acknowledge the help and co-operation of local residents, in particular the various logging operators and the staffs of both the Mineral King Mine on Toby Creek and the Giant-Mascot Mine on Jubilee Mountain. In particular the help and co-operation of the British Columbia Forest Service in all districts included within Lardeau east-half is gratefully acknowledged.

In the field work the writer was ably assisted in 1953 by R. A. Kretz, J. M. McAndrew, and Ed Freeman; in 1954 by J. A. Chamberlain, P. W. Brock, A. M. Laird, and Peter Allen; in 1955 by R.A. Hodder, P. B. Read, E. MacCosham, and Ed Schiller; and in 1956 by T. Onodera, D. W. Hyndman, and B. Burch; in 1957 by K. Schryver and M. C. LeBlanc. Some petrographic work and compilation of some of the figures has been aided by E. Hsu. This help is gratefully acknowledged. The manuscript has been critically read by G. B. Leech and J. O. Wheeler. Their comments and criticisms have much improved the report and their efforts are much appreciated.

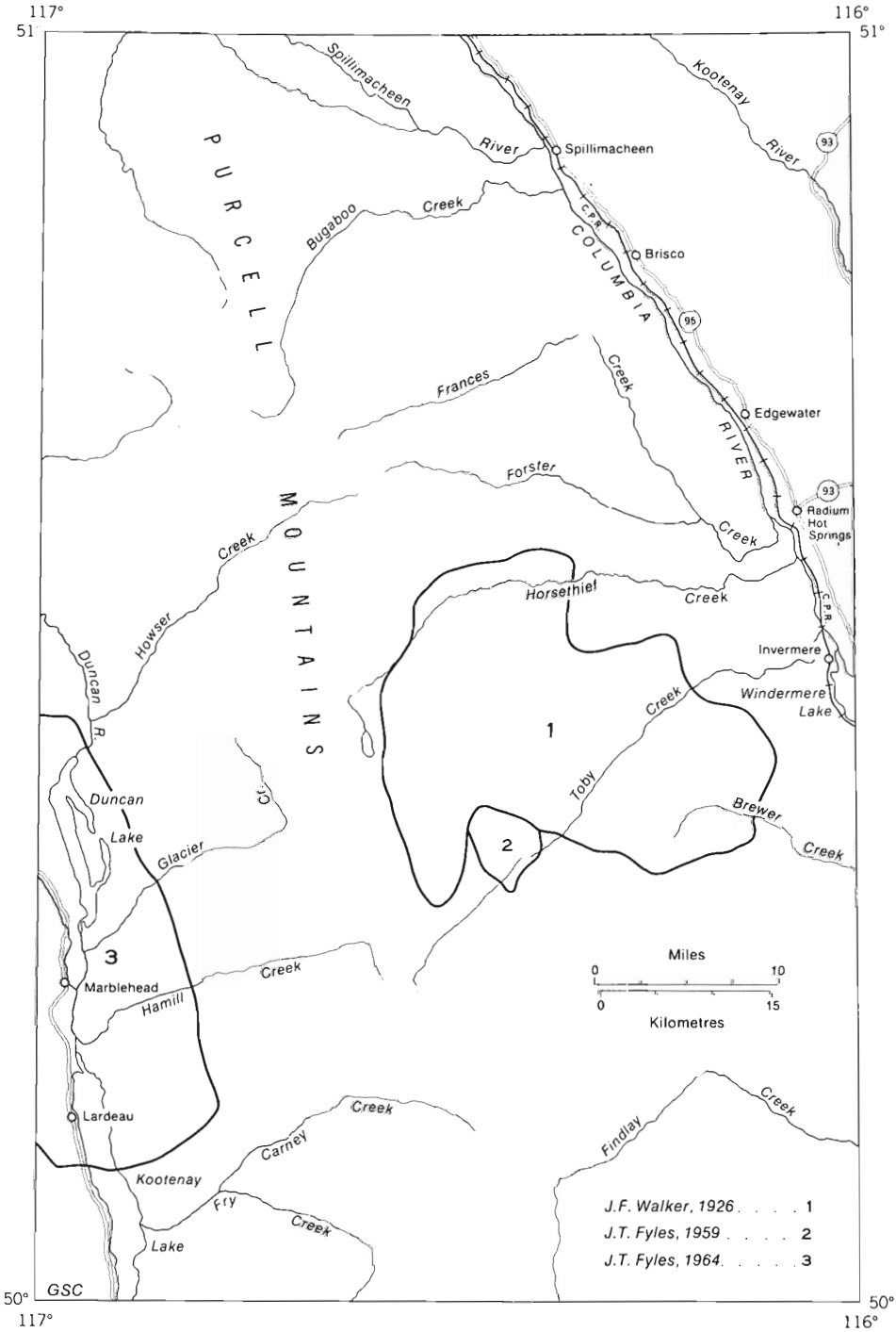


FIGURE 2. Source of geological data plotted on map with little or no modification.

General Character of the Area

Topography and Drainage

Lardeau map-area, east-half, includes the entire central, and highest part of the Purcell Mountains of southeastern British Columbia, as well as a part of the Brisco and Vermilion Ranges of the western Rocky Mountains in the north corner of the map-area, and the lower slopes of the Selkirk Mountains west of upper Kootenay Lake in the southwest corner.

In the central Purcell Mountains alpine glaciation has sculptured the dominant land forms, and discontinuous, serrate ridges and mountain masses ranging in maximum height from 9,000 to 11,000 feet asl surround the viewer from any mountain peak along the divide of the Purcells (Pls. I and II). Eastward, toward Columbia Valley, ridges and spurs are more rounded and maximum elevations seldom rise above 8,000 feet. The mountain slopes then drop off abruptly 4,500 feet or more to the higher slopes of the Rocky Mountain Trench thence more gradually to Columbia River, a further 1,600 feet below, at elevation 2,600 feet asl. West of the Purcell Divide elevations drop off abruptly from 8,000 to 9,000 feet to Duncan and Kootenay Lakes at about 1,800 feet asl. Thus local valley relief in the Purcell Mountains varies from 4,500 to 6,000 feet with exceptional maximum relief of 7,000 to 7,500 feet on the western slopes.

Although the waters draining this area eventually all reach the Pacific Ocean via Columbia River, they follow diverse routes. The streams of the eastern Brisco Range and Vermilion Range drain into the upper Kootenay River and flowing southward are joined below Canal Flats by the drainage from the Findlay Creek system. All other streams of the eastern Purcell Mountains drain into the upper Columbia River and flow northward. The shorter, swifter streams on the western slopes of the Purcells drain to Duncan River and Kootenay Lake and flow directly south and west (Fig. 1). The three-way divide of these drainage patterns occurs at Trikootenay Peak at the head of Carney, Dutch, and Findlay Creeks in the southern part of the map-area.

Most of the east- and northeast-flowing streams are much longer due to the asymmetrical pattern of the drainage in the Purcell Mountains. As a result most of the main valleys have relatively gentle gradients. Most tributary streams, however, plunge through deep canyons from hanging valleys, 400 feet or more above the main stream valleys. All the main eastern streams cut deep gorges through glacial drift and bedrock alike before reaching the main valley of Columbia River. The shorter westward flowing streams have steeper gradients and cut through steep rocky canyons at their lower ends (Pl. II).

Numberless tarn and paternoster lakes occur in the Purcell Mountains most commonly between 7,000 and 8,000 feet elevation. They range in size from Lake of the Hanging Glacier, over a mile long, down to small, round, tarn lakes not over 100 yards across.

Many small ice fields and numerous glaciers occur throughout the central part of the Purcell Mountains, as well as large areas of perennial snow on high, sheltered slopes. In contrast there are no glaciers and few small patches of perennial snow in the Brisco Range east across the Rock Mountain Trench.

Climate, Flora, Fauna, and Settlement

The climate is typical of the southeastern interior of British Columbia and is characterized by heavy precipitation, mainly as snow, in the mountains and very light precipitation in the rain-shadowed major north- or northwest-trending valleys. Parts of the Columbia Valley under cultivation must be irrigated and annual precipitation there does not exceed 15 inches on an average. In the mountains to the west the extensive snow cover lasting well into June shows a much higher annual precipitation and in the central part of the Purcell Mountains may exceed 50 inches per year. This is reflected in the dense stands of timber and thick undergrowth in the central and western Purcells.

The valley bottoms and the lower slopes of the mountains to an elevation of nearly 7,500 feet are thickly timbered with pine, fir, spruce, hemlock, tamarack, and in some localities birch, poplar, or alder. Alpine larch is common in high cirque basins at elevations over 7,000 feet asl. Many slopes of the larger creeks, particularly Findlay, Dutch, and Toby Creeks have been burned and the resulting mesh of fallen logs and thick second growth makes the hillsides almost impenetrable on foot.

On the western slopes of the Purcell Mountains timber is much more dense, with many thick, almost impenetrable stands of small second-growth cedar. A thick undergrowth of willow is found, particularly between elevations of 5,000 and 6,700 feet asl. Some stands of very large cedar up to 4 or 5 feet in diameter are found in many of the larger creeks on the west side of the Purcell Mountains.

In marked contrast the dry Columbia Valley with wide-spaced trees and grassy slopes is almost park-like. Most of the timbered slopes of the Brisco Range are open, but the burned areas of Upper Kootenay River, choked with small second-growth pine, are as thick as any of the Purcell slopes to the west.

Game in the region varies from plentiful to sparse. Elk (wapiti) are common in the western Rocky Mountains and sparse in upper Dutch and Findlay Creeks. Deer are ubiquitous, both black-tailed (mule) and white-tailed (virginia). Mountain goat are plentiful in the high ridges of the central Purcell Mountains. Black bear are plentiful at lower altitudes in most major creeks, and in midsummer grizzly bears are fairly common in some of the high cirque basins along the Purcell Divide.

The few small settlements are confined to the valley of Columbia River and Duncan–Kootenay Lakes.

Physiographic Development

The general aspect of the Purcell Mountains is one of a 'fretted upland' sculptured by intense alpine glaciation aided by frost and stream action. Thus unequivocal evidence of a preglacial, rolling, upland surface has been swept away by later alpine phases of the glaciation. The rather gentle upland surfaces at about 8,000 feet elevation west of Invermere, as well as north of Bugaboo Creek may be remnants of such a surface. Yet they may as easily be interpreted as partly due to erosion by an extensive mountain ice sheet and partly to the fact that they are underlain by thin-bedded slates, argillites, and pebble-conglomerates of the Horsethief Creek Group. Erosion by an ice sheet would be expected to yield more subdued topography, with such horn-like peaks as Mount Nelson and Mount Slade extending above the ice as isolated nunataks. Once the ice retreated, the rolling upland between 7,500 and 8,500 feet elevation was too low for intense alpine glaciation to develop for more than a very short time. Thus

incipient cirques occur only on north and east sides and high serrate ridges have not had the opportunity to develop as in the region immediately to the west.

It seems a reasonable assumption that great erosion has not taken place east of Mount Nelson in the vicinity of Paradise Mine, for deeply weathered secondary ores of the upper levels of the mine were not removed by erosion. This however, gives no clue as to the shape of the pre-Pleistocene topography, for Pleistocene erosion could well be responsible for the rather subdued topography in this region.

Examination of the Purcell Mountains from a distance shows a general accordance of summit levels but again this need not be interpreted necessarily as evidence of a former rolling upland deeply dissected by various erosional agents subsequent to uplift. As in many other mountain ranges it may represent only an accordance of levels due generally to the relatively greater efficiency of erosional agents such as frost wedging on higher peaks, that tends eventually to lower all exceptionally high peaks to the general level of the remainder of the range (von Engeln, 1949, p. 97–101).

Glaciation

The existence of a widespread continental ice sheet is nowhere proven in this area, though it is certainly clear that ice was at one time much more extensive than now. For example, erratics of granite were found a few miles northeast of Bugaboo Batholith on the high dissected upland northwest of Bugaboo Creek showing that the ice from the Bugaboo centre crossed the 8,000-foot ridge northeast of Cobalt Lake. Other Bugaboo granite erratics are found down Bugaboo Creek up to an elevation of at least 6,000 feet on the valley wall below the point at which the band of Toby conglomerate crosses the creek (Map 1326A, *in pocket*). Other similar boulders of granite, some as much as 20 feet on a side, are found in Bugaboo Creek as well as smaller ones south of the point at which Bugaboo Creek empties into the valley of the Rocky Mountain Trench. This indicates that the last movement of ice in this main, broad valley west of Jubilee and Steamboat Mountains was south. The ice may well have extended above 6,000 feet elevation along the valley sides but erratics or other deposits either have not been noted or have been eroded away. An erratic of Horsethief Creek Group pebble-conglomerate was noted on top of Steamboat Mountain at elevation 6,000 feet. This boulder may have come from the north or from the south, and indicates that the valley glacier was at least 2,000 feet thick, but not its direction of flow. Similarly, erratics of coarse granite occur just below 4,000 feet elevation east of upper Duncan Lake, again showing that the ice in this valley was at least 2,000 feet thick. The granite boulders there could have come from the head of Howser Creek (Horsethief Batholith), East Creek (Bugaboo Batholith), or the head of the Duncan River (Battle Batholith).

The drainage lines of the Purcell Mountains commonly cut across the main structural and stratigraphic trends except for Findlay and Dutch Creeks. However well established this drainage pattern may have been before Pleistocene glaciation, an examination of the topography shows immediately the extent to which this pre-existing stream pattern has been modified by cirque and valley glaciers, presumably acting for a considerable period. Typical forms of an alpine glaciated region are common: many glaciers above 8,500 feet elevation with associated moraines and outwash flats; abandoned cirques edging the flanks of serrate ridges; tarn lakes, paternoster lakes; hanging valleys and U-shaped valleys (*see*, for example Pls. I, II, and VI).

Possibly even greater evidence of a long period of effective glaciation may be noted in the asymmetric arrangement of the drainage, not only between streams flowing east and west from the sinuous divide of the Purcell Mountains, but between individual eastward- or westward-flowing streams. Hamill and Toby Creeks show the asymmetry of profile both in greater length of the east-flowing stream and steeper gradient of the west-flowing one. Both have a 'hanging' relation to the main valley, the Columbia and Duncan Rivers, respectively. Similarly the greater length of tributary streams flowing north into the main streams is particularly well shown by the tributaries flowing north into Horsethief, Forster, and Frances Creeks. It is equally evident that this is not a structural phenomenon, for rocks of the Mount Forster syncline plunge north to the south of Horsethief Creek, but similar rocks plunge south, north of Forster Creek, yet the overall stream pattern remains the same. This asymmetry of drainage pattern along both the major and minor divides is interpreted as showing the relatively greater efficiency of glacial erosion on the east and north sides of mountain ridges, reflecting not only greater accumulation of ice on the lee side of the prevailing westerly winds, but also much less melting on the shaded north and east slopes. The orientation and character of the longer tributary streams that enter the main streams from the north or northwest further demonstrate the greater efficiency of glacial erosion on the north and east sides of mountain ridges. An examination of the tributaries of Horsethief Creek demonstrates this principle. In contrast to the numerous, long tributaries from the south, Stockdale Creek is the only major stream entering from the northwest. Stockdale Creek not only turns east a short distance from its mouth, but it then works south as a result of headward erosion of valley glaciers. All along its course it cuts across the local structural and stratigraphic trends. Similar patterns may be noted in the tributaries of most of the other major streams, e.g., Findlay, Toby, and Carney Creeks. Thus the tendency for such tributaries is to work headward to the south and southwest whether the main stream flows east or west (*see* Map 1326A, *in pocket*).

Certain exceptions to the asymmetry of stream pattern may be noted on the map. Forster Creek, working headward into Horsethief Batholith, is much shorter than other major streams on the eastern slopes of the Purcell Mountains. Possibly the more competent granitic rocks of the Horsethief Batholith prevented rapid headward erosion, whereas Howser Creek has worked headward in relatively softer Horsethief Creek slates, phyllites, and pebble-conglomerates. Similarly the short Dunbar Creek and Templeton River terminate westward in the steep cliffs of Mount Nelson dolomites, although Bugaboo Creek, immediately to the north, has cut roughly along strike of the Mount Nelson rocks and worked headward to the west and south in the softer Horsethief Creek Group rocks behind the ridge at the head of Templeton River and Dunbar Creek.

Although valley glaciers once existed in all the main valleys to a depth of at least 2,000 to 3,000 feet and have widened and reshaped these valleys, the main evidence of glacial deposition exists in the Rocky Mountain Trench between the eastern Purcell front and the western limit of the Brisco Range. As shown by erratics on top of Steamboat Mountain, this valley was apparently completely filled with ice to a depth of up to at least 3,000 feet. Deposits of silt and gravels (stratified drift), that dip at very low angles on either valley side toward the river bed, are found on both sides of the Columbia River valley. This drift is everywhere considerably dissected by dry gulleys. Many deposits of drift both stratified and unstratified occur, in some places to a considerable depth, as on the benches west of Invermere and in the valley west of Steamboat and

Jubilee Mountains. Much of this drift both stratified and unstratified may well have been deposited in contact with ice because:

1. Patches of till occur everywhere; in some places all the drift is till and in some it all appears to be stratified drift.

2. A lag concentrate of boulders often appears on top of the drift—it may have formed on top of ice and been lowered gradually as the ice melted.

Drumlins, crag-and-tail phenomena, and kettle-and-ridge topography all occur in this valley west of Steamboat and Jubilee Mountains. Many meltwater channels cut along curves on the hillside that are convex to the south. Each successive channel to the north along the hillside is at a lower elevation, showing clearly that the ice retreated northward. The ice tongue thinned at the same time.

Although there are extensive ice fields and glaciers along the Purcell Divide, they show the effect of considerable retreat during the past 25 years or so. Valley glaciers are no longer the important agent in shaping this landscape.

Frost and Stream Action

Frost and stream action combined with slump and creep of material down valley walls are the active agents shaping and modifying the present landscape. Frost is the most effective agent on the mountain ridges and peaks that lie above timberline. Extensive talus slopes, in many places accumulating in rock glaciers, attest the efficiency of frost wedging. On gentler mountain slopes above timberline extensive areas of felsenmeer have been developed.

At present with all of the valleys and most cirques empty of ice, piles of talus at the base of steep slopes and numerous rock glaciers in steep, high valleys testify to the relatively puny efforts of minor present-day streams to carry away the frost-broken slabs and blocks of rock that were formerly transported with ease by long valley glaciers. Thus streams today are relatively inefficient compared with the alpine glaciers, in modifying or developing the landscape. Nevertheless in late June and early July during the period of high water streams carry large amounts of debris and most are actively down-cutting. Certainly, once the ice had retreated from the larger valleys and from most of their main tributaries rapid down-cutting began that has resulted in deep canyons at the lower ends of almost every stream (Pl. II). The lower ends of such streams as Toby, Horsethief, and Bugaboo Creeks are cut into drift and solid rock for depths up to several hundred feet.

Chapter II

THE PRECAMBRIAN

The Precambrian rocks of Lardeau east-half map-area consist of two great systems. The Purcell (Beltian) has an exposed thickness of over 31,000 feet of dominantly fine-grained clastics. Sedimentation in this succession began with thin-bedded impure quartzite (subgreywacke) interbedded with dark argillite (Aldridge Formation), all without marked shallow-water features. These rocks were succeeded by shallow-water impure quartzite, argillite, and slates. The entire upper part of the succession is characterized by carbonate and noncarbonate-bearing very fine clastics in thin-bedded sequences showing, at frequent intervals, much evidence of shallow-water deposition. The Purcell rocks were deformed prior to 800 m.y. into northerly trending open folds and faults. An unconformity separates this succession from the overlying Windermere System.

Deposition of the Windermere began with an extremely variable, polymictic basal conglomerate, followed by thick successions of slate, quartzite, grit, and oligomictic quartz-pebble conglomerate. These rocks show a remarkable lithological contrast to the underlying Purcell rocks. Red bed facies and coarse pebble-conglomerate as well as stream channels and other evidence of basin-edge deposition are found in the southeastern exposures of these rocks. To the northwest and west the succession thickens rapidly and becomes somewhat finer grained. Wherever observed the rocks of the Windermere lie concordantly beneath the lower Cambrian succession.

Purcell System

Precambrian rocks of the Purcell System[1] outcrop over about 800 square miles in the map-area. They are confined mainly to the eastern slopes of the Purcell Mountains from the southern map boundary north to Bugaboo Creek.

Walker (1926, p. 7), in Windermere area, within the central part of Lardeau map-area, established a division of the Purcell into an Upper and a Lower Purcell Series, in these terms, "... These two formations, Dutch Creek and Mt. Nelson and their equivalent strata, it is now proposed to designate the Upper Purcell series whose base is defined as being the horizon of the uppermost Purcell lava at the boundary between the Gateway (lowest horizon of the Dutch Creek Formation) and the underlying Siyeh."

[1] The rocks of the Purcell are here referred to as a system, unsatisfactory though this may be. Eventually work in this region will result in further subdivision of the individual formations of the present Purcell succession, and the Purcell will then become a supergroup with some individual formations within it becoming groups. This reconnaissance work has not resulted in such subdivision—therefore this terminology is not introduced here. In the descriptions that follow it will be seen that the Purcell is the equivalent of the Belt Supergroup to the south.

Table of Formations—Proterozoic

ERA	PERIOD OR EPOCH	GROUP OR FORMATION	LITHOLOGY	THICKNESS (feet)
PROTEROZOIC	WINDERMERE (HADRYNIAN)	HORSETHIEF CREEK GROUP	Varicoloured slate, argillite, and phyllite; quartzite, grit, and quartz-pebble conglomerate; minor limestone	3,000 to 8,000
		TOBY FORMATION	Polymictic conglomerate with pebbles, cobbles, and boulders of varied composition; matrix of impure limestone, shale, and quartzite	0–1,500
	UNCONFORMITY			
	PURCELL (HELIKIAN)	MOYIE INTRUSIONS	Metadiorite and meta-quartz diorite sills	
		INTRUSIVE		
		MOUNT NELSON FORMATION	Buff and grey dolomite and dolomitic limestone, slate, argillite, quartzite	∽4,000
		DUTCH CREEK FORMATION	Varicoloured argillite and slate, quartzite, and some carbonate rocks	±4,000
		KITCHENER–SIYEH FORMATION	Very thinly bedded quartzite, black argillite, and some dolomite, sandy dolomite, and limy argillite	6,500
		CRESTON FORMATION	Green chloritic quartzite, grey quartzite with purple laminae, green and grey phyllite and argillite	8,000
		ALDRIDGE FORMATION	Upper division: Sericitic quartzite, argillite, thin-laminated argillite and quartzite	∽9,500
			Lower division: Fine-grained quartzite	unknown
		Base not exposed		

This division, based on the occurrence of the Purcell lava, is useful as a time-stratigraphic marker in the Clark and southern Flathead Range adjacent to the International Boundary in the Rocky Mountains (Price, 1964, p. 410). However, it is not a useful dividing horizon in the extensive Purcell Mountain outcrops of the Purcell System, for the lava is either absent or occurs at more than one horizon (Reesor, 1957; Leech, 1958, 1960). Since the division into Upper and Lower Purcell is inapplicable in the area in which it was originally designated it is suggested that this usage be dropped. In the discussions that follow the formal designation of Upper and Lower Purcell, originally established in this area, will not be used.

Aldridge Formation

Lower Division

Within this map-area only a very little of the lower division of the Aldridge Formation is found, principally as thin septa between massive sills of Moyie Intrusions in the southeast part of the map-area. In this locality, south of the headwaters of Doctor Creek, these rocks are thinly laminated, fine-grained quartzite, in places exceptionally rusty weathering, elsewhere white to grey weathering.

The lower division here represents a minor extension of the much larger outcrops in Dewar Creek map-area to the south. A more extensive lithologic and petrographic description is given in the report on the Dewar Creek map-area (Reesor, 1958, p. 7–9).

Upper Division

The upper division of the Aldridge Formation outcrops over about 75 square miles in the southeast corner of the map-area and is about 9,500 feet thick. In this locality, as in Dewar Creek area to the south (Reesor, 1958, p. 10–14), this division consists of a great thickness of thin-bedded, impure quartzites with minor interbeds of black argillite and laminated light and dark grey argillaceous quartzite. The central part of the formation is traversed by a number of diorite and quartz diorite sills of the Moyie Intrusions.

The average thickness of quartzite beds is commonly less than a foot yet competent, cliff-forming successions up to several hundred feet are encountered in the lower part of the section in which beds 2 feet or more thick predominate with only very minor black phyllitic partings. In those successions in which quartzite beds range in thickness from 2 to 6 inches, black phyllite and black and grey laminated phyllite and phyllitic quartzite form up to 50 per cent of the section.

The quartzites weather generally light grey or almost white in some successions but many joint faces, and thinner, more deformed beds commonly weather rusty brown and from a distance this sequence of rocks is quite rusty in appearance. The argillites and laminated impure quartzites weather black or grey, though they, too, may be rusty weathering near a Moyie sill or a granitic intrusion.

In contrast with the succeeding formations of the Purcell System primary sedimentary features are not abundant in the Aldridge Formation. Graded bedding is sometimes evident in the thin-bedded successions in which a quartzitic layer grades upward into a black, dominantly pelitic layer. It is not uncommon in some localities to find black phyllite in sharply pointed waves, of several inches wavelength, penetrating an overlying quartzitic bed. This is interpreted as deformation within rapidly deposited quartz sands that forced relatively mobile muds upward into the overlying sands.

In thin section the quartzites of the upper Aldridge division are seen to consist predominantly of very fine quartz. Individual grains of quartz vary from angular to subrounded, though they are invariably much recrystallized, and, may be from 0.01 to 0.5 mm in size. It is seldom that particles of more than a half millimetre are noted in these rocks. In some thin sections sericite composes less than 10 per cent of the total, but in most it comprises up to perhaps 25 per cent of the rock in the form of scattered folia well distributed through the grains of quartz. In places laminae within a bed of quartzite may contain up to 50 per cent sericite in wavy masses with intermixed, fine, silt-sized quartz particles. Scattered grains of albite, orthoclase, and oligoclase may be found in many thin sections. Rock particles are not identifiable in these fine-grained rocks.

Thus the thin section examination shows the predominant rock in the upper division of the Aldridge Formation to be sericitic quartzite or siltstone, derived from a subgreywacke that contained generally less than 25 per cent clayey material and 1 or 2 per cent feldspar and no rock particles.

The less dominant light and dark grey or black laminated rocks in thin section are seen to consist of extremely fine quartz of silt size intermixed with wavy masses of sericite with some chlorite. Darker bands contain more sericite, lighter bands more quartz. Similarly, the black phyllite partings of the sericitic quartzite consist generally of wavy masses of muscovite and sericite.

The following stratigraphic section, showing approximate mapped thicknesses, was measured north from the head of Doctor Creek along the north-trending ridge over Doctor Peak, to the base of the Creston Formation. This section summarizes the gross lithology of the upper division.

Conformable, gradational contact with overlying Creston Formation

Aldridge Formation, upper division	Thickness (feet)	
	of unit	from base
Argillite, black, rusty weathering with some laminae of grey quartzitic argillite, many sections and beds of both rusty brown weathering and green weathering fine-grained quartzite; minor black argillite with wide irregular bands of light grey siliceous argillite	800	9,500
Quartzite, grey weathering, rusty in joints, 2- to 4-inch beds, very fine grained; thick section of black argillite near base; minor laminated black and grey argillite associated with the quartzite	1,000	8,700
Quartzite, brownish stained with a light green hue grey to greenish grey, very fine grained; base of this section predominantly of crenulated black phyllite	1,800	7,700
Sill, metadiorite	100	5,900
Quartzite, grey weathering, rusty on some faces and in joints, in beds to 18 inches, very fine grained, with partings of black argillite and laminated argillaceous quartzite a few inches to a few feet thick	750	5,800
Sill, meta-quartz diorite	50	5,050

Aldridge Formation, upper division	Thickness (feet) of unit	Thickness (feet) from base
Quartzite, grey weathering, beds to 24 inches, very fine grained; argillaceous quartzite, weathering brown to buff; black argillite, the last two rock types predominate near base of this section	600	5,000
Sill, meta-quartz diorite	200±	4,400
Quartzite, grey weathering, 2- to 24-inch beds, very fine grained; very thin, ¼- to 2-inch sheared partings of black, rusty weathering argillite; minor, light and dark grey laminated argillaceous quartzite in beds to 2 inches thick	4,200	4,200

Contact with lower division of the Aldridge Formation not exposed in head of Doctor Creek.

In Dewar Creek area to the south the upper part of the upper Aldridge division consists of rusty weathering, very thinly laminated black argillites and arenaceous argillites (Reesor, 1958, p. 10–11). The base of the Creston Formation in the eastern half of Dewar Creek map-area consists of easily recognizable argillites, arenaceous argillites, and siltstones commonly showing abundant mudcracks and other shallow-water features. In Lardeau map-area neither of these features is present and the Aldridge Formation grades imperceptibly northward into Creston Formation through a sequence of about 600 feet or more of mixed grey, black, and green quartzites and phyllites. The division between the Aldridge and Creston Formations was arbitrarily selected at a point where green argillite and green weathering quartzite predominate over the rusty weathering argillite and light grey weathering quartzite. This division was highly arbitrary and perhaps varied as much as several hundred feet from point to point.

Creston Formation

The Creston Formation occurs in a broad belt that trends across the north-plunging geanticline of Purcell strata in the southeast part of Lardeau map-area. It outcrops over an area of at least 75 square miles and consists of fine-grained clastic rocks ranging from quartzite to argillaceous quartzite and argillite or phyllite. They are dominantly grey to green weathering in contrast to the rusty and grey weathering Aldridge rocks below. The estimated thickness is not less than 8,000 feet.

The lithology of the Creston is characterized by grey, watery green to green quartzite and chloritic quartzite. Some successions are dominantly quartzite in massive beds to 12 inches thick with very thin green to dark phyllite partings. Grey quartzite is commonly characterized by purple laminae or an irregular purple mottling formed by purple coloured layers up to an eighth inch wide and varying in spacing from a fraction of an inch to more than an inch. In some cases the light coloured quartzite is characterized by dark grey laminae a quarter inch or less thick. Other successions within the Creston are characterized by green and dark grey laminated, cleaved phyllite in ¼- to ½-inch layers interspersed with green phyllitic quartzite that forms about one half

the section. Dominantly pelitic successions may in some localities be light and dark green banded phyllite and phyllitic quartzite, or grey and purple laminated argillite. Thus the Creston outcrops range from dominant, cliff-forming quartzites to dominant, recessive pelites and semipelites (*see* Pls. XI and XII). Primary sedimentary structures are relatively rare in the Creston of Lardeau map-area in contrast to parts of the Creston of the area to the south (Reesor, 1958, p. 15).

When seen in thin section Creston rocks are a very fine grained assemblage of quartz, chlorite, and albite, with very minor sericite. Grain size is commonly less than 0.1 mm but muscovite euhedra may be up to 0.5 mm long. Rarely small grains of biotite may be seen to have grown across the faint foliation. Pure quartzite is relatively uncommon, but where present consists of an allotriomorphic mosaic of quartz grains with scattered shreds of sericite throughout the section. Argillaceous laminae consist of a matrix of very fine quartz, chlorite, and muscovite with grains of quartz and albite up to 0.1 mm forming up to 50 per cent of the rock. Primary textures are not preserved in these rocks, but the assemblage has clearly been derived from a succession of siltstone, argillaceous siltstone, and shale.

No complete section of the Creston Formation is exposed in the eastern part of the Purcell Mountains, the area of least metamorphism and deformation. The two sections tabulated below show the lithology and transition at the base as well as at the top of the Creston. Thicknesses are estimated.

Section No. 1

Section showing gradation with underlying Aldridge Formation on slope due south of 9,000-foot peak due south of the big bend of Findlay Creek, between the Creston–Aldridge contact at elevation 6,900 feet and the peak.

Present erosion surface	Thickness (feet)	
	of unit	to base
Argillaceous quartzite, thin alternating beds weathering pale green and black; pale green beds are arenaceous, black beds are argillaceous; scattered beds of green quartzite up to 6 inches thick	900	2,400
Argillite, grey to pale green, weathering buff-brown to pale green; laminated argillaceous quarztite, with scattered 3- to 4-inch beds of quartzite, rusty weathering no longer common, replaced by buff, pale green and patchy red; some dark and light green laminated argillite	1,500	1,500
Arbitrary, gradational, conformable, contact with underlying Aldridge Formation.		
Upper Aldridge division		
Argillite, black, thinly laminated, black to rusty weathering, in part arenaceous, interbedded grey quartzite, very fine grained, dense, rusty weathering, in beds 3 inches to 18 inches; argillite near top of this section is laminated, up to ½ inch, and weathers black to patchy green	700	700

Section No. 2

Section from elevation 5,000 feet north of the big bend of Findlay Creek to the Kitchener–Siyeh Formation contact at elevation 8,000 feet below Mount St. Maur.

	Thickness (feet)	
	of unit	above base
Green argillite and buff weathering calcareous or dolomitic argillite, alternate buff and green bands occur every 4 to 16 inches; all well cleaved	500	5,500
Argillite, arenaceous, in alternate beds to ½ inch thick of purple and light green; green argillaceous quartzite with purple laminae	1,000	5,000
Quartzite, very competent, purple and purple laminated and 'mottled' grey coloured, buff to limonite rusty weathering on joint surfaces; purple laminae variable in thickness with individual laminae $\frac{1}{32}$ to ¼ inch, spaced up to several inches	1,100	4,000
Quartzite, argillaceous and chloritic, grey to light grey, grey weathering; purple laminae and purple 'mottling'; very little purplish grey and light green argillite	1,900	2,900
Quartzite, grey, grey weathering with purple laminae up to ⅛ inch wide, sericitic and chloritic; minor bluish black argillite and pure light grey quartzite	1,000(?)	1,000
Base not exposed		

The transition from Creston to Kitchener–Siyeh Formation is not difficult to recognize in the excellent exposures along the mountain ridges north of the big bend of Findlay Creek. On timbered hillslopes, or in the more highly metamorphosed and tightly folded strata westward toward the Purcell Divide, a precise location, within even a few tens of feet, is almost impossible. In good outcrops the contact is marked at the first occurrence of a 200-foot section of limy, buff, and grey slate. There is, however, up to 300 feet of grey to green very thinly laminated pelites above this succession that in poor outcrop or in metamorphosed successions are similar to the Creston. They are considered here to belong to the Kitchener on the basis of the absence of typical green quartzites and their extremely thin lamination, a quarter inch or less, that is characteristic of the Kitchener.

The Kitchener–Siyeh and Dutch Creek Formations

These formations are best considered together, for in parts of Lardeau east-half their precise distinction as separate units is not possible. Schofield (1915) used both Kitchener and Siyeh as separate formations in the vicinity of the Rocky Mountain Trench in the Cranbrook area. Most workers in the Purcell Mountains since that time have experienced difficulties in applying these formations as originally used. Thus, Rice (1937, p. 10–11) in the Cranbrook area used the Siyeh somewhat differently from Schofield. In Nelson east-half Rice (1941, p. 10) no longer considered the divi-

sion between Kitchener and Siyeh possible and mapped them as a single formation. Similarly Leech (1958; 1960) in the same general region accepted the Kitchener–Siyeh as a single formation.

Within Lardeau east-half, a succession of green argillites and quartzites similar to those mapped above Kitchener Formation in Dewar Creek map-area (Reesor, 1958, p. 20–21) can be recognized along the lower part of Dutch Creek. However, a few miles to the west along Dutch Creek these rocks no longer form a distinctive unit at the top of the Kitchener, and thus Kitchener–Siyeh is here used as a single formation. In addition to the doubtful recognition of the Siyeh as a separate formation within the Purcell Mountains, it is not stratigraphically equivalent to the Siyeh as used in the Rocky Mountains of southern Alberta (Price, 1964). The Siyeh as used there is largely equivalent to the Kitchener–Siyeh as used in the Purcell Mountains.

The precise distinction of the Dutch Creek Formation above the Kitchener–Siyeh is equally beset with difficulties in Lardeau east-half. In the Windermere area Walker (1926, p. 7) established the Dutch Creek Formation as the group of rocks lying above the Purcell lava and below the Mount Nelson Formation. The Purcell lava was seen by Walker only in one outcrop on lower Skookumchuck Creek, about 20 miles south of Windermere area. The lava is nowhere found in Lardeau map-area and the division between Kitchener–Siyeh and Dutch Creek is uncertain or impossible in localities of poor exposure, or in areas of intense development of cleavage and increasing metamorphism westward from a point a few miles east of Coppercrown Mountain. In this locality it has been necessary to combine Kitchener–Siyeh and Dutch Creek (*see also* Leech, 1959). In lower Dutch Creek the division between Kitchener–Siyeh and Dutch Creek Formations has been marked above a succession of green, noncalcareous argillites and impure quartzites at the top of the Kitchener–Siyeh Formation. There can, however, be no certainty that this is the horizon equivalent to that of the Purcell lava on Skookumchuck Creek.

Distribution and Lithology

The Kitchener–Siyeh Formation is found in a narrow band extending from Whitetail Lake to the vicinity of Trikootenay Peak, and covers an area of approximately 120 square miles. The overlying Dutch Creek Formation is found in a narrow belt north of Dutch Creek from the east boundary of the map-area westward to Toby Creek, thence northward in a broad zone along the central Purcell Mountains to Horsethief Creek. In all, this formation underlies an area of about 300 square miles.

The thickness of these formations is best estimated along the eastern limit of their exposure. The Kitchener–Siyeh, from a point at the base southeast of Mount St. Maur to a point at the upper contact north of Dutch Creek, is at least 6,500 feet thick. Thicknesses of this formation in the western limits of outcrop are impossible to measure with precision, but are roughly of this order of magnitude.

Since most of the region of outcrop of Dutch Creek Formation occurring in Windermere map-area was not re-examined in this work, except along its southern boundary, thicknesses are difficult to estimate. North of lower Dutch Creek it is between 4,000 and 5,000 feet thick. Walker (1926, p. 10), in this area (Fig. 2), recognized a thickness of 3,500 feet but nowhere recognized the base of the formation (and thus did not have to apply the division of the Upper and Lower Purcell at the base of the Dutch Creek that he had established south of Windermere map-area). Far to the southwest in Rose Pass, Rice (1941, p. 11) measured a section of Dutch Creek formation at 4,300 feet.

The base of the Kitchener–Siyeh Formation is marked by carbonate-bearing slate and argillite in alternating buff and green weathering thinly bedded successions a few inches to a few feet thick. Higher in the section green weathering slate is not common and the formation is characterized by black and light grey, thinly interbedded slate and argillite, with much grey quartzite, often rose to light red weathering, in beds as much as 2 inches thick. Typically the rose weathering quartzites contain some carbonate in the matrix, and the surface weathers rough. These quartzites are the dominant rock type in the central part of the Kitchener–Siyeh Formation. Some successions contain limestone, buff weathering dolomite, sandy dolomite, and limy argillite. Commonly the black argillite interbeds in quartzite successions show well-developed mudcracks, and some sandy layers show a faint crossbedding. Some of the limestone or argillaceous limestone beds show a characteristic 'molar-tooth' structure. Approximately the upper 1,500 feet of the Kitchener–Siyeh Formation along lower Dutch Creek is characterized by nonlimy, green weathering, impure quartzite and thin-bedded argillite. The argillite is often thinly bedded in $\frac{1}{4}$- to $\frac{1}{2}$-inch beds of alternating light and dark green layers; some layers are purple and green and some are buff and green. Farther west, with increasing development of cleavage and isoclinal folds, the upper Kitchener–Siyeh becomes a series of cleaved slates and silty slates, buff, rose, or green weathering, that are not easily distinguished from the overlying Dutch Creek Formation. Near the Purcell Divide, at the head of Dutch Creek, rocks become more highly metamorphosed and are phyllites and phyllitic quartzites (*see* Chapter V).

The Dutch Creek Formation contains many rock types characteristic of the underlying Kitchener–Siyeh. Varicoloured slates, which often change colour along strike, green and buff, white to grey quartzites, grey limestone, buff dolomite, and sandy dolomite are all found in this formation. The base of the section north of Dutch Creek consists of light red to grey weathering quartzite, often in beds as much as 10 inches thick. There is also some cream to light buff weathering dolomitic limestone and sandy dolomite, in some localities very thinly laminated. Above this, although some quartzite successions are found along with some dolomite and limestone, the Dutch Creek Formation is dominated by rapidly alternating, grey, black, and buff or silty slates. Successions of any particular colour are characteristically very thin bedded and may be a few feet to a few tens of feet thick.

When seen in thin section rocks of these formations are extremely fine grained with individual grains not more than 0.05 mm even in the quartzite beds. Most dolomitic beds consist of a fine mosaic of carbonate with silt-size quartz forming 5 to 50 per cent of the rock. Argillaceous or slaty rocks in the eastern exposures consist of very fine chlorite, quartz, and locally sericite. Phyllites and phyllitic quartzite farther west contain coarser shreds of sericite (muscovite) and chlorite with anhedral quartz.

Contacts between these formations and the Creston below and Mount Nelson above are gradational and conformable. In places the Toby Formation rests unconformably on the Dutch Creek Formation. The difficulty in making divisions within these formations has been discussed above. Nevertheless, there are recognizable lithological successions within the sequence, and in the well-exposed region north and south of central Dutch Creek from Mount Abel to Coppercrown Mountain it would be possible to select lithologically consistent units for mapping at larger scales than used in this reconnaissance. The regional units, Kitchener–Siyeh and Dutch Creek Formations, could be classed as rock groups, and formations could be delineated within them, at least in the high mountains between Mount St. Maur and Horsethief Creek.

Mount Nelson Formation

This formation was named and defined by Walker (1926, p. 7) from typical exposures on, and east of Mount Nelson in the Windermere area. According to Walker these formed, "... a hitherto undescribed formation with distinctive lithologic characters ... above typical Roosville beds in the vicinity of lower Skookumchuck Creek." Although the Mount Nelson Formation contains rock types found in parts of the underlying Kitchener–Siyeh–Dutch Creek Formations it is, nevertheless, as a whole a distinctive unit at the top of the Purcell System in the southeastern Canadian Cordillera, and is used here essentially as defined by Walker.

The Mount Nelson Formation is exposed over an area of more than 200 square miles in Lardeau east-half. The most extensive outcrops are found along the eastern slope of the Purcell Mountains from Brewer Creek to Bugaboo Creek, with a narrow belt along the Purcell summit east and south of Mount Toby. Walker (1926, p. 10) quotes a thickness of approximately 3,400 feet for this formation and certainly in the region north of Frances Creek it is at least this thick and could be as much as 4,000 feet thick (*see* cross-section F-G, Map 1326A, *in pocket*).

Lithologically the Mount Nelson Formation is characterized by thick cliff-forming, competent successions of dolomite and dolomitic limestone. It is commonly reddish buff weathering and light grey to light purple on a fresh surface. Although it may be well bedded in layers from a few inches to two feet, it is sometimes very thinly laminated, less than 1/64 inch wide, often emphasized by differential weathering. Dolomite or dolomitic limestone may in some localities be interbedded with purple argillite. In many localities the dolomite is characterized by dark, discontinuous lenses or nodules of chert arranged parallel with bedding. Other extensive successions within the Mount Nelson Formation consist of argillite and slate of varying colours from grey to black and purple. They may be very thinly laminated and platy to massive, and in some localities exhibit a good slaty cleavage. A distinctive purple argillite with brownish polka dots occurs in the upper part of the formation.

The Mount Nelson Formation is marked by a basal quartzite often very dense and siliceous, medium grained and white. It may be as much as 150 feet thick and on Templeton River and Dunbar Creek is overlain by dolomite in well-bedded sequences. An upper quartzite, white, dense, and fine grained, up to 350 feet thick, may also be found in the formation. It may contain some interbeds of black argillite as on the mountainside due west of Steamboat Mountain.

Mudcracks in shaly successions and ripple-marks in quartzite are rather common in the Mount Nelson; crossbedding on the other hand is rare. Algal structures are present in some horizons near the middle of the formation. They were noted at roughly the same horizon on Bruce Creek and again on upper Forster Creek (Pl. III). West of the Toby conglomerate between Forster and Frances Creeks and about 200 to 300 feet below the Toby conglomerate, is a conglomerate consisting of limestone and dolomite blocks and boulders in a brown dolomitic matrix. They are overlain by slate, dolomite, and quartzite. Similar limestone pebble or cobble conglomerate is found north and south of lower Jumbo Creek. These rocks are considered a part of the Mount Nelson succession since typical Mount Nelson strata overlie them. Local solution breccias are sometimes encountered in the dolomites of this formation. Surrounding beds are undisturbed and some of the more extensive breccias may have had a similar solution cavity origin. All the above features are considered to indicate shallow-water deposition of the Mount Nelson Formation.

In thin section quartzite in the Mount Nelson is seen to range in grain size from 0.2 to 0.8 mm. Grains are well rounded, often spherical, commonly with quartz cement in optical continuity and with minor hematite and a few shreds of sericite. Impurities do not form more than 2 per cent of the rock. A more impure argillaceous quartzite (quartz greywacke or subgreywacke) consists of rounded to subrounded quartz grains 0.15 to 0.2 mm, with some grains to 0.4 mm. The matrix consists of fine-grained, clayey material with scattered patches of carbonate. There is a scattering of hematite throughout, and some accessory zircon. In thin sections of quartzite showing grains between 0.3 and 0.8 mm and a fine fraction less than 0.1, the former are rounded and perfectly spherical, the latter show poor sphericity and are angular.

Thin sections of dolomite consist of fine-grained carbonate often with much interstitial hematite and scattered silt-sized quartz grains throughout. The table below shows partial analyses for a number of dolomitic rocks from various horizons within the formation.

TABLE I | *Analyses of dolomite, Mount Nelson Formation*

Spec. No.	286	288	295	300	305	341	383	386	*
CaO	24.96	27.42	27.70	20.74	15.58	22.86	25.05	22.54	31.27
MgO	17.14	19.93	18.64	14.63	11.43	16.40	17.67	15.54	21.12
CO_2	38.30	42.80	42.75	31.85	24.35	36.30	38.10	34.55	47.22

*Dolomite (Deer *et al.*, 1966, p. 474).
GSC rock and mineral analysis laboratory; analysts: M. Staples, G. Bender.

A partial section at the head of Templeton River is shown below and for comparison a similar section measured by Walker at Mount Nelson is included (*see also* section of Toby Formation).

Section from a point just above Templeton Lake to large peak just north of the lake (*see* Pl. I). Thicknesses estimated.

Toby conglomerate—cobbles and boulders up to 16 inches in sandy and dolomitic matrix

	Thickness (feet)	
	of unit	above base
Unconformity		
Mount Nelson Formation		
Argillite, grey and black, dark weathering, thinly bedded	200	2,200
Dolomitic limestone, purple, brown weathering; argillite, grey, greenish grey weathering in thin interbeds to 6 inches thick; argillite, purple with brown bleached zones to ¾ inch diameter	300	2,000
Argillite, grey, carbonate-bearing, grey to buff weathering, interbedded with dolomitic limestone, grey, brown weathering, all in beds up to several inches thick	100	1,700

	Thickness (feet)	
	of unit	above base
Limestone, blue-black, interbedded with dolomite, grey, buff weathering, all in beds 2 to 6 inches, rarely up to 3 feet or more; some nodules and lenses of chert	100	1,600
Dolomite, light grey, dense, buff to red-brown weathering	150	1,500
Quartzite, grey, red-brown weathering, thin bedded	10	1,350
Dolomite, light grey, buff to red-brown weathering, fine-grained, in beds 6 to 10 inches, upper part is very thinly laminated, ⅛ inch or less	450	1,340
Argillite, black, thinly laminated with lenticular stringers and lenses of dark grey, argillaceous quartzite	150	890
Argillaceous quartzite, dark green, green to grey weathering, thinly laminated; minor interbedded black argillite	50	740
Dolomite, grey, buff weathering, minor dark argillite	20	690
Quartzite and argillite, grey, greenish grey weathering, beds 2 to 12 inches	20	670
Dolomitic limestone, dark grey, dirty grey weathering; very thinly laminated but massive cliff-former	150	650
Argillite, grey to black, and dolomite, grey, brown weathering, interbedded, the former in 1- to 2-inch beds, the latter in 2- to 6-inch beds	250	500
Dolomite, dark grey, buff weathering, very fine grained, thin-bedded	100	250
Quartzite, white, medium-grained, thin-bedded, some ripple-marks; some interbedded green argillite with mudcracks	150	150

This unit exhibits considerable variation along strike and is not the basal quartzite

Base not exposed

Section between Paradise Basin and Mount Nelson (Walker, 1926, p. 11)

Unconformity	
Dark grey to black slate	130+
Grey, siliceous, magnesian limestone	200
White quartzite (upper)	240
Grey, siliceous, magnesian limestone	100
Purplish slate	100
Purplish magnesian limestone	50
Purplish slate	20
Purplish magnesian limestone and slate	170
Grey magnesian limestone	50
Blue-grey magnesian limestone	100+
Several hundred feet of highly crumpled beds . . . ?	
Blue to grey, siliceous, magnesian limestone	150+
Buff weathering purplish slate	80
Purplish slate	80
Grey slate	50
Blue to grey magnesian limestone	95
Greenish slate	90
White quartzite (lower)	160
	1,865+

The rocks of this formation conformably overlie the Dutch Creek Formation and are in turn overlain unconformably by the Toby conglomerate. As a result the upper part or, in some localities, all the Mount Nelson may be missing.

Windermere System

Walker (1926) first recognized and defined the Windermere System[1] in Windermere area. He divided it into a basal conglomerate, the Toby Formation, and the Horsethief Formation. Later Walker (1929, p. 9) extended the Windermere to include the younger Hamill 'Series', Badshot Formation, and Lardeau 'Series' of Lardeau area. Evans (1933), in Dogtooth Range of the northern Purcell Mountains, renamed the Horsethief Formation the Horsethief Creek Formation and finally Walker (1934), in Salmo area near the 49th Parallel, named it the Horsethief Creek Series.

Park and Cannon (1943) and Campbell (1947) in northeastern Washington, Little (1950) in Salmo area, and Wheeler in Rogers Pass (1963) and Lardeau west-half (pers. com. 1967) discovered fossils in rocks equivalent to the upper part of the Hamill Series, Badshot Formation, and succeeding Lardeau Series that indicated these rocks to be of Lower Cambrian and later age. Therefore, Walker's original (1926, p. 13–20) definition and use of the Windermere is retained, and includes only the Toby Formation and the Horsethief Creek Group with, locally, the Irene Volcanic Formation. The last is found only in the region southwest of Kootenay Lake about 60 miles south of Lardeau map-area (Rice, 1941, p. 15–17).

Toby Formation

Distribution and Lithology

This formation was named (Walker, 1926, p. 13) from its extensive, easily accessible occurrences on Toby Creek immediately west of Invermere. In Lardeau map-area, east-half, the Toby Formation occurs along the limits of the major, north-plunging anticlinorium of Purcell strata, and outlines the major structures of the eastern Purcell Mountains.

This basal formation of the Windermere consists of a polymictic conglomerate exhibiting extreme variability of occurrence, composition, and thickness. In some localities it is absent, in others it varies in thickness from a few feet to more than 1,500 feet.

Lithologically the most remarkable characteristic of the Toby Formation is its variability from point to point throughout the region of exposure. Particles found in the Toby conglomerate are pebbles, cobbles, and boulders of the underlying Purcell rocks. They consist principally of dolomite, quartzite, and slate in all shapes and sizes. At one locality brownish weathering, light coloured dolomite predominates; a few hundred yards or less along strike quartzite cobbles predominate, or again both may be freely intermixed in all proportions. In the vicinity of the Rocky Mountain Trench some gra-

[1] As with Purcell System above, the use of Windermere System here is something less than precise. It consists essentially of a group and a formation deposited during the interval from at least 800 m.y. to the Early Cambrian. Since no specific further subdivisions of the Horsethief Creek Group have been attempted in this reconnaissance work, no changes in terminology have been introduced. Such changes are best left until new work adds sufficient data to warrant changes in nomenclature.

nitic gneiss cobbles as much as 6 inches in largest diameter are found in the Toby Formation, in a few isolated outcrops west of Windermere Lake. Boulders, and very much larger similar material, were found by Leech (1959) to the south.

Larger cobbles and boulders of quartzite may have poor sphericity, but show good rounding of corners. Almost invariably where cobbles of rounded to subrounded quartzite predominate the few scattered, brownish weathering, dolomite blocks are angular and usually much larger than the surrounding quartzite particles (Pl. III B). If dolomite particles predominate, some may be rounded. In those phases of the Toby conglomerate in which particles form up to 90 per cent of the total rock and in which particle sizes range from a fraction of an inch to several feet, the smaller particles are almost invariably the most angular, but the larger particles, particularly of quartzite, almost always show rounding of corners, whatever may be their overall shape.

Particles distributed in the matrix may form up to 90 per cent of the rock, or they may be so sparsely distributed that only one or two pebbles or a cobble is found per square yard of exposed surface. In the latter the rock might rightly be called a pebbly or cobbly slate. They are here referred to as conglomerate since they are always continuous along strike with, or interbedded with conglomerate.

Particles in the localities in which the conglomerate has apparently undergone little or no internal deformation are generally disoriented. At the opposite extreme, along the western limit of outcrop, the conglomerate may be so deformed that all cobbles and boulders are flattened in the plane of schistosity (Pls. IV and V).

The matrix of the Toby conglomerate, as diverse as the particles contained, most often consists of argillite, phyllite or schist, depending on the degree of deformation and metamorphism which the formation has undergone. Nevertheless, grit, quartzite, and limestone may form the matrix and furthermore each rock type may vary rapidly to the next along or across strike.

At one locality, just north of upper Frances Creek, the matrix of the conglomerate consists of a vesicular andesitic flow (Pl. V A). In thin section the vesicles are seen to be lined with quartz and filled with calcite. Although many original textures of the igneous rock are preserved there is much alteration and some shearing. Laths of plagioclase are oligoclase–andesine; all mafic minerals are chloritized.

The conglomerate at this locality otherwise contains cobbles and boulders of the same range of composition and size as found elsewhere in the Toby Formation. There appear to have been several flows for thin sedimentary interbeds of dolomitic siltstone are found within the conglomerate. The upper few feet of these beds appears to be more metamorphosed than the lower part indicating a volcanic flow followed by sedimentation, in turn followed by further flows. A few miles to the south, just north of Horsethief Batholith the Toby Formation contains cobbles of greenstone not seen elsewhere in this map-area. It thus appears that locally not only were volcanic flows contemporaneous with the deposition of the Toby Formation, but that penecontemporaneous erosion of this or nearby volcanic material provided debris locally for the Toby.

Several specific localities demonstrate particularly well the variability of the Toby conglomerate. At Rocky Point on Bugaboo Creek, about 20 miles west of Spillimacheen, the Toby Formation is about 100 feet thick. The base of the conglomerate consists of very angular, disoriented, dolomite fragments, from a fraction of an inch to several feet across, set in a matrix of dolomite that forms not more than 10 per cent of the rock

volume (PI. IV B). At intervals across the strike of the conglomerate blocks of quartzite predominate, generally with a quartzitic matrix. Only a small number of the quartzite cobbles and boulders have rounded corners. Again certain layers of the conglomerate may contain both dolomite and quartzite fragments. Black chert fragments are often associated with the dolomite, presumably from the same beds of dolomite of the underlying Mount Nelson Formation that contain many layers and discontinuous stringers of chert. At an elevation 1,000 feet above and north of the Bugaboo Creek road, the conglomerate appears to thin suddenly and it may be seen to truncate underlying, well-bedded dolomite. At one point a large boulder of quartzite lies against the dolomite beds. At an elevation of 2,500 feet above the road, the conglomerate consists of less than 30 feet of scattered, rounded, quartzite cobbles in a shaly matrix.

On the mountain top north of Frances Creek near the Rocky Mountain Trench, the conglomerate is several hundred feet thick and consists almost exclusively of very angular and slabby blocks of purple and grey quartzite, purple argillite and white quartzite in a matrix of purplish, quartzitic argillite. Some of the white quartzite cobbles, up to 10 inches in diameter, are subrounded. The remaining particles here, through 500 feet of the Toby Formation, are flat angular slabs varying from a fraction of an inch to 5 or 6 inches long and 1 to 3 inches thick, oriented parallel with the plane of the bedding. All occur in a very competent and blocky outcrop and here indeed the Toby conglomerate might be more accurately termed a breccia. Yet, on the western limit of this outcrop, the conglomerate again consists of scattered, rounded, quartzite cobbles in a grey, slaty matrix.

On the east wall of the Purcell Mountains west of Steamboat Mountain and north of the outcrop of Jubilee dolomite, the variability both along and across strike of the conglomerate is well demonstrated. At this point west of, and above the fault the section is as follows:

Present erosion surface

Toby Formation	Thickness (feet)	
	of unit	above base
Quartz-pebble and boulder-conglomerate with dark grey slaty matrix; particles, well rounded, average 1 to 3 inches but boulders a foot or more occur; particles may be white quartzite, grey or purple quartzite and dolomite; matrix predominantly argillaceous	++50	++580
Slate, bright purple with irregular, unevenly spaced bright green laminae at intervals of 1 to 8 inches	±70	530
Argillite, grey, grey weathering; contains scattered cobbles of white quartzite up to 4 inches in diameter; at some horizons quartz-cobble conglomerate beds up to 4 feet thick	±250	460
Slate, rusty red to brown weathering, black; all very thinly laminated	±100	210
Quartzite, dark weathering, dark green; alternating with dolomite, buff weathering, grey, very dense and fine grained; many of the dolomite beds contain scattered quartz grit	±100	110

Toby Formation	Thickness (feet) of unit	Thickness (feet) above base
Quartz-cobble and pebble-conglomerate, very well sorted, well rounded and subspherical; some beds show good gradation from fist-sized particles at base to pea-sized pebbles at top (Pl. IVA)	±10	10
Concordant contact		
Mount Nelson Formation		
Argillite, dark grey weathering, dark grey; occasional bed of dark quartzite	150?	
Quartzite, thin-bedded, dark grey or dark green weathering dark grey; often with lighter grey irregular laminae; some distorted mudcracks and crossbedding	150(?)	
Quartzite, thin-bedded, reddish weathering, pinkish to grey, impure and fine grained; some interbedded dark grey phyllite	100(?)	
Quartzite, fine-grained, white, siliceous, very pure; broken outcrop	60	
Base not exposed		

In this section there appear, interbedded with the conglomerate, a number of both dolomite and argillite successions that in isolated outcrop would be mistaken for Mount Nelson Formation. About a mile south of this locality the equivalent section consists almost entirely of conglomerate.

Stratigraphic Relations

The stratigraphic relations of Toby conglomerate to both underlying and overlying rocks is of particular interest in any attempt to unravel the mode of origin of this formation.

In the outcrop exposed in any one locality the unconformity between the Toby conglomerate and the underlying Purcell rocks is not profound. Nevertheless, a local angular unconformity may often be seen in which the Toby conglomerate cuts underlying beds at a low angle, e.g., on the south slope of Taurus Mountain, at the headwaters of Forster Creek. At this exposure Toby conglomerate cuts across upper Mount Nelson quartzite at an angle of perhaps 10 degrees for several hundred feet. In other places the Toby appears almost to have been interbedded with the normal succession of Mount Nelson rocks as, e.g., at the foot of Toby Glacier, where cream-coloured, light red-brown weathering dolomite lies immediately below and above Toby conglomerate almost as though conglomerate had slid into the locality of dolomite deposition. A few hundred yards east of this locality the Toby rests on white quartzite (*see also* Toby Formation section, above).

On a regional scale, however, there can be no doubt that the Toby Formation rests with an angular unconformity on Purcell strata. Everywhere around the limits of the Mount Forster syncline it lies at varying stratigraphic intervals above the massive dolo-

mites of the Mount Nelson Formation. In some places the upper quartzite is apparently eroded away; in some places the Toby lies above it. Neither massive dolomites nor the upper quartzite of the Mount Nelson is to be found beneath the Toby conglomerate along the Purcell Divide, and there it overlies the Dutch Creek Formation. It may be noted that Toby conglomerate rests with only very slight unconformity above roughly the same stratigraphic horizons along a southeast-trending line, but lies on considerably different stratigraphic levels along an east–west line. The conclusion may be that gentle, open folds and north-trending faults were formed in the Purcell strata before deposition of the Toby, and that these folds trended roughly in the same direction as the later Mesozoic folds (*see* Chap. V).

In areas such as that south of the Mineral King Mine on Toby Creek and on, or immediately north of Mount Pambrun no Toby conglomerate occurs and Horsethief Creek slates or pebble-conglomerates rest directly on Purcell strata. Two interpretations of this are possible:

1. The equivalent of the Toby here is a rock similar to those in the Horsethief Creek Group.

2. The Toby either was not deposited in these localities or was eroded before deposition of the Horsethief Creek Group.

Either possibility is acceptable since the Toby conglomerate shows sufficient variation in lithology and thickness along strike to enable the possibility to be accepted that it might easily grade from a cobbly or pebbly slate to a slate similar to those of the Horsethief Creek Group. Nevertheless, both Toby Formation and the overlying Horsethief Creek Group are known to thin rapidly to the southeast (Leech, 1954) and finally to disappear entirely south of Canal Flats (Fig. 1), where Lower Cambrian rocks lie directly on the rocks of the Purcell System. Thus it is equally possible that Horsethief Creek rocks overlapped the Toby Formation in the vicinity of Coppercrown Mountain and again on Mount Pambrun, just as the Lower Cambrian later overlapped the Horsethief Creek. Thus no Toby was deposited on the high central Purcells but Horsethief Creek rocks gradually overlapped a part of the Purcell anticlinorium. Not far south of these localities and east of the Rocky Mountain Trench no evidence of deposition of either formation is found (Leech, 1954).

In outcrops within this map-area the Toby Formation appears to lie conformably beneath the Horsethief Creek Group. As noted above, however, it is possible that, in some localities near the southeast limit of deposition of Windermere rocks, the Toby conglomerate and the lower strata of the Horsethief Creek may grade into each other laterally.

Horsethief Creek Group

Distribution and Lithology

In Lardeau map-area, east-half, the Horsethief Creek Group occupies by far the greatest area of any rock unit. It covers a broad area in the northwest quarter of the map-area, a narrow belt trending north from Fry Creek Batholith, most of Mount Forster syncline, as well as an area of scattered outcrop west and south from Steamboat Mountain. In all, the area covered is about 600 to 700 square miles.

The thickness of this group increases from east to west and from southeast to northwest. On the ridge between Law and Horsethief Creeks, on the west limb of the Mount Forster syncline, the Horsethief Creek Group is about 3,000 feet thick, but at the head

of Jumbo Creek, just east of the Purcell Divide, it is about 5,400 feet thick. In the region north of Howser Creek, north and south of the Bugaboo Range, the thickness in these irregularly folded rocks is more difficult to assess. Clearly, they are much thicker, for equivalent lithologies whether limestone, slate, or conglomerate are many hundreds of feet thick, whereas in the Mount Forster syncline they are a few tens or at the most 200 feet thick. Cross-sections, in the region both north and south of Bugaboo Range, show the Horsethief Creek Group to be as much as 8,000 feet thick.

The Horsethief Creek Group contains great thicknesses of slate, argillite, and phyllite as well as lesser amounts of quartzite, greywacke, and limestone. In addition, and in marked contrast to the underlying Purcell rocks, it contains considerable thicknesses of quartz-pebble conglomerate and pebbly grit. Precise proportions of each rock type are not possible to deduce from this work, but in a very general way the lower part of the group consists dominantly of argillite and slate with some limestone. The middle part is characterized by quartzite, grit, and pebble-conglomerate, although here too slate and phyllite are common. The upper part of the formation in its eastern and southeastern limits contains much purple and red slate and siltstone with only very minor limestone. West of the Purcell Divide the upper part is dominated by dark slate and phyllite with a much greater proportion of limestone.

Extreme variation in lithology both across and along strike is particularly evident in the eastern and southeastern exposures of the Horsethief Creek Group in this map-area, and rapid interfingering of pebble-conglomerate and finer grit or quartzite is commonly visible in a single outcrop (Pl. VI A). Some stream-cut channels have angular blocks of dolomite and coarse pebbles or cobbles of quartzite as fill. In contrast, bedding is much more continuous to the west and northwest, and conditions of deposition were evidently more stable.

The principal rock types of the Horsethief Creek are examined in more detail below, not in the order of abundance, but from the coarsest components to the finest.

Pebble-conglomerate

Conglomerate beds are most often hard and competent, ranging from a few inches to several feet thick, and are sharply bounded against adjacent slate or quartzite beds. The rock breaks across the pebbles except in rare occurrences in which matrix represents less than 10 per cent of the total. When this happens, mainly in the eastern part of the area, the conglomerate is friable.

Pebbles in the conglomerates of the Horsethief Creek Group are predominantly of white vein quartz, although feldspar, chert, quartzite, blue quartz, dolomite, and slate all occur in varying amounts. The pebbles vary in size from $\frac{1}{4}$- to 1-inch although some as much as $1\frac{1}{2}$ to 3 inches may be found in conglomerate along the eastern limit of Horsethief Creek outcrops (e.g., lower part of Law Creek or just east of map boundary south of Invermere). Feldspar is seldom more than a third of an inch, but dolomite may be up to several inches in size, and slabs of slate or argillite may be several inches wide and several feet long. Such slabs of slate may be oriented parallel to a prominent cleavage in very deformed conglomerate west of the Purcell Divide, but in less deformed outcrops east of the divide they lie near the base of a pebble-conglomerate bed and are parallel to it. Slate particles occur throughout the Horsethief Creek section wherever interbedded slate and pebble-conglomerate are found. Sphericity of particles is variable, from good to very poor, although roundness is usually excellent except for dolomite and slate which are invariably rather angular.

Matrix in the pebble-conglomerate is variable both in amount and composition. It may represent 10 to 60 per cent of the total volume of a conglomerate and may be composed of carbonate, quartzite, argillaceous quartzite, or a mixture of fine chlorite, quartz, feldspar, and small amounts of rock particles. Rarely, detrital muscovite may be found up to an eighth inch in outcrops along the eastern boundary of the map-area. Colours may vary from a predominant green and rust-flecked buff or brown to, more rarely, grey or reddish brown.

In areas of excellent exposure irregular lenses of pebble-conglomerate can be seen to interfinger with quartzite or grit beds (Pl. VIA). Elsewhere, U-shaped stream channels cut in grit and quartzite are filled with pebble-conglomerate. In one such channel a cobble about 4 inches in diameter of Horsethief quartz-pebble conglomerate was noted, perhaps representing a partly consolidated conglomerate from a nearby stream bank.

In the areas west of the Purcell Divide beds of pebble-conglomerate are more continuous, although here also they may grade across strike as well as laterally into finer grits, quartzite, and greywacke. Beds may be graded, starting with a few inches of pebble-conglomerate, followed by a pebbly quartzite, topped with slate, which is then followed abruptly by another pebble-conglomerate. Narrow slabs of slate and argillite are common near the base of conglomerate beds. A typical conglomerate sequence, west of the headwaters of Horsethief Creek, near the headwaters of Glacier Creek, consists of a thick alternating sequence of pebble-conglomerates, with all sizes of particles up to 1 inch diameter averaging ¼- to ½-inch in a greenish, phyllitic matrix interbedded with black and grey slate sequences. Thickness of alternating conglomerates and slates may vary from 10 to 200 feet.

A similar conglomerate sequence near the top of Horsethief Creek Group north of Law Creek, consists of brownish or rust-spotted brown to grey pebble-conglomerate, pebbly grit, and pebbly quartzite with a quartz–carbonate matrix. Pebbles in some of the conglomerate beds average 1 inch and reach a maximum size of 2 to 3 inches. Here, interbedded slate is deep red to purple.

Rarely, within the limits of Lardeau map-area, east-half, a coarse conglomerate may be found interbedded within Horsethief Creek strata. One such occurs just east of the tongue of Starbird Glacier at the head of Horsethief Creek. It is about 100 feet thick and consists mainly of pebbles, cobbles, and boulders up to 2 feet in diameter of limestone and dolomite in a phyllitic matrix. Boulders are flat, oblong in plane of bedding, fairly well rounded, but of poor sphericity. A very few quartzite cobbles or pebbles may be found in this bed.

Another such conglomerate, consisting entirely of brownish weathering, subangular to subrounded dolomite boulders, in all not over 15 feet thick, occurs in the basin at the head of the first west fork of Rory Creek. No quartzite particles were found in this bed. Other conglomerates of this nature were found at scattered localities in Horsethief Creek Group, but none appeared to be more than local lenses of conglomerate. No important, continuous beds of polymictic conglomerate were noted anywhere above the Toby conglomerate.

Grit, Quartzite, and Greywacke

Rocks of varying composition ranging in grain size up to 4 mm are found most commonly in sequences predominantly of coarse clastic rocks, although they may be found in minor amounts, at most a few tens of feet thick, in predominantly slate sequences. Rocks of grain size within these limits are most easily examined in thin sec-

tion and yield much information concerning the origin and deposition of Horsethief Creek Group.

These coarse clastic rocks vary from the dominant greens to dark grey, rusty spotted, or brownish buff. Particles in the grits and quartzites range in size from less than ½ to 4 mm on the average. With increasing particle size the grits grade to pebbly grit and pebble-conglomerate. Larger particles may be subrounded with poor sphericity, but most particles below 4 mm in size are subangular to sharply angular (Pl. VII). Rarely, well-sorted beds may be found with rounded quartz grains in a siliceous matrix.

Most particles consist of quartz, sometimes as aggregates of grains, but commonly as single grains. Grains of blue quartz are characteristic of many of these rocks. Other clasts consist of very fine grained, impure siltstone or quartzite clearly derived from the underlying Purcell rocks, or chert grains possibly derived from chert layers in the underlying Mount Nelson dolomites. Although large slabs of slate are visible in conglomerate, such rock particles are seldom identifiable in the grits. They may be present but are deformed and recrystallized in such a way as to merge into the matrix. Rarely, a grain may be noted that consists of intergrown quartz and euhedral sericitized plagioclase, or potash feldspar clearly derived from an igneous or metamorphic crystalline rock. Plagioclase, most commonly albite, both sericitized and clear, often well twinned, is common as clastic grains in the grits. Potash feldspar grains, sometimes showing a perthitic intergrowth and sometimes kaolin dusted, are common components (Table II and Fig. 3).

The matrix in the grit may range from 10 per cent in some of the more quartzitic members to 90 per cent in rocks that grade to slate and phyllite. It is composed of varying proportions of chlorite, sericite, and fine quartz. Carbonate may form from 5 to 100 per cent of the matrix and scattered hematite or limonite is common particularly in rust-spotted, brown, buff or red weathering rocks. Much recrystallization is evident and quartz particles often show indented, comb-like boundaries with the surrounding matrix (Pl. VII). Some of the matrix may be deformed pelitic or semipelitic fragments, but they are rarely identifiable as clasts (Table II). Furthermore, rocks in different localities have undergone different degrees of deformation and recrystallization, so that 'quantitative' measurement of the relative amounts of matrix and clasts as a measure of lack of sorting in these rocks is reliable only in a very general way.

Slate and Argillite

Slate and argillite and their metamorphic equivalents are the predominant rock types in Horsethief Creek Group. Even in the coarse, clastic sequences slate may form up to 50 per cent of the total rock.

Variations in colour and structural character of these rocks are considerable. Finely laminated slates to massive argillites varying from light grey to black are found everywhere in the succession. Light grey slates often have black or buff to rusty coloured laminae at irregular intervals from $\frac{1}{16}$ to 1 inch. In places, however, the regular alternation of laminae is such as to resemble Quaternary varved clays. Dark red to purple, thinly bedded slate and argillite is found near the top of Horsethief Creek succession in the Rocky Mountain Trench area and the Mount Forster syncline. Farther west, in the great outcrop area of the northwest part of the map-area, are found many varieties: grey slate with paper-thin parting planes; black slate containing large amounts of pyrite cubes up to a third inch or more on a side; pencil slate with quadrilateral cross-section up to a half inch and as much as 12 inches long; massive argillite from grey to silvery

TABLE II *Model analyses (volume per cent) of selected grits from Horsethief Creek Group and quartzites from Hamill Group–Cranbrook Formation*

Map-unit	HORSETHIEF CREEK GROUP GRITS										HAMILL GROUP AND CRANBROOK FORMATION		
Sample number	128-RA-55	397-RA-56	249-RA-55	H246-RA-57	248-RA-55	451-RA-57	452-RA-57	282-RA-55	S-5-RA-57	177-RA-56	171-RA-55	66a-RA-54	379-RA-56
Quartz	15.6	24.4	34.4	30.8	20.5	79.5	65.9	78.4	63.8	41.0	80.8	86.7	95.3
Rock fragments (quartzite, chert, and granitic rock)	17.3	8.3	16.4	3.1	47.2	3.4	18.5	5.8	21.3	31.0	—	1.4	1.7
Unstable rock fragments (rare, shale and limestone) + Matrix (mica, argillite, and iron oxide)	55.0	53.9	32.6	24.1	18.6	5.5	14.3	10.1	4.4	1.3	10.0	9.1	3.0
Carbonate	—	9.1	6.0	42.0	—	—	—	—	—	18.4	—	2.8	—
Plagioclase	7.3				9.8			5.0	5.3	6.6	8.4	—	—
	—	4.3	10.6	—	—	11.6	1.3	—	—	—	—	—	—
K-feldspar	4.8				3.9			0.7	5.2	1.7	0.8	—	—

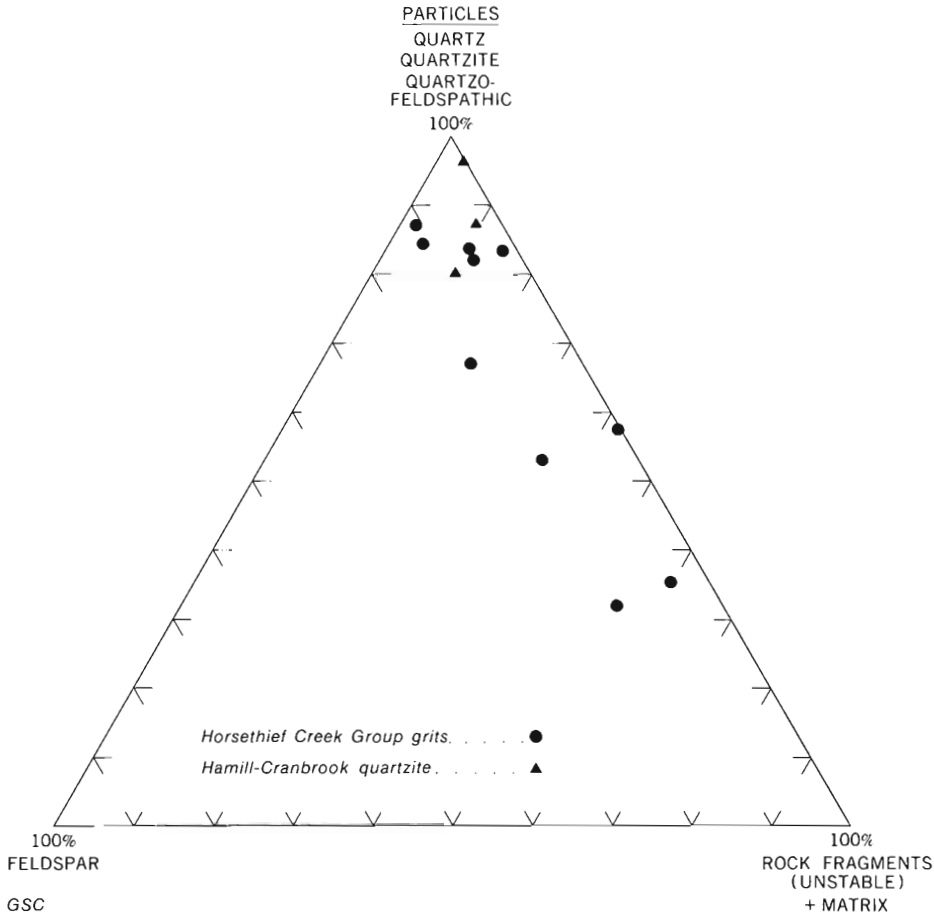


FIGURE 3. Plot of modal analyses (volume %) of selected samples of Horsethief Creek Group grits and Hamill–Cranbrook quartzite.

to black. Nowhere is the dark maroon or deep red slate common to the eastern outcrop areas found. Apparently conditions of weathering and deposition were such as to inhibit the formation of red slate, on the other hand, perhaps the highly pyritiferous black slate was deposited in deep isolated basins similar to the environment postulated for later graptolitic shale.

Limestone

Limestone occurs in minor amounts at a number of stratigraphic levels within Horsethief Creek Group, but is most common in the upper part. Generally it is black, fine grained, impure, in very thin beds or interbedded with thin layers of argillite. It may, in places, be sandy or even pebbly. Within the Mount Forster syncline a very thin-bedded limestone occurs above the red and maroon slate and argillite near the top of the section on the ridge north of Law Creek. A similar limestone interbedded with thin layers of shale occurs near the base of the same section. Farther west, the limestone in

Horsethief Creek may be dark grey weathering, bluish black, finely crystalline, massive, with individual units up to 50 feet or more thick. On lower Howser Creek a number of thick, massive, beds of crystalline limestone are interspersed in the slates and impure quartzite of the upper part of Horsethief Creek succession. In this locality, it forms a much greater proportion of the section than anywhere in the eastern limits of outcrop of Horsethief Creek rocks. Minor thicknesses of brownish to buff weathering, dolomitic limestone may also occur at intervals in the section, often thinly interbedded with slate sequences.

Stratigraphic Relations

Specific variations in the lithology of Horsethief Creek rocks and the relative proportions of the component rock types are shown in three stratigraphic sections (*see* Appendix). The two complete sections, one measured at the head of Jumbo Creek, the other north of Law Creek, show some of the variation in lithology from point to point. A thick sequence of slate and phyllite in the former section in the lower part of the group contains no grit or conglomerate. The section north of Law Creek shows all units somewhat thinner, but conglomerate occurs throughout the section. In general these conglomerates are coarser and the upper part of the section contains red slate and siltstone not present in the Jumbo section. Only the upper part of the Jumbo section contains coarse clastics and pebble-conglomerate, with dark slate and phyllite at the top. The section north of Bugaboo Creek shows, near the base of the group, a rapid variation in lithology similar to the Law Creek section, again contrasting with the Jumbo section.

The Horsethief Creek Group lies conformably above the Toby conglomerate although in a few localities it may rest directly upon the underlying Purcell strata as on Mount Pambrun and northwest of Coppercrown Mountain. The top of Horsethief Creek succession appears to lie concordantly beneath the quartzites of the Lower Cambrian Hamill from the region of the Purcell Divide, westward. On Mount Forster and north of Forster Creek, Middle and (or) Upper Cambrian, Jubilee Formation lies directly on Horsethief Creek strata. On both Jubilee and Steamboat Mountains in the Rocky Mountain Trench a few tens of feet, at most, of Lower Cambrian strata is found between Jubilee Formation and Horsethief Creek rocks.

Age and conditions of deposition of the Windermere System are considered below.

Origin, Correlation, and Age of the Precambrian

The Precambrian rocks of the Purcell and Windermere underlie most of Lardeau map-area. The equivalents of the Purcell are found extensively to the south and southeast in the Purcell and Rocky Mountains, as well as in northwestern Montana and Idaho. The equivalents of the Windermere System are found largely to the west and north in the Selkirk, northern Purcell, Monashee, and Cariboo Mountains as well as in some localities of the Rocky Mountains. The Lardeau map-area and the adjoining Canal Flats area (Leech, 1954) immediately to the southeast contain the locus of the junction between these two great rock units and display, in excellent exposures, their mutual relationships as well as their relation to the overlying Lower Cambrian formations of the Paleozoic System. Table III summarizes these relations and shows the correlation between selected localities within this general region.

Source and Conditions of Deposition of the Purcell

Workers in the Purcell rocks have been in general agreement that the lithological features and abundance of primary shallow-water structures necessitated their deposition in a slowly subsiding trough or basin of relatively great tectonic stability (Walker, 1926, p. 11–12; Reesor, 1957, p. 156–157). These conditions would be satisfied by the extensive flood plain of a large subsiding delta similar in scale and character to the Gulf Coast at the delta of Mississippi River. More recently Price (1964) has assembled a substantial body of stratigraphic data on the Purcell rocks of the Rocky Mountains in southwestern Alberta, showing clearly the derivation of these sediments from an eastern source, and discussing the conditions of deposition of the Purcell strata as a whole.

Within the Purcell Mountains however, in which a great total thickness of these rocks is to be found, precise correlation of units from locality to locality is not reliable. Thus, even extensive variations in thickness of a map-unit may be, in part, the result of difficulty in recognizing exact stratigraphic boundaries. The total thickness of a succession of units may be considered more reliable than that of any one unit. Deductions based upon variations of thickness within single units anywhere in the Purcell Mountains may thus be open to considerable doubt.

Variations in lithologies and in grain size show consistently an eastern source within the southern Rocky Mountains of Alberta (Price, 1964, p. 421–422). Within the Purcell Mountains in these universally fine-grained rocks, neither a regular variation in grain size nor consistent variations in overall lithology of a map-unit indicate unequivocal source area directions. For example, there is no systematic change in lithology of the Mount Nelson Formation between the Purcell front west of Steamboat Mountain and Dunbar Creek, or between either of these localities and the area south of Mount Toby at the Purcell Divide. It is true that shallow-water features such as crossbeds and mudcracks are observed in both the former localities and not at Mount Toby. However at Mount Toby the rocks are more intensely deformed and more highly metamorphosed and such features may not be preserved. There are greater changes from very fine to fine clastics or to carbonates up and down the Purcell stratigraphic section than can be observed laterally in any single formation in this succession. There is no indication of direction of source area in these uniformly fine-grained rocks in any of the extensive exposures examined during this work.

Source and Conditions of Deposition of the Windermere

Source

The overlying Windermere succession shows a remarkable contrast to the fine-grained successions and stable environment of deposition of the Purcell rocks. The lithological character and variations in the Toby conglomerate and Horsethief Creek rocks within the Lardeau map-area were discussed above. These rock units extend a short distance to the southeast (Leech, 1954) where they rapidly wedge out on the underlying Purcell strata. The approximate southeastern limit of deposition of Toby Formation is shown in Figure 4 and the stratigraphic relations of the Purcell, Windermere, and Lower Cambrian are diagrammatically summarized in Figure 5. Both units of the Windermere extend southward, along the western slope of the Purcell Mountains into northeastern Washington. Near the International Boundary, Rice (1941, p. 14–19) described great thicknesses of Toby conglomerate and the succeeding Irene volcanics.

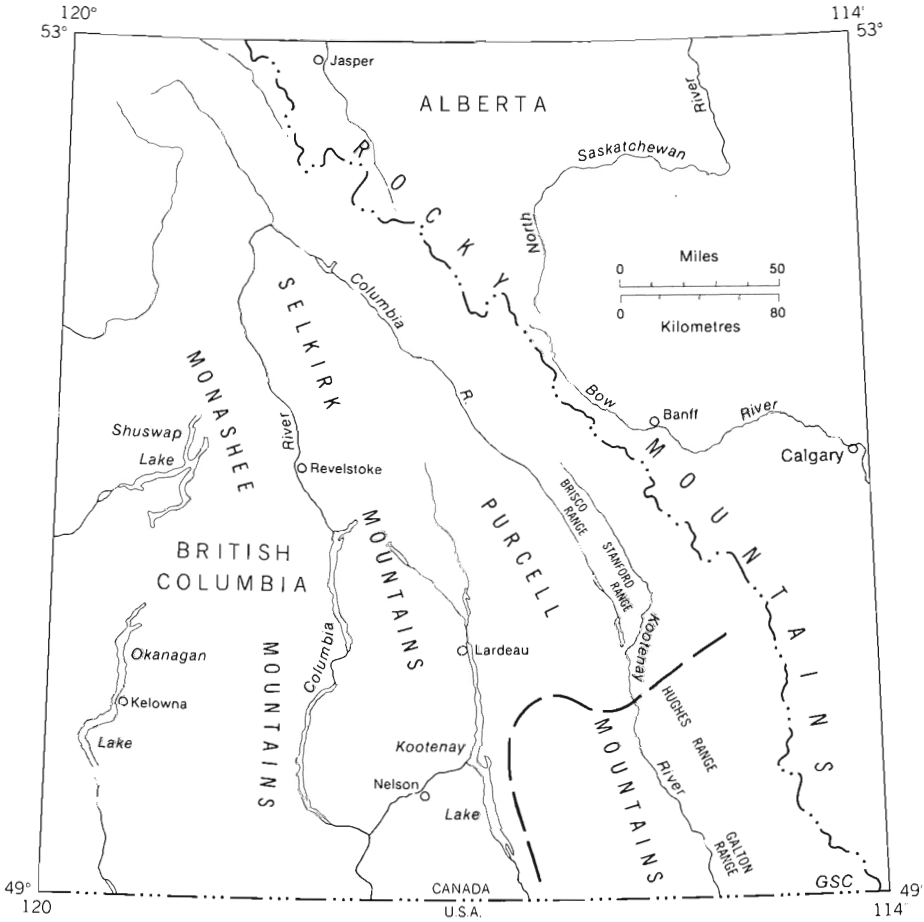


FIGURE 4. Diagrammatic representation of approximate southeastern limit of deposition of Toby conglomerate.

Rice also described coarse pebble- and cobble-conglomerate within Horsethief Creek Group in Nelson east-half area, east of Kootenay Lake. Thus Horsethief Creek there contains coarser clastic assemblages than are found anywhere in the succession in the northwestern part of Lardeau map-area. Only within the Mount Forster syncline and southeastward in the Rocky Mountain Trench are similar coarse pebble- and cobble-conglomerate beds found in Horsethief Creek Group. The Corral Creek Formation in upper Bow Valley, northwest of Banff, may represent a similar coarse equivalent (for localities mentioned *see* Fig. 1).

Northwestward in the northern Selkirk, northern Monashee Mountains and Cariboo Mountains equivalents of the Horsethief Creek Group continue that are lithologically similar to the slate, phyllite, grit, quartzite and minor limestone of the northwest part of Lardeau area (Wheeler, 1963; Campbell, 1968). Thus the coarsest members of the Windermere are found in the vicinity of the anticlinorium of Purcell strata now exposed in the southern Purcell Mountains. The thickest successions of Horsethief Creek Group and equivalent strata are found northward and northwestward (Table III; Fig. 5).

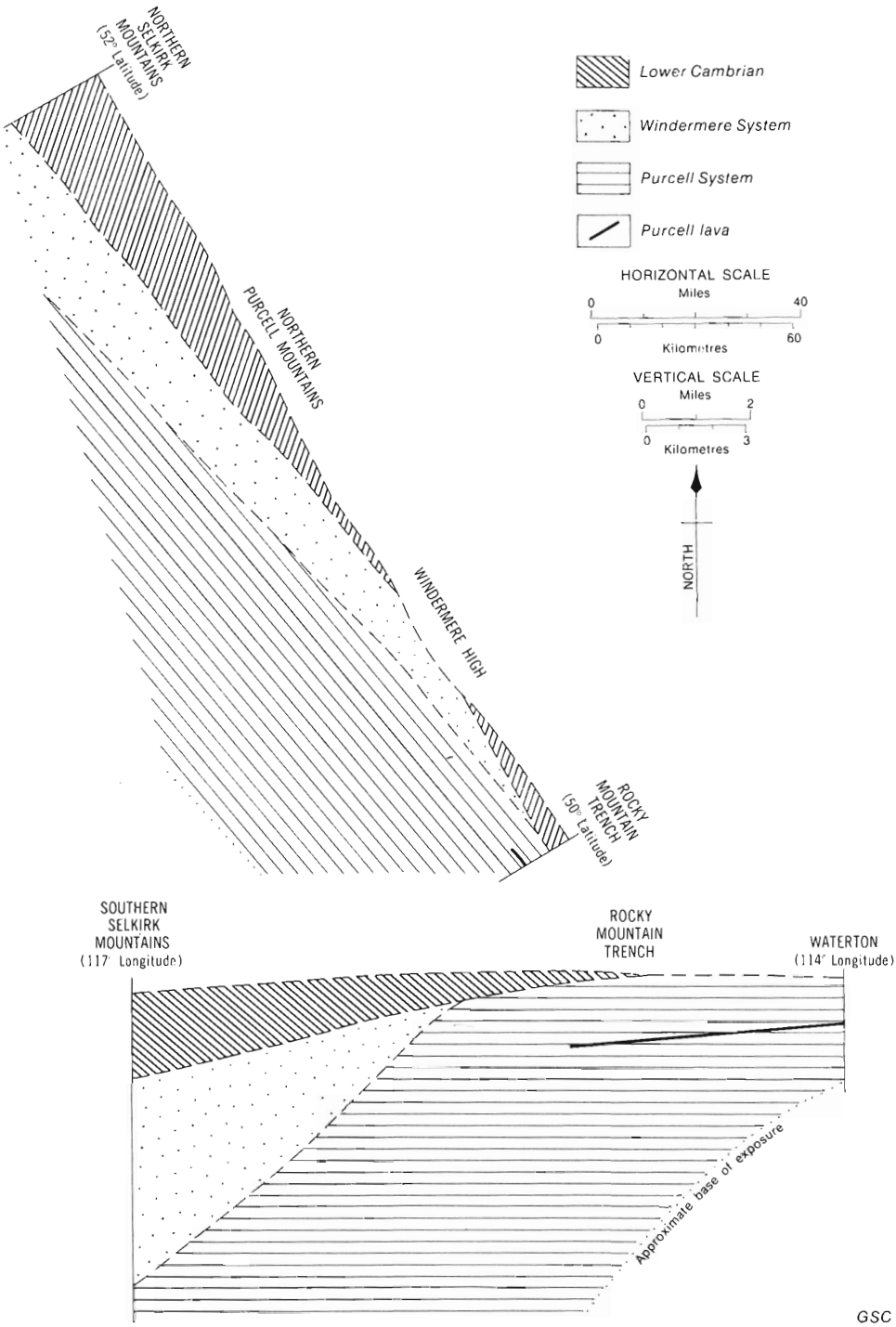


FIGURE 5. Diagrammatic cross-sections representing relations between Precambrian and Lower Cambrian of southeastern British Columbia.

TABLE III *Correlation, lithologies, and thickness variations in Precambrian–Lower Cambrian rocks of southeastern British Columbia–southwestern Alberta. See Figure 1 for locations.*

		CARIBOO–SELKIRK–PURCELL MOUNTAINS			
		Cariboo Mtns. (Campbell, 1968)	Northern Selkirk (Wheeler, 1962)	Central, western, and southern Purcell (Reesor, 1958; and this report; Rice 1941)	Southern Selkirk Mtns. (Salmo) (Little, 1960)
LOWER CAMBRIAN	CARIBOO GROUP	Yankee Belle Fm. (sh, st)			
		Cunningham Ls*	–?– Badshot Fm.* (mb, ph; 1,000 ft.)	Badshot-Mohican Fms. (mb, sc; 200–2,000 ft.)	Laib Group* (arg, arg qtzt, Ls; + 3,000 ft.)
		Isaac Fm. (ph, sl. arg)	Hamill Gp. (qtzt, sc; 8,000 ft.)	Hamill Gp. (qtzt, sc, ph;+ 6,500)	Reno and Quartzite Range Formations (qtzt, sc; up to 5,200 ft.)
		Conformable	Disconformable(?)	Disconformable(?)	Conformable
WINDERMERE		Kaza Group (gt, sc, gn)	Horsethief Ck. Group (argillite, slate, grit, pebble-conglomerate; +5,800 ft.)	Horsethief Creek Gp. (pebble-cgl, sl, ph, sc, qtzt, gt; 8,000 ft)	Three Sisters Fm. (gt, qtzt, cgl; 4,000–6,000 ft.)
				Toby Fm. (polymictic cgl; 0–2,000 ft.)	? Monk Fm. (arg, ph, sc;4,000 ft?)
					Irene Volc. Fm. (6,000 ft.)
					Toby Fm. (polymictic cgl; 5,000 ft.?)
		(base not exposed)	(base not exposed)	Unconformable	(base not exposed)
PURCELL				Mount Nelson Fm. (do, qtzt, arg; 3,00–4,000 ft.)	
				Dutch Creek Fm. (arg, sl, st, do; 4,000 ft.)	
				Kitchener–Siyeh Fm. (st, qtzt, arg, do; 6,500 ft.)	
				Creston Fm. (arg. qtzt, qtzt, arg, sl; 8,000 ft.)	
				Aldrige Fm. (qtzt, st, arg, sl; +15,500 ft.)	

Legend: **olenellus* or archeocyathids present;
arg.—argillite; cgl.—conglomerate; do—dolomite; gn—gneiss; gt—grit; ls—limestone; mb—marble; ph—phyllite; qtzt—quartzite; sc—schist; sh—shale; sl—slate; ss—quartz sandstone; st—siltstone.

ROCKY MOUNTAINS–EASTERN PURCELL–SOUTHERN ROCKY MOUNTAINS

Bow Valley–Mt. Robson (Mountjoy, 1962)	Eastern Purcell Hughes Range (Leech, 1954, 1958, 1960; also Evans, 1933, and Reesor, this report)	Clark Range–Waterton area (Price, 1964)
		Middle Cambrian Flathead ss
Gog Group* (ss; arg. ss, sh, Ls; 4,500 ft.)	—?— Eager (Donald) Fm.* (sh, Ls, st, ss; 0–6,000 ft.)	
	Cranbrook Fm. (St. Piron etc. Evans) (qtzt, gt, cgl; 0–5,000 ft.)	
Disconformable(?)	Unconformable	Unconformable
Miette Gp. (sh, ph, ss, cgl, ls)		
(base not exposed)		
	Roosville Fm. (arg, st, qtzt; 1,740 ft.)	Roosville Fm. (ss, qtzt; 2,500 ft.)
	Phillips Fm. (qtzt, st, arg; 400 ft.)	Phillips Fm. (ss, sh; 500–1,000 ft.)
	Gateway Fm. arg, st, qtzt, lava; 2,500 ft)	Gateway Fm. (upper-sh, ls; 1,500 ft) (lower-do, qtzt; 100–650′)
	Kitchener–Siyeh Fm. (arg, do, qtzt; 5,000 ft.)	Purcell Flow
		Siyeh Fm. (arg; 2,000 ft.)
	Creston Fm. (arg., st, qtzt; 5,000–6,000 ft)	Grinnell Fm. (arg, qtzt; 700–1,700 ft.)
	Aldridge Fm. (qtzt, st, arg; 8,000 ft.)	Appekunny Fm. (arg, qtzt, ss do; 1,800 ft.)
	Fort Steele Fm. (qtzt, ss, arg. arg do; 6,000 ft)	Altyn Fm. (ls, arg; 500–4,000 ft.)
		Waterton Fm. (ls, do, arg; 1,000 ft.)

Neither the source area of the Toby conglomerate, nor the variety of conditions in the region of its deposition (*see* Toby Formation, Stratigraphic relations) can be in doubt. Everywhere within the Lardeau and Nelson east-half map-areas the Toby contains pebbles, cobbles, boulders, and blocks of the immediately underlying Purcell strata. One exception to this occurs in the Toby conglomerate in the Fernie west-half area in which Leech (1958; 1962) found granitic and gneissic boulders. Similar gneissic cobbles occur in the Toby on Goldie Creek just west of Windermere Lake. In a number of localities along the Rocky Mountain Trench coarse detrital mica is found in the Windermere rocks. The source of these materials is in doubt, for gneissic granitoid rocks are not known anywhere in the exposures of Purcell rocks in the Purcell Mountains. Thus the presence of the gneissic boulders implies the existence of a crystalline basement exposed immediately to the east during Windermere time. A sample of detrital mica from equivalent strata, collected by Price (*in* Wanless *et al.*, 1967, p. 76) south of Mount Robson (Fig. 1) yielded a potassium–argon age of 1,535 m.y. Thus the source of this material must have been the Hudsonian terrain to the east.

Many of the clastic particles and rock fragments found in Horsethief Creek Group were clearly derived from the underlying Purcell strata. The source of sodic plagioclase and potash feldspar, often forming up to 10 per cent of a coarse clastic bed and not uncommonly 5 mm or more on long axis, is not nearly so evident. Yet here also the coarseness of grain and the amount of feldspar seem to be directly related to proximity of the anticlinorium of Purcell strata in the southern Purcells in both this map-area and Nelson east-half (Rice, 1941). Now-covered Precambrian basement to the east must be considered to be the main source of feldspar in the Windermere, although contributions may have been made by acid intrusions and pegmatitic rocks in Purcell strata that yield ages between 700 and 800 m.y. (Leech, 1962), as well as local occurrences of medium-grade metamorphic rocks.

Conditions of Deposition

Although the source area for much of the Windermere, both Toby and Horsethief Creek strata, is not in doubt the conditions of deposition of a unit such as the Toby Formation is less easily deduced from the evidence available. The stratigraphic character and lithological variation in the Toby indicate a source area of considerable relief. Rapid deposition is also indicated, for rocks lying beneath the conglomerate are freshly broken, and no evidence is found of a regolith developed during the interval represented by this unconformity.

In further discussing the deposition of a succession such as the Toby Formation it is necessary at least to consider the possibility of a glacial origin, if for no other reason than the remarkable similarity of such rocks to Pleistocene deposits visible everywhere in the map-area. Lithological equivalents for many beds of the Toby Formation may be found in Pleistocene glacial and postglacial deposits. Boulder tills with a carbonate shale matrix, pebbly sands, and cobbly shales are all present in glacial deposits. It is in the search for specific, unequivocal evidence of glaciation in the Toby Formation such as faceted pebbles, striated boulders, or striated pavements, that the idea of a glacial origin fails. Even in such ideal outcrops of Toby conglomerate, as for example on Taurus Mountain, in which conglomerate lies on well-exposed, slabby, white quartzite, neither striated pavement nor grooved cobbles could be found. Since no evidence specific to glaciation was found even in perfect outcrops the writer does not favour a glacial interpretation for the origin of Toby Formation[1]. Other alternatives must be considered even

[1] Aalto (1971) reached the opposite conclusion, and presents the case for a glacial origin for Toby Formation.

though unequivocal proof of these also is not available and the question must remain open.

Without doubt an area of considerable relief is required to produce a formation of this type over such an extensive region. Slides and flows of gravels, pebbly muds, and boulder accumulations along or across faults could account for the extensive variation in stratigraphic association throughout the Toby Formation. Within Lardeau east-half map-area only one locality of contemporaneous volcanism was noted. Perhaps volcanism was more extensive than this, for clasts of cobble size are found within the Toby near Taurus Mountain. Certainly there is evidence near the International Boundary about 60 miles to the south (Rice, 1941, p. 14–17) that extensive volcanism was associated with the deposition of the Toby.

The sites of deposition of the Toby ranged from surf-washed beaches or stream mouths, and fault scarps, to deeper levels of slide deposition. The landmass at the time must have been extremely irregular with faulted headlands and open-folded strata that contributed to rapid erosion without the development of extensive soil deposits. The extensive deposition of Toby conglomerate over a broad area may be accounted for by the gradual erosion and subsidence of the ancestral Purcell Mountains such that first Toby Formation, then Horsethief Creek Group, then Lower Cambrian successively overlapped to the southeast. This supposition is, in general, borne out by the stratigraphic information in the surrounding region.

Deposition of the Toby Formation was presumably rapid and terminated abruptly, for Toby-like conglomerate in the Horsethief Creek Group is virtually absent. The southeastern edge of the basin of deposition of Horsethief Creek rocks is approximately coincident with that shown for the Toby conglomerate (Fig. 4). This is confirmed by the thinning of the strata, the coarsening of the pebble-conglomerates, and the rapid variation in grain size both along and across strike (Pl. VI A) in the southeastern exposures of these rocks. Rarely, cross-sections of stream beds can be found in cliff exposures and presumably large rivers provided stream-washed gravels along with grits and sandy deposits. Shales and limy muds were deposited in interfluve areas. Farther to the west and north, units are much thicker, more continuous, less rapidly varying across strike, and both shale and limestone units are more plentiful. Thus the basin of deposition of Horsethief Creek rocks deepened rapidly to the north, northwest, and west (Fig. 5). Within the Mount Forster syncline and southeast, the upper part of the section is characterized by red slate, argillite, and argillaceous siltstone. Thus the basin-edge deposits of Horsethief Creek rocks are characterized by a red bed facies, presumably reflecting high oxidation in the shallow deltaic zone. Farther west and north in deeper parts of the basin, slate is characteristically black or green and no red beds occur.

Clearly a landmass existed south and east of the region of deposition of the Windermere rocks. Even by the end of Precambrian time some of this landmass must still have been emergent as evidenced by coarse clastics in the Hamill Group in the Blockhead syncline along the Purcell Divide. However, by late Early Cambrian time the only emergent landmass in this part of southeastern British Columbia was the Windermere High.

Age of Precambrian Sedimentation and Deformation

The age of deposition of both the Purcell and Windermere is essential in any reconstruction of the Precambrian geological history of this region yet the available data indicating age are not unequivocal. Recently Obradovich and Peterman (1968) have reported on extensive isotopic dating of Beltian rocks to the southeast that are

broadly stratigraphic equivalents of the Purcell rocks of southeastern British Columbia. They obtained an age of 1,325±15 m.y. from a series of strata equivalent to the lower part of the Purcell. This was interpreted as yielding approximately the time of sedimentation of these rocks. Since the Belt (Purcell) is known to rest unconformably upon Precambrian basement rocks in Montana dated as about 1,800 m.y. this age is not unreasonable. They considered that K/Ar age of 760 m.y. on biotite from a sill indicated a minimum age for the younger Belt rocks and suggested (op. cit., p. 746) three distinct ages of deposition for Belt rocks, about 1,300 m.y., 1,100 m.y., and about 900 m.y., with a hiatus between periods.

Leech (*in* Wanless *et al.*, 1968, p. 52–53) separated two size fractions of muscovite from an Aldridge Formation quartzite in the southern Rocky Mountains. He obtained 1,310±40 m.y. from the coarse fraction and 890±72 m.y. from a fine fraction (K/Ar on muscovite). He interprets neither as a significant age of deposition, only that the former reflects older detrital mica partly updated by younger events, and that the latter represents a mixture of detrital and younger metamorphic muscovite (op. cit., p. 53). Thus ages here, of comparable range to those reported by Obradovich and Peterman, are interpreted not as significant dates of deposition of Purcell sediments but as hybrid ages reflecting only varying effects of later events on detrital material from the Hudsonian source area of Purcell (Belt) rocks.

In this respect it is interesting to note the K/Ar age of 1,535 m.y. obtained from a sample of detrital mica from Miette rocks (Windermere equivalent) by Price (*in* Wanless *et al.*, 1967, p. 76). This indicates a minimum age for a source area for these rocks and implies a source in the Hudsonian basement to the east. Thus, to some extent the basement source of both Purcell and Windermere has been the same even though much of the Windermere, at least in the Purcell Mountains, was derived from the Purcell strata.

Hunt (1962, p. 438–441) reported a number of K/Ar dates on Moyie Intrusions and Purcell lavas at about 1,100 m.y. As Moyie Intrusions have been emplaced conformably within the Purcell strata, and as the lava is interbedded with upper Purcell strata, this age must give at least a minimum for deposition of early Purcell rocks as well as an approximate age for deposition of the later Purcell strata.

The K/Ar ages of 705 m.y. and 740 m.y. on intrusive granitic stocks[1] in the southern Purcell Mountains, as well as 790 m.y. (Leech, 1962) on metamorphic rocks, and other similar ages given by Hunt (1962) indicate a minimum age for the deformation of the Purcell sequence.

Deposition of the Windermere immediately followed this deformation for there is no evidence in the strata directly below the Toby Formation for the development of an extensive regolith. The deposition of the Windermere presumably extended to the beginning of the Cambrian, for although evidence of an unconformity between the Windermere and the Cambrian is found near the eastern boundary of the map-area and in Canal Flats no profound unconformity exists between the two to the west and northwest. Thus the deposition of the Windermere occurred between at least 800 m.y. and the beginning of the Cambrian.

In summary, the depositional interval of the Precambrian Purcell–Windermere succession in this region occurred during a span of time about twice that of the Paleozoic and younger rocks.

[1] Since this was written a Rb/Sr isochron on Hellroaring Creek stock has yielded an age of 1,260±50 m.y. (*see* Ryan and Blenkinsop, 1971).

Chapter III

THE PHANEROZOIC

The Phanerozoic sedimentary succession within Lardeau map-area was deposited mainly during the Paleozoic Era, with only a very small exposure of early Mesozoic rocks in the southwestern corner of the map-area. The Paleozoic of the eastern Purcell and western Rocky Mountains began with deposition of coarse clastics followed by an extensive thickness of carbonate and shale–carbonate sequences. The strata deposited during this time interval, from the Purcell Divide westward, now exist in, and were probably deposited in a very different environment. The sequence here began with a great thickness of medium to coarse clastics, overlain by carbonates and very fine clastics all of Early Cambrian (?) age. Within Lardeau east-half map-area no faunal information is available from these rocks. Beyond Lardeau area to the west and northwest the carbonates yield fossils of Early Cambrian age. Following the carbonate of the Lower Cambrian and underlying the Mississippian and later rocks of the Milford Group is a thick sequence of fine clastics, impure quartzites, some carbonates, and some volcanic rocks of the Lardeau Group. These rocks are highly deformed and are metamorphosed to upper greenschist and lower amphibolite facies.

These two localities thus represent in this map-area two contrasting environments, a stable shelf of miogeosynclinal environment to the northeast and a eugeosynclinal environment to the southwest. Specific correlation of lithological units between the two localities is impossible because of the lack of faunal information in the southwest.

Eastern Purcell Mountains, Brisco and Vermilion Ranges

Cranbrook Formation

Nomenclature and Correlation

The Lower Cambrian quartzites of the Dogtooth Range and southward along the Rocky Mountain Trench into the Lardeau map-area were first recognized and mapped by Evans (1933, p. 119A-122A). He used the terms St. Piran, Fort Mountain, and Lake Louise, following the original usage of Walcott in the Lake Louise–Assiniboine region of the Rocky Mountains. Since this time the same succession has undergone a number of revisions of nomenclature as it became recognized that the threefold division was not valid in the original area (North and Henderson, 1954). These strata from the Mount Assiniboine area to Mount Robson are now referred to as the Gog Group (Mountjoy, 1962, p. 6), and include all the "... sandstone strata above the Miette Group and beneath the carbonate and argillaceous strata of...," succeeding map-unit that in its lowest beds contains *Olenellus* (op. cit., p. 9). This unit as now

Table of Formations — Paleozoic and Younger Rocks

ERA	PERIOD OR EPOCH	GROUP OR FORMATION	LITHOLOGY	THICKNESS (feet)
CENOZOIC	PLEISTOCENE AND RECENT		Till, gravel, sand, silt	
MESOZOIC	CRETACEOUS	Bugaboo, Horsethief Creek, Fry Creek and White Creek Batholiths; Frying Pan and Lake of the Hanging Glacier stocks.	Granodiorite and quartz monzonite	
	JURASSIC	Glacier Creek, Mt. Toby, Cauldron Mountain and Tea Creek stocks	Quartz diorite, granodiorite, some hypersthene syenodiorite and minor quartz monzonite	
	TRIASSIC	INTRUSIVE		
PALEOZOIC		EASTERN PURCELL MOUNTAINS BRISCO AND VERMILION RANGES		
	PERMIAN AND CARBONIFEROUS			
	DEVONIAN (Mt. Forster) Upper	Starbird Fm. (Mt. Forster)	Limestone; minor quartzite	+200
	Middle(?)	Mount Forster Fm. (Mt. Forster)	Varicoloured shales; minor limestone and quartzite	750
	DEVONIAN (Brisco Range) Middle	Harrogate Fm. (Brisco Range)	Limestone and shale	293

WESTERN PURCELL AND SELKIRK MOUNTAINS		
GROUP OR FORMATION	LITHOLOGY	THICKNESS (feet)
KASLO GROUP	Volcanic rocks and related intrusions; minor pelites and tuff	(?)
MILFORD GROUP	Black argillite and slate; some chert and limestone	4,500(?)
UNCONFORMITY		

PALEOZOIC (Conc.)	Middle ?	Cedared Fm. (Brisco Range)	Quartz sandstone, limestone, and quartzite	698	LARDEAU GROUP	Chlorite–muscovite quartz schist, garnet–biotite–muscovite schist, tremolite marble, some impure quartzite, carbonaceous black phyllite, chlorite–plagioclase schist	±6,500
		EROSIONAL UNCONFORMITY					
	ORDOVICIAN AND SILURIAN	Tegart Fm.	Shale and limestone				
		Beaverfoot Fm.	Dolomite and dolomitic limestone	25–1,500			
		EROSIONAL UNCONFORMITY					
	ORDOVICIAN	Mount Wilson Quartzite	White quartzite	0–200+			
		EROSIONAL UNCONFORMITY					
		Glenogle Shales	Black shale	0–1,000			
	CAMBRIAN AND ORDOVICIAN	McKay Group	Shale and limestone; intraformational conglomerate	0–4,000			
		Relation not known					
	CAMBRIAN Upper	'Olenus' strata	Limestone and shale	(?)			
		Relation not known					
	Middle and/or Upper	Jubilee Fm. (Ottertail)	Thin-bedded (lower) and massive (upper) dolomite	270–3,000			
	Middle	Chancellor Gp.	Argillaceous limestone, paper slate; some black limestone	(?)			
					COMFORMABLE		
	Lower	Eager(Donald) Fm.	Dolomite, dolomitic limestone, argillite, argillaceous quartzite	0–200	BADSHOT–MOHICAN FMS.	Marble, dolomitic marble, schist, quartz–schist phyllite	200–2,000(?)
		DISCONFORMITY (?)			HAMILL GROUP	Quartzite; pebble-conglomerate, feldspathic grit, phyllite and schist; minor carbonate	4,300–+6,500
		Cranbrook (GOG) Fm.	Quartzite; some pebble-conglomerate and sandy carbonate	0–2,500			
		EROSIONAL UNCONFORMITY			STRUCTURALLY CONCORDANT—RELATION UNKNOWN		

Precambrian–Windermere (*see* Table of Formations p. 11)

used in the Rocky Mountains appears to include all strata of the time interval encompassed by the period of deposition of both Evans' St. Piran–Lake Louise–Fort Mountain and his Donald Formation. Therefore it is not the exact equivalent of the quartzite unit of the Dogtooth Range.

Leech, in work extending from the Canal Flats area southward to Cranbrook, established the continuity of the Lower Cambrian Cranbrook quartzite unit (Leech, 1954, 1958, and 1959). Above this he has also followed the continuity of the overlying Eager Formation of Early Cambrian age (op. cit.). These two formations in their stratigraphic position, in lithology, and in their contained faunal assemblages are, respectively, closely similar to the quartzite unit earlier called St. Piran Formation and the overlying strata formerly called Donald Formation in Lardeau east-half (Reesor, 1957). Rather than rename the quartzite formation within Lardeau east-half it is proposed to call it Cranbrook Formation in this report. In this connection it is interesting that Evans originally intended this correlation (1933, p. 121A). It is evident as well that the Donald and Eager Formations are close correlatives on the basis of faunal content in Dogtooth Range (Evans, 1933, p. 122A) and in Canal Flats area (Leech, 1954, p. 8). Therefore it is proposed that these beds in Lardeau east-half be called the Eager Formation.

The designation Hamill Group is retained, however, for the strata approximately equivalent to the Cranbrook Formation in the unfossiliferous successions of the central and western Purcell Mountains of this map-area. This follows the general usage in the Selkirk Mountains to the west and northwest, although there the immediately overlying strata are sparsely fossiliferous (Wheeler, 1963, and pers. com. 1967).

Distribution and Lithology

Rocks of the Cranbrook Formation occur in isolated outcrops around the fringes of Steamboat and Jubilee Mountains as well as on Lead Mountain northwest of Jubilee Mountain. The best exposures are found on the west side of Lead Mountain where the succession is about 2,500 feet thick. Folds were not recognized within the Cranbrook Formation at this locality but it is faulted against rocks of the McKay Group. At other localities, such as at the south end of Jubilee Mountain and on the northeast side of Steamboat Mountain, as much as 1,000 feet is exposed. At the south end of Steamboat Mountain only a few tens of feet of gently dipping strata of the formation is exposed. On Mount Forster, 7 miles to the southwest, the Cranbrook is absent and Jubilee Formation rests on Horsethief Creek Group. On the ridge south of Horsethief Creek, however, about 15 feet of white pebble-conglomerate, pebbly purple dolomite, and purple quartzite are found immediately beneath the Jubilee Formation. These rocks are here mapped as Cranbrook Formation although they could be any pre-Jubilee age. Thus within a restricted locality west of the Rocky Mountain Trench the Cranbrook Formation varies in thickness up to as much as 2,500 feet. In a distance about 20 miles to the southwest of Mount Forster the correlative Hamill Group reaches a thickness of 4,300 feet (Map 1326A *in pocket*).

White quartzite and white quartz-pebble conglomerates as well as quartzitic grits are present in all exposures. Purple, red and pink are common colours in the quartzitic rocks and some arenaceous, purple shale is found on Jubilee Mountain. On Lead Mountain the section changes rapidly along and across strike. Quartzite is marked by

purple and grey laminae as in the quartzite of the Hamill Group north of Blockhead Mountain. The upper part of the section consists of coarse quartzite, crossbedded grits, and pebbly grits in beds a few inches to a few feet thick. Some detrital muscovite and coarse feldspar are present. Some beds of quartzite traced along strike show a rapid change from hard siliceous quartzite to friable carbonate quartzite. Sandy carbonate beds are found locally in the quartzite succession.

In thin section, fine- to medium-grained quartzite is seen to consist of well-rounded, spherical, quartz grains cemented by quartz in optical continuity. Hematite is sometimes noted as an intergranular cement. Large grains of detrital muscovite bent around quartz grains are observed in some sections. Accessory minerals consist of zircon and tourmaline.

Structural Relations and Age

In any outcrop the beds of the Cranbrook Formation and underlying Horsethief Creek Group are concordant, and the presence of an erosional unconformity is based upon an evaluation of the rapidly varying thickness of the formation that might well have resulted, in part, from post-Cranbrook erosion. Quartz and quartzite particles, detrital mica, and feldspar are in all places similar to those in the underlying Horsethief Creek rocks. Red slate and hematite-cemented pebble-conglomerate beds are present in both successions. The principal difference is the lack of pelitic groundmass in the quartzite and conglomerate of the Cranbrook Formation. Within the confines of this map-area it might be possible to suggest that reworked Horsethief Creek rocks have provided the detritus for the Cranbrook, and thus an erosional unconformity is present. No specific evidence exists for an angular unconformity between these formations. Similarly, the Eager strata lie concordantly above the Cranbrook.

Faunal evidence within the map-area is not available and the dating of the Cranbrook rests upon Evans' *Callavia*-bearing, rusty sandstone at the top of the succession, northwest of Golden (1933, p. 120A). Similarly, Leech (1954, p. 7) reported *Callavia,* and possibly *Nevadia,* 100 feet below the top in Canal Flats area. In addition, the Cranbrook is immediately overlain by the Lower Cambrian Eager (Donald) Formation in the Dogtooth Range as well as on Jubilee Mountain (Evans, 1933, p. 123A). Similar relations are found in Canal Flats area (Leech, 1954, p. 8; 1959).

Eager (Donald) Formation

Distribution and Lithology

As already noted the term Eager Formation is used in this report for the Donald strata as mapped by Evans (1933, p. 122A–123A). Only a few isolated outcrops were found on both Jubilee and Steamboat Mountains, in most places isolated by soil cover from both the underlying Cranbrook and overlying Jubilee Formations. The formation varies in thickness up to 200 feet. In the Steamboat Mountain outcrops this formation is very thin and occurs in scattered exposures. Limited outcrop prevents its separation from the underlying Cranbrook Formation, and they are mapped as a single unit.

On Jubilee Mountain the rocks consist of cream to white dolomite or dolomitic limestone, with interbeds less than an inch thick of green and grey argillite, and argil-

laceous quartzite. Sandy limestone, thinly laminated, purple argillaceous quartzite, red argillite, and black limestone also occur in the succession. In all, it is a thin-bedded, varicoloured succession that grades upward into a few feet of sandy dolomite followed by very thinly laminated dolomite of the overlying Jubilee Formation.

On Steamboat Mountain similar sandy limestone and reddish limestone, as well as purple shale are found above the quartzites. In one place $\frac{1}{8}$- to $\frac{1}{4}$-inch pebbles of quartz occur in a thin bed of limestone. Other outcrops are found of black limestone and shale as well as more massive blue-black limestone, followed through an area of drift by thinly laminated, lower Jubilee dolomite. The lithology of these rocks is similar to those of the Eager Formation described by Leech (1954, 1958) from Canal Flats and Cranbrook area.

Age and Stratigraphic Relations

Evans (1933, p. 123A) considered the fauna of the Eager (Donald) strata on Jubilee Mountain to correspond to the upper part of the formation near Canyon Creek northwest of the map-area and "... the strata overlap towards the southeast" (op. cit.). An extensive faunal assemblage occurs in the Donald, all indicative of Early Cambrian age. A similar assemblage occurs in the Hughes Range, south of Canal Flats in the Eager Formation (Leech, 1954, p. 8; 1958).

Considerable thickness variation in the Eager Formation is evident not only within Lardeau area but also in the general environs north to Dogtooth Range and south in Canal Flats region. The formation is about 200 feet thick on Jubilee Mountain, a few tens of feet on Steamboat Mountain, but is absent on Mount Forster where Jubilee Formation of Middle and/or Late Cambrian age rests directly upon Horsethief Creek Group. Similarly in Stanford Range, immediately to the east, the Eager-equivalent beds are absent (Henderson, 1954, p. 18) yet a few miles to the south in Hughes Range the formation is as much as 1,500 feet thick (Leech, 1954, p. 8). Evans (1933, p. 123A) gives a thickness of 1,500(±) feet northwest of Golden. Thus the Eager Formation, as with the Cranbrook Formation below, is absent or very thin in the Mount Forster–Steamboat Mountain–Stanford Range region, but thickens rapidly both north and south and west (*see* Hamill Group and Badshot–Mohican Formations). Although much of the thinning may be the result of erosion before deposition of the succeeding Jubilee Formation some may result from nondeposition. As pointed out by Evans (1933, p. 123A) the beds on Jubilee Mountain are equivalent to the upper strata of the Eager (Donald) Formation northwest of Golden, and there is, therefore, an overlap of upper Eager strata southward onto the Windermere High. A disconformity therefore exists between the Eager and Cranbrook Formations in this locality.

Chancellor Group

A very small part of the Chancellor Group outcrops in the extreme northeast corner of Lardeau map-area, where it consists of very thinly bedded, red-brown to buff, argillaceous limestone, as well as a grey paper slate, and minor black limestone. It is a varicoloured, thin-bedded unit in contrast to the dark, more massive cliffs of the overlying Jubilee (Ottertail) Formation.

The Chancellor Group is Middle Cambrian, although fossil collections in this locality were too poorly preserved for specific identification.

Jubilee (Ottertail) Formation

Distribution and Lithology

Evans, in Brisco–Dogtooth map-area, mapped as Jubilee Limestone the unfossiliferous strata on Jubilee Mountain lying between fossiliferous Lower Cambrian below, and fossiliferous Upper Cambrian just above. Fossils have not been found within this formation. Henderson (1954, p. 19), in Stanford Range, showed most of the unit to consist of dolomite and called it the Jubilee Formation. The Ottertail Formation represents approximately equivalent strata in the Vermilion Range to the northeast. In this report these formations are considered to be equivalent and the names Jubilee and Ottertail are used interchangeably.

In Lardeau east-half the Jubilee Formation occurs in extensive outcrops on Jubilee and Steamboat Mountains as well as below Mount Forster and north of Forster Creek. It occurs in a few isolated localities on the ridge between Horsethief and Law Creeks and near Radium Hot Springs. The Ottertail Formation occurs only in the northeast limit of the map-area in Vermilion Range.

The Jubilee Formation varies in thickness from about 2,000 feet on Jubilee Mountain to about 1,300 feet on the east slope of Mount Forster (Pl. VIII). About 400 feet of this formation occurs on the ridge south of Horsethief Creek. The Ottertail Formation shows a mapped thickness of not less than 3,000 feet on the cliffs east of Mount Wardle.

The basal few feet of the Jubilee Formation consists of sandy dolomite with scattered grains of sand in thin-bedded, grey dolomite. Above this is a succession of very thinly laminated, thin- to medium-bedded, grey and white, cream to dark grey weathering dolomite, and siliceous dolomite. The upper part of the formation consists of massive, white to grey crystalline dolomite with beds up to 20 feet thick. In all the main occurrences, including that on Mount Forster, the lower half or a little more consists of the thinly laminated dolomite.

In thin sections the thinly laminated lower Jubilee Formation is seen to consist of alternating layers of 1 to 2 mm up to 5 mm wide. They comprise layers of different grain size, the very fine layers less than 0.01 mm, the coarser layers from 0.02 to 0.05 mm. There is a very sharp contact between layers and there is commonly considerable irregularity at the interface, although it appears smooth and continuous in hand specimen. The massive dolomite of the upper section consists of a mosaic of intergrown anhedral grains up to 5 mm or more in size.

The Ottertail Formation consists of an extensive cliff-forming sequence of massive limestones. At the base it is characterized by thin irregular stringers of lighter grey lenticles and anastomosing veins, roughly parallel with bedding. On Mount Wardle, at the top of the formation, the succession consists of hard, blue-grey limestone in beds 2 to 8 inches thick. There are a few interbeds of buff weathering, coarsely crystalline limestone.

Age and Stratigraphic Relations

The Ottertail Formation occurs beneath a middle Upper Cambrian zone within the McKay Group or its equivalents and above *Glyptagnostus* beds in the transition zone at the top of the Chancellor Group. Thus it is of pre-Franconian, Late Cambrian age (G. B. Leech, pers. com. 1970).

In Lardeau east-half, as well as in Stanford and Hughes Ranges to the south, the Jubilee Formation is overlain by McKay Group with basal beds of Late Cambrian age and is underlain by latest Lower Cambrian strata (Leech, 1954, 1959).

The Jubilee Formation in common with the Lower Cambrian rocks of this part of Lardeau map-area varies considerably in thickness both within the area and in the immediate environs. Thus it changes from about 2,000 feet at Jubilee Mountain to 400 feet on the ridge south of Horsethief Creek, then to 3,875 feet in Hughes Range (Ram Creek) south of Canal Flats (Leech, 1954, p. 10). It is notable that both the upper and lower divisions of the Jubilee Formation thin between the Ram Creek section (op. cit.) and Mount Forster. The Lower Division (laminated) at Ram Creek is 2,320 feet but at Mount Forster it is about 700 feet. The Upper Division (massive) is 1,554 feet thick at Ram Creek and about 600 feet on Mount Forster. Thus thinning of this formation is, in part, nondepositional as well as erosional (Fig. 6, *in pocket*).

'Olenus'-bearing Strata

At the north end of Jubilee Mountain, in a burned-over and partly drift-covered area, are a few small outcrops of blue-grey limestone interbedded with grey shales. Resser (*in* Evans, 1933, p. 125A–126A) identified a faunal assemblage from these rocks as Upper Cambrian on the basis of *Olenus* sp., *Pseudagnostus* sp., *Agnostus reticulatus, Agnostus pisiformis, Husia*?

In 1966, G. B. Leech found, along new road-cuts at the northeast end of Jubilee Mountain, a faunal assemblage of similar age. These were identified as *Arapahoia?* sp., *Pseudagnostus?* sp. by W. H. Fritz who comments as follows, ". . . since a single trilobite pygidium and a single agnostid cephalon are the only diagnostic fossils . . . age assignment must be . . . tentative . . . probably . . . Upper Cambrian . . . may belong to *Cedaria-Crepicephalus* Zone . . . . . If . . . correct, then the strata . . . correlate with the Sullivan Formation." Also this considerably extends the area in which these fauna are located at the north end of Jubilee Mountain and it is possible that strata mapped by the writer as McKay Group on Lead Mountain, immediately northwest, are of this age.

The strata so far identified as 'Olenus'-bearing beds' occur in a highly faulted and drift-covered locality with Cranbrook, Eager, and Jubilee Formations, and McKay Group not far away. Their stratigraphic relations to these formations are not known.

McKay Group

Nomenclature

The McKay Group was named by Evans (1933, p. 126A) from its type section on John McKay Creek in the southern Brisco Range. For the same rocks in Windermere area Walker (1926, p. 22–24), however, applied Goodsir Formation as used by Allen in Field map-area (1914, p. 94). Henderson (1954) and Leech (1954) used McKay Group. Evans gave a general discussion in which he reached the conclusion that McKay Group and Goodsir were essentially correlative. Later Aitken and Norford (1967, p. 159), in a review of Lower Ordovician stratigraphy in the southern Rocky Mountains, suggested that the term Goodsir Group was obsolete and strata termed Goodsir in the Ottertail Range should be referred to the McKay Group. This practice is followed here, for McKay Group of the Brisco Range appears to be continuous across the upper Kootenay River with strata previously called Goodsir in the Vermilion Range.

Distribution and Lithology

The McKay Group in Lardeau east-half occurs mainly within the Brisco Range and, with the exception of a few small outcrops of Jubilee Formation near faults, is the oldest succession exposed there. It occurs as well on Steamboat and Jubilee Mountains and on Mount Forster. Similar strata occur above the Ottertail Formation in Vermilion Range in the northeast corner of Lardeau map-area.

Commonly the McKay outcrops in cleaved or faulted axial zones of anticlines. Thus, good continuous sections are not common, the best still being Evans' type section on John McKay Creek (Evans, 1933, p. 126A) where Evans gives a thickness of more than 4,000 feet. On the northwest side of Steamboat Mountain, about 14 miles to the northwest of Evans' section, about 2,500 feet of McKay Group strata lie between Jubilee Formation and Beaverfoot Formation. On Mount Forster, about 12 miles east-southeast of Evans' section, the McKay Group is about 700 feet thick, and on Law Ridge, another 5 miles south, it is absent (Fig. 6, *in pocket*).

On Steamboat Mountain the McKay Formation begins with cleaved grey argillite interbedded with ¼- to ½-inch beds of grey argillaceous limestone. The proportion of limestone increases upward although there is much dirty grey argillite and some limestone intraformational conglomerate. Limestone in limestone-dominant successions occurs in beds as much as 3 feet thick with a few partings of argillaceous limestone as much as 2 feet thick, and is followed by more shale and blue-grey limestone and some intraformational conglomerate consisting of blue limestone pebbles in brown shale. This in turn is followed by some beds of massive blue limestone, then by a brown to rusty weathering intermixture of limestone and shaly lenses and beds, lithologically rather similar to the strata near the top of the section on John McKay Creek. The top of the group, on the west side of Steamboat Mountain, consists of a recessive unit a few tens of feet thick of an argillaceous limestone, followed by pure orthoquartzite (Mount Wilson Quartzite) about 10 feet thick. The upper strata just below the quartzite yielded *Bellefontia* cf. *platana* Kobayashi identified by T. E. Bolton as belonging to Evans' *Symphysurina* Zone. Thus the upper strata of the group are absent here and Mount Wilson Quartzite lies disconformably on the McKay Group.

On Mount Forster, the section begins with dirty brown weathering, argillaceous limestone and grey fissile shale; the remainder of the section comprises much intraformational conglomerate in dirty brown weathering shale and a few thin beds of blue-grey limestone.

Throughout other exposures the McKay Group consists of alternating, recessive and resistant successions of very thinly interbedded shale and limestone, in which shale dominates followed by limestone-dominant successions in which beds may be several feet thick. Intraformational conglomerate is common in shaly strata, particularly about the middle of the succession. They contain rounded, thin, flat pebbles of limestone that average ½ inch by 2 inches, but may be up to 6 inches long by 2 or 3 inches thick. The upper part of the section is characterized by a rather resistant section of limestone with thin streaks or lenses and thin beds of shale. It weathers characteristically rusty or brown. This is followed by thinly interbedded limestone and dark shale. On Mount Wardle the rocks consist of green and fawn to white-grey weathering, carbonate-bearing, cleaved shale with interbedded grey limestone. At the base interbeds of brown to buff grey limestone and shale are 2 to 6 inches thick, all highly cleaved. In the valley of upper Kootenay River occur a few small exposures of cleaved, silky, light coloured slate, almost a phyllite.

The McKay Group forms a sharp though apparently conformable contact above the Jubilee Formation. It appears in all outcrops to grade into the overlying Glenogle Shales but where these shales are absent lies in sharp contact with overlying Mount Wilson Quartzite or Beaverfoot Formation (*see also* Glenogle Shales, below, for stratigraphic relations of this group).

Age

The McKay Group ranges in age from Late Cambrian to lower Middle Ordovician. Evans (1933, p. 127A–128A) lists fauna found in the type section on John McKay Creek. He further lists the faunal zones in the McKay (op. cit., p. 129A) with the *Dikelocephalus* zone of the Upper Cambrian at the base. Norford (1969, p. 11 and Fig. 16) lists the faunal zones of the Ordovician part of the McKay Group.

Glenogle Shales

Lithology and Stratigraphic Relations

The Glenogle Shales in this map-area is found only within the Brisco Range. It is thickest in its northwestern exposures and there consists of not less than 1,000 feet of thin-bedded black shale at the base followed by brown, platy, argillaceous sandstone near the top. Some shales are limy, grey, and thin bedded. Southward and southwestward, the Glenogle progressively thins to a more uniform black, fissile shale about 200 feet thick in upper Kindersley Creek. West of this, no Glenogle strata are present and Mount Wilson Quartzite rests on McKay strata.

Locally the Glenogle lies gradationally above the McKay Group and they are arbitrarily divided at a point at which the very thinly bedded, uniform succession of dark shales with only minor limestone lies above interbedded shale and limestone. Nevertheless, Evans (1933, p. 130A) showed in Brisco Range that the Glenogle represents a black shale facies, equivalent in age to the upper part of the McKay Group at its type section on John McKay Creek. The upper contact of the Glenogle, northward in the Brisco Range, is easily recognized at the base of the Mount Wilson Quartzite even though the upper few tens of feet of the Glenogle is very quartzose and contains a few beds of white quartzite.

However, not only within Lardeau east-half, but also in the region to the south both McKay and Glenogle strata thin considerably so that Beaverfoot Formation lies directly upon lower McKay strata (Leech, pers. com.) near Fairmont Hot Springs. Similarly, Leech (1954, p. 19) described a surface of disconformity between Glenogle and Mount Wilson [Wonah] and between McKay Group and Beaverfoot Formation. Thus an extensive erosional unconformity is present between the McKay Group – Glenogle Shales and the succeeding strata (these relations are illustrated in Fig. 6, *in pocket*).

Age

An abundant graptolite fauna has been collected from the Glenogle Shales by many workers in this region. It ranges in age from late Early Ordovician to late Middle Ordovician. Norford (1969, p. 13; Fig. 16) summarized the graptolite zones in the Glenogle. Faunal lists from the Glenogle Shales of this district are included in Walker (1926, p. 26–30) and Evans (1933, p. 127A–128A). More recently these and other collections have been listed and assigned to zones by Jackson (1964) and by Larsen and Jackson (1967).

Mount Wilson (Wonah) Quartzite

Nomenclature

Norford (1969, p. 28) in a study of Ordovician and Silurian stratigraphy confirmed the suggestion of North and Henderson (1954, p. 68) that the Wonah was synonymous with Mount Wilson Quartzite. Mount Wilson Quartzite is, therefore, used in this report for the Ordovician quartzite formation in the Brisco Range previously termed Wonah Quartzite by Evans (1933, p. 138A–139A).

Distribution and Lithology

The quartzite occurs throughout the Brisco Range and later work by McCammon (1965, p. 197) showed up to 200 feet of Mount Wilson Quartzite on the northeast end of Steamboat Mountain. It is absent on Jubilee Mountain and on Mount Forster. The Mount Wilson Quartzite ranges in thickness from about 20 feet in the southern exposures of Brisco Range to well over 200 feet in the north and northeast exposures. It is commonly a pure white, white to pink weathering orthoquartzite that in thin section is seen to consist of rounded, spherical quartz grains $\frac{1}{4}$ to 1 mm, cemented by quartz in optical continuity. Some exposures show the basal beds to be massive or vaguely cross-bedded white quartzite, followed by an argillaceous, brown weathering, crumbly, quartz sandstone in the centre, overlain by quartzite in 4- to 12-inch beds to the top of the unit.

Stratigraphic Relations and Age

The Mount Wilson Quartzite regionally rests upon various horizons of the underlying strata, but appears to be conformable with the overlying Beaverfoot Formation. Norford, however, notes evidence of minor erosion surfaces at the Beaverfoot–Mount Wilson contact at Pinnacle Creek. Evans (1933, p. 139A) bracketed the age of the Mount Wilson Quartzite from fossil horizons immediately above and below as "... Chazy, Richmond, or some age between those ...." Norford (1969, p. 26) at Pinnacle Creek found conodonts in a shaly interbed 33 feet below the top of the quartzite that indicate an age of Middle or Late Ordovician.

Beaverfoot and Tegart Formations

Nomenclature

The rocks of these two formations were formerly included in the Beaverfoot–Brisco Formation as used by Walker in the Windermere area (1926, p. 31) and by Evans in the Brisco Range within this map-area (1933, p. 139A). Norford (1969, p. 28–34) in a study of Ordovician and Silurian stratigraphy in the southern Rocky Mountains proposed dropping the term Beaverfoot–Brisco Formation and replacing it with the Beaverfoot and Tegart Formations. The Beaverfoot Formation includes all strata of the former Beaverfoot–Brisco Formation lying above the Mount Wilson Quartzite (Wonah) and below a recessive succession of strata near the top. The recessive succession, particularly well exposed on Mount Tegart in the Stanford Range immediately south of the Brisco Range, Norford named the Tegart Formation (1969, p. 32–34). In addition he separated the Whiskey Trail Member to include the basal beds of the Beaverfoot Formation (op. cit., p. 29) (*see* Fig. 6, this report).

Distribution and Lithology

In Lardeau east-half map-area rocks of the Whiskey Trail Member of the Beaverfoot Formation occur extensively and a few outcrops of Tegart Formation are present. They have not been mapped separately. The Whiskey Trail Member is not noted in the southern and southwestern part of the Brisco Range in this map-area. It is not present on Jubilee or Steamboat Mountains, or on Mount Forster. In the central and northeastern Brisco Range it consists of a thin sequence of sandy dolomite, dolomite, sometimes with chert nodules, and very minor shale or argillaceous dolomite. It is characteristically thin bedded in contrast to the massive dolomites of the overlying Beaverfoot Formation.

The Beaverfoot Formation is found at scattered localities from the ridge south of lower Horsethief Creek to Mount Forster, Jubilee, and Steamboat Mountains and throughout the Brisco Range. It is about 1,500 feet thick in Brisco Range and consists of massive, cliff-forming dolomites of a grey colour that weathers very light, almost white to light pink. The basal beds are in some cases extremely fossiliferous. Bedding is often obscure and in some successions orientation of strata is more easily observed from a distance. About 700 feet of this formation is found on Mount Forster consisting of massive, grey weathering, bluish grey, dolomitic limestone. About 40 feet of the Beaverfoot is found on the ridge south of Horsethief Creek.

The Tegart Formation as established by Norford (op. cit., p. 32–34) typically occurs east and southeast of Lardeau map-area. Nevertheless there are three possible occurrences of this formation in the map-area:

1. East of the headwaters of John McKay Creek.
2. Northwest of this locality, southwest of the point at which the 5,000-foot contour crosses upper Kindersley Creek.
3. The upper 30 feet of the Beaverfoot section on Mount Forster.

Some shaly beds and dark impure limestones occur in thin beds above massive Beaverfoot at locality 2. Locality 1 was not visited, but beds of this formation occur just southeast of the map-area in this syncline. The upper few feet of the Beaverfoot on Mount Forster consists of thin-bedded, cream weathering, cream coloured and black weathering black limestone in beds 2 to 8 inches thick. They are very fine grained and dense and are in marked contrast to the underlying Beaverfoot and the overlying multicoloured shales of the Mount Forster Formation. Therefore they may be a possible equivalent of Tegart Formation.

Stratigraphic Relations and Age

In Lardeau map-area the Beaverfoot Formation rests conformably upon Mount Wilson Quartzite in the central and northeastern Brisco Range. On Mount Forster, the Beaverfoot Formation rests directly upon McKay strata; the Whiskey Trail Member, the Mount Wilson Quartzite, and the Glenogle Shales are absent. South of Horsethief Creek the Beaverfoot rests directly upon the Jubilee Formation and again Whiskey Trail Member as well as the underlying formations are absent. As already observed by Norford, where the Beaverfoot overlaps Mount Wilson Quartzite to rest on Jubilee Formation, it also overlaps the Whiskey Trail Member, and "... the horizon of widespread Beaverfoot transgression seems to be the top of the Whiskey Trail Member, not the Mount Wilson–Beaverfoot contact" (Norford, 1969, p. 32).

Norford (1969, p. 36–40) showed the Beaverfoot and Tegart Formations to range from Late Ordovician to Early Silurian documented by four coral-brachiopod assem-

blages. These are, respectively, from base to top; *Bighornia–Thaerodonta, Eostropheodonta, Pentamerus, Eophacops–Cheirurus.* The Tegart Formation lies entirely within the last and the Whiskey Trail Member at the base of the Beaverfoot is assigned to the 'conodont zone' at the base of the Upper Ordovician (op. cit., p. 38).

Cedared and Harrogate Formations

Nomenclature

The Harrogate Formation as originally mapped by Evans in Brisco Range included an extensive section of barren dolomite, sandy dolomite, and sandstone lying below the highly fossiliferous limestones of the upper Harrogate (Evans, 1933, p. 142A). Belyea and Norford (1967) recognizing that the Harrogate as mapped by Evans contained two diverse units divided it into an upper, Harrogate Formation and a lower, Cedared Formation (op. cit., p. 7). The Cedared Formation, "... is introduced for the virtually barren beds beneath the Harrogate Formation and above a regional unconformity that rests on different horizons within the Lower Silurian in the Beaverfoot, Brisco and Stanford Ranges." The type section for both Cedared and Harrogate was designated the Hatch Creek section at the north boundary of Lardeau map-area, northeast of Harrogate.

Distribution, Lithology, and Age

In Lardeau east-half map-area both Cedared and Harrogate Formations are found at intervals along the centre of a faulted syncline from Pinnacle Creek to the north boundary of the map-area. Harrogate Formation is found at the bottom of Sinclair Creek canyon in fault contact with Beaverfoot Formation.

Poor outcrops of Cedared Formation were noted a little more than 2 miles northwest of Pinnacle Lake and consist of crumbly, red quartz sandstone, quartz-bearing limestone, dolomite and quartzite in thin beds in contrast to the massive underlying Beaverfoot Formation. Another outcrop, possibly Cedared Formation, is found just north of the head of Luxor Creek. Belyea and Norford give a thickness of 698 feet for this formation at Hatch Creek. The Cedared Formation is very sparsely fossiliferous and may be of Middle Devonian age (Belyea and Norford, 1967, p. 38–39).

The Harrogate Formation consists of a thin-bedded assemblage of limestone, shale, and dolomite. In Sinclair Canyon it consists of thinly interbedded fossiliferous limestone and shale. It is of Middle Devonian (Givetian) age (Belyea and Norford, 1967, p. 46).

Mount Forster and Starbird Formations

Distribution and Lithology

These formations were first mapped by Walker (1926, p. 34–35) and assigned to the Devonian on the basis of fossil collections from the upper strata of the Starbird Formation. The Mount Forster Formation occurs on Mount Forster (Pl. VIII), where it is about 750 feet thick, and on the ridge south of Horsethief Creek. The overlying Starbird Formation occurs on Starbird Ridge west of the Mount Forster peak. Although more than 200 feet is exposed (Walker, 1926, p. 35), its total thickness is unknown for it is everywhere cut by the present erosion surface.

The Mount Forster Formation consists of pale green, rose-red, and brick-red shale in interbedded sections 1 to 3 feet thick. Interspersed beds of brown weathering, grey limestone are 2 to 12 inches thick. The base of the formation consists of buff to brown

weathering, grey limestone, minor grey quartzite, and a few interspersed successions, as much as 10 feet thick, of purple and green shales. The base of the formation on the ridge east of Mount Forster consists of about 10 feet of limestone breccia in a dolomitic matrix. There is an abrupt, irregular contact with the underlying Beaverfoot (Tegart?) Formation. The upper contact appears to be conformable with the strata of the overlying Starbird Formation.

The Starbird Formation is dominantly grey, buff weathering limestone in beds as much as 12 inches thick. There are some rose to white quartzite beds commonly 2 to 6 inches thick but in places several feet thick, as well as some beds of cross-laminated, quartzitic limestone that on a cursory examination showed current directions from the west.

Age and Correlation

The age assigned to these formations is dependent upon fossils collected by Walker from the top 30 feet of exposure of the Starbird Formation. These were dated as doubtfully Late Devonian by Kindle (*in* Walker, 1926, p. 35) and later re-examined and confirmed by McLaren (1962, p. 3). No fossils have been found in the Mount Forster Formation with the exception of a placoderm plate collected 10 feet above the base, east of Mount Forster peak. It was identified by Wann Langston Jr. of the National Museum "... Tuberculated plate of a placoderm, otherwise unidentifiable...."

Henderson (1954, p. 27), on a lithological basis, suggests a correlation on the basis of multicoloured shales between the Mount Forster and the Burnais Formation to the east across the Rocky Mountain Trench in the Stanford Range. This would in turn imply a correlation with the Cedared Formation. However, failing further faunal evidence such correlations even within this map-area must remain conjectural. Similarly, correlation of the Starbird Formation with the Harrogate is conjectural as long as the specific assignment of the Starbird to Middle or Upper Devonian remains in doubt.

Western Purcell–Eastern Selkirk Mountains

Hamill Group

Nomenclature

Previously referred to as Hamill Series (Walker and Bancroft 1929, p. 9–10; Rice, 1941, p. 19–20) these rocks are here referred to as Hamill Group. Although they are overlain by Lower Cambrian Badshot Formation, they may be, in part, late Precambrian. This predominantly quartzite succession is not fossiliferous, but because over a very large region it is a recognizable horizon immediately beneath sparsely fossiliferous Lower Cambrian rocks it is arbitrarily assigned to the Lower Cambrian.

In the Blockhead syncline the upper part of the Hamill Group, although generally finer grained than the lower, is nevertheless dominantly fine to coarse quartzite with very few pelitic interbeds. At the headwaters of Clint Creek the upper part of the Hamill contains large amounts of pelitic strata interbedded with the more typical quartzite of the Hamill. Farther west only these upper strata appear, complexly interfolded with both the Badshot and Mohican Formations and Lardeau Group. Previously the writer (1957) divided this part of the group from the remaining Hamill and called it Upper Hamill Group. Although these strata are in fact the upper part of the Hamill they are stratigraphically equivalent to strata on the Purcell Divide that were mapped as Lower Hamill Group. Thus this division cannot be used consistently between the

Blockhead syncline and the southwest part of the map-area, and the designation Upper and Lower Hamill is dropped in this report.

Distribution and Lithology

These rocks are best exposed in the cirque north of Blockhead Mountain, at the head of the south branch of Jumbo Creek. They occur throughout the Blockhead syncline as well as in two more belts to the west between Fry Creek and Howser Creek. The Hamill varies in thickness from about 4,300 feet in the cirque north of Blockhead Mountain, to approximately 6,500 feet a few miles to the west.

Rocks of this formation characteristically form high, rugged, mountain masses and narrow sharp ridges, in places not more than one bed wide along the ridge top. Blocky, massive outcrops exhibit identical features to massive granitic rocks, and from a distance the two cannot be differentiated.

In outcrop, the Hamill rocks vary from a very pale green to grey or light brown and white. Rarely, some reddish or purple beds occur, particularly in the easternmost exposures. Commonly, dark laminae form discontinuous, blurred lines on the surface of the rock. Some appear to mark a clear crossbedding, others are thin semipelitic separations between layers of quartzite. These are repeated at intervals varying from less than an inch to several inches (Pl. IX A). Bedding is usually well marked and varies from an inch to several feet.

Rocks are generally medium to fine grained, but there are many pebble-conglomerates, particularly near the base of the formation. In some places the pebble-conglomerate forms thin, discontinuous layers in quartzite, or lenses or pockets in quartzite successions, as on Mount Monica. In one place, south of Jumbo Pass, a cobble-conglomerate consisting of flattened cobbles of quartzite as much as 5 inches in diameter is interbedded in quartzite. In general, however, pebbles are of quartz or quartzite, well rounded, and average about a quarter inch, although half inch pebbles are not uncommon. Some pebbles are of purple, almost amethystine quartz and rarely they are of light blue quartz. Some pebble-conglomerates and grits contain appreciable amounts of sodic plagioclase and potash feldspar. Pebble-conglomerates are most plentiful in the Blockhead syncline (Pl. IX B), but are found to some degree in the lower part of the formation wherever it is exposed.

North of Carney Creek near the base of the section (*see* measured Section 2 below) is a sequence of feldspathic pebble-conglomerate and feldspathic pebbly grit interbedded with pure white quartzite. Feldspar is rounded, porcelaneous or dull white, and may be up to a quarter inch in size although an eighth inch is more general. Some of this grit is similar to that found in the Horsethief Creek Group beneath the Hamill. However, the Horsethief Creek rocks are invariably interbedded with slate or phyllite but here they are interbedded with typical Hamill quartzite and the succession forms a continuous, competent unit within the quartzite. They also appear to grade along strike to the north into massive quartzite. Therefore, they are included here with the Hamill Group. However, it must be noted that Rice (1941, p. 19) mapped somewhat similar rocks at the base of the Hamill with the Horsethief Creek Group.

The upper part of the Hamill Group in the Blockhead syncline is dominantly quartzite with few pelitic interbeds. The upper part of the Hamill to the west, e.g., just north of the headwaters of Clint Creek, consists of pelitic successions as much as 150 feet or more interbedded with fine-grained, thin-bedded quartzite in units of similar thickness (Pl. IX A). Farther west the upper beds of the Hamill consist of thin-bedded,

white, dense, siliceous quartzite interbedded with phyllite and quartz–mica schist. In the more highly metamorphosed strata of the southwest corner of the map-area the Hamill consists of sericitic, fine-grained, white quartzite, brown micaceous quartzite, green garnet–mica schist, dense grey quartzite, and in places biotite–muscovite schist.

In thin section these rocks are seen to be dominantly quartz seldom with more than 10 per cent sericite and chlorite, usually much less (*see* modal counts Table II). Quartz varies in size from 0.05 mm to several millimetres. Commonly it is much recrystallized and occurs as a mosaic of well-oriented grains with length four or five times greater than width. Original textures are commonly obscured by extensive recrystallization. Sericite occurs as tiny shreds, not more than 0.1 mm long scattered throughout the section. It shows a good preferred orientation and provides additional evidence of penetrative recrystallization within the rocks. In the grit and pebble-conglomerate fine- to medium-grained quartz forms the matrix rather than chlorite and sericite. In some of the finer grained quartzite in the outcrops of the Blockhead syncline, distribution of impurities shows apparent original size to be 0.15 to 0.3 mm in subangular to subrounded grains.

Feldspar is clearly detrital and consists of rounded to subrounded grains of poor sphericity ranging in size from several millimetres down to half a millimetre or less. Although it never forms over 5 per cent of the rock it is a conspicuous component in thin section as in hand specimen. In order of abundance feldspars noted were sericitized plagioclase, microcline, albite, and perthite.

In the more metamorphosed section, in the southwest part of the map-area, the quartz of the quartzite is commonly in fine-grained mosaics less than 0.2 mm in grain size, with interstitial muscovite or chlorite forming up to 15 per cent of the thin section. Garnet as much as 2 mm in grain size is found in some pelitic schists. Rare, patchy carbonate may be found in the matrix of the white quartzites. Porphyroblasts of biotite up to half a millimetre or more are found in some of the pelitic schist interbeds. Epidote may be found in some sections in small discontinuous patches or individual grains in some of the carbonate-bearing quartz schists. In most thin sections accessories are not abundant, but zircon, apatite, tourmaline, sphene, and magnetite have been noted.

The following two sections summarize the lithologic character of these rocks.

Section 1

Section of Hamill Group in basin north of Blockhead Mountain at head of Jumbo Creek.

Conformable contact with Badshot–Mohican Formations.	Thickness (feet) of unit	Thickness (feet) above base
Quartzite, white, fine- to medium-grained; some coarse quartzite; all in a very competent section in beds varying from a few inches to a few feet.....	2,000	4,300
Quartzite and grit, grey and white, dense, hard and competent; some thick beds of grit have 4- or 5-inch layers of pebble-conglomerate at the base containing quartz pebbles to ¾ inch diameter; the coarse quartzite in turn may show graded repetition from grit at the base through dense hard quartzite at the top, then again, sharply, to grit; some cross-lamination in the coarse quartzite.....	1,500	2,300

	Thickness (feet)	
	of unit	above base
Quartzite, grit, and pebbly grit, white to green weathering in beds 2 to 8 feet thick; minor interbedded green argillite and buff or brown weathering dolomite in beds to 4 feet thick, rarely up to 20 feet. Toward the top of this section the quartzite, grit, and pebble-conglomerate is predominantly grey to white; the grits and conglomerates typically contain many purple quartz pebbles, and the grits, thin layers of coarse purple quartzite; some crossbedding in the coarse-grained rocks	800	800
Structurally concordant		
Horsethief Creek Group		

Section 2

Section at elevation 8,000 feet, immediately west of small cirque lake about 2,000 feet above Carney Creek, 12 miles above mouth of Fry Creek on Kootenay Lake (thicknesses approximate).

Conformable contact with overlying Badshot–Mohican Formations.	Thickness (feet)	
	of unit	above base
Quartzite and schist, thin-bedded in alternating sections up to 200 feet thick, much folded	1,000(±)	6,500
Quartzite, white to very light green weathering, grey to white, fine-grained, predominantly pure siliceous quartzite with minor horizons of phyllite, schist or phyllitic quartzite	4,000(±)	5,500
Quartzite, medium- to fine-grained, with rare layers containing coarse feldspar or quartz particles, weathering white to very light green, all in a very competent section	300(±)	1,500
Quartzite, coarse, pebbly, and feldspathic in beds 1 inch to 6 or 8 inches, alternating with fine- to medium-grained beds generally 1 foot to 5 feet or more in thickness, all weather grey to very light green or white, all in a very competent section	700(±)	1,200
Quartzite, gritty and feldspathic, very competent beds up to 6 feet, weathers very light green with some brown, rusty spots of limonite; some rocks with little or no matrix, some with small amount green phyllitic matrix; grain size as much as ¼ inch but ⅛ inch or less is average, very rare blue quartz grains, some mauve or amethystine quartz particles; rare, thin, sandy, dolomite beds	500(±)	500
Structurally concordant		
Horsethief Creek Group: Phyllite and biotite schist, rusty weathering, silvery grey to dark grey, massive or finely laminated	600(±)	

Structural and Stratigraphic Relations

The Hamill Group is in structurally conformable contact with the Windermere below and the Badshot and Mohican Formations above.

Although the quartzite units of the Hamill Group are lithologically correlated with similar successions to the southwest (Rice, 1941, p. 19–20) and to the northwest (Fyles and Eastwood, 1962, p. 16–17; Wheeler, 1963, p. 3) it is not precisely correlated with Cranbrook Formation in the northeastern limits of this map-area because of the absence of fauna. It nevertheless occupies the same stratigraphic position between the Horsethief Creek Group and the Badshot–Mohican Formations. In other areas the latter contains Lower Cambrian fauna equivalent, at least in part, to that contained in Eager (Donald) Formation in the northeast part of the area. Thus the Hamill Group must be a close correlative of the Cranbrook Formation (*see* Table III).

Badshot–Mohican Formations

Nomenclature

The delineation of the Badshot–Mohican in Lardeau east-half is dependent upon lithology and stratigraphic position, for no faunal evidence has been found within this area to substantiate the assignment of these strata to the Lower Cambrian. Nevertheless equivalent strata in the Dogtooth Range (Evans, 1933) contain abundant Lower Cambrian fauna and the Badshot to the west and northwest (Wheeler, 1963; Wheeler, pers. com. 1967) as well as to the southwest (Little, 1960, p. 30) contain archaeocyathids. These fossiliferous strata lie just above the typical quartzites of the Hamill or its correlatives.

Fyles (1964) in Duncan Lake area (Fig. 2) confines the Badshot Formation to the 'crystalline limestone' unit. The Mohican Formation below the Badshot consists of an ". . . interbedded sequence of limestones and schists . . . quite distinct from the underlying Hamill quartzite" (Fyles, 1964, p. 22). He separated this unit from the Hamill Group and mapped it with the Badshot Formation (op. cit., p. 17). Originally the Mohican was considered a part of the Hamill Group (Fyles and Eastwood, 1962), following the original definition of Walker and Bancroft (1929, p. 10). The usage proposed by Fyles is more acceptable in that the Badshot–Mohican sequence lies immediately above the dominantly quartzitic successions of the Hamill. Therefore this usage will be followed in this report and the strata lying above the dominantly quartzitic rocks of Hamill Group and including the Badshot marble will be termed the Badshot–Mohican Formations.

Distribution and Lithology

Strata of this formation occur typically in tightly folded synclinal zones with competent Hamill quartzite, at the Purcell Divide as well as in the complexly folded area in the southwest limit of the map-area. It outcrops at most over a few square miles, but is, nevertheless, of great significance as a marker horizon as well as economically as a host for lead–zinc mineralization. The thickness of the formation is difficult to estimate; Fyles in Duncan Lake area (1964, p. 23–25) considered the thickness of the combined formation to vary from a few hundred feet to well over a thousand feet. Although strata are considerably folded in the Blockhead syncline, particularly east of Mount Hamill, the succession here must be about 2,000 feet, but some strata from the overlying Lardeau Group may be included.

Within the Blockhead syncline the rocks above the quartzites of the Hamill Group consist of very thinly interbedded, brown weathering limestone and carbonate-bearing quartzite of reddish purple hue. This is followed by a variegated succession of grey, black, and buff phyllite with some thin limestone interbeds. At one locality south of Jumbo Pass about 100 feet of limestone was noted near the centre of the complex syncline. A grey marble containing black laminae was noted near the base of the section. East of Mount Hamill a similar marble is complexly folded, but occupies nearly 300 feet across the centre of the syncline.

Both south and north of the headwaters of Clint Creek limestone as much as 40 feet thick, again appears in the stratigraphic section, associated with black schist, rusty weathering, silvery muscovite–quartz schist and green, thinly laminated dark schist. Marble as much as 100 feet thick was noted in this same stratigraphic position, on the north side of Hamill Creek and on the slope at elevation 6,700 feet on the ridge north of Mount Simpson.

This formation appears again in a series of complex folds cutting northwesterly across the southwest corner of the map-area. Here a number of bands of marble and dolomitic marble are found in the succession. Dolomite content of the marbles as well as rapid lithological variation within the Mohican equivalent is shown by the detailed mapping of Fyles in Duncan Lake area (Fyles, 1964, p. 22–25). Along with the changing stratigraphy, and increasing structural complexity, the grade of metamorphism increases progressively toward the southwest with the development of coarse mica schists and staurolite–garnet schist (*see* Chapter V). Everywhere the Badshot–Mohican Formations are internally much deformed; therefore a measured section is difficult to obtain. Fyles has indicated the complex lithological variations within the Duncan Lake area. It is clearly evident that if the relations suggested here are correct there is much further variation in this formation between the localities examined by Fyles and the Purcell Divide, some 12 miles farther east.

Stratigraphic Relations and Age

The Badshot–Mohican Formations appear to lie conformably above the Hamill Group. Even though the complex structural relations with the overlying Lardeau Group would obscure any disconformable or unconformable relation no evidence was found to suggest other than a conformable sequence in this work. Fyles (1964) suggested a conformable relationship between Badshot–Mohican and Lardeau.

The Badshot–Mohican Formations are, at least in part, equivalent to the Eager, the Donald (Evans, 1933, p. 122A), as well as the Badshot of Wheeler (1963, p. 3 and 6) and Rice (1941, p. 20), and the Laib of Little (1960, p. 34) (*see also* Table III).

Lardeau Group

The Lardeau Group comprises the section lying between the Badshot–Mohican Formations of Lower Cambrian age and the base of the Milford Group of Mississippian age. Thus the Lardeau Group in the southwest corner of Lardeau map-area is, in part, the time equivalent of the entire early Paleozoic succession lying above the Eager Formation in the northeast corner of the map-area.

Fyles and Eastwood (1962) in a detailed study in the Ferguson area divided the Lardeau Group into a number of formational units. Later, Fyles (1964, p. 25–31)

applied the same units with some degree of success in the Duncan Lake area. At the scale of mapping employed here the Lardeau Group is retained as a map-unit.

Distribution and Lithology

The Lardeau Group outcrops over a few square miles in complexly folded, narrow, northwest-trending belts in the southwest corner of the map-area. As a result of combined rapid facies changes and complex structural features Fyles (1964), despite detailed mapping, did not venture a thickness estimate for the combined units of the Lardeau Group. It is likely that the Lardeau Group in this map-area represents some thousands of feet of stratigraphic thickness. Fyles and Eastwood in Ferguson area (1962) gave considerable ranges of thickness for the individual formations of this group and the total varies from about 6,500 feet to double this amount. In the southwest corner of Lardeau east-half map-area, from the outcrops of Badshot–Mohican Formations on Schroeder Creek to the base of the Milford Group above to the west, the mapped thickness of the Lardeau Group is about 7,000 feet. There is much evidence of small-scale folding in these rocks and the true thickness may be appreciably less. The Broadview Formation (upper Lardeau Group) of Fyles and Eastwood (1962, p. 27–30) is apparently absent at this locality.

Rocks of this group in Lardeau east-half are metamorphosed to upper greenschist facies and in some localities to lower almandine–amphibolite facies (*see* Chapter V). The succession consists of chlorite–muscovite–quartz schist, biotite–muscovite schist, micaceous quartzite, garnet–biotite–muscovite–quartz schist, and tremolite marble. Chlorite–feldspar schists are found that commonly contain epidote and/or carbonate. They are deep green, commonly massive, and are of volcanic origin (considered to be Jowett Formation by Fyles, 1964, p. 30–31; Index Formation by Read, 1966; and Broadview by Wheeler, pers. com.). Black carbonaceous calcite–biotite–quartz schist and black, dense carbonaceous phyllite are commonly found near the base of the group.

Although porphyroblasts of garnet or of biotite may reach several millimetres rocks of this group are generally fine grained, commonly less than 1 mm. When seen in thin section they show a strong foliation resulting from preferred orientation of micaceous minerals. Biotite is commonly developed across such foliation, sometimes parallel with a crenulation foliation (strain-slip cleavage) that crosscuts the dominant, penetrative foliation.

The stratigraphic succession in this group as outlined by Fyles (1964, p. 25–31) consists generally of alternating successions of dominantly pelitic and semipelitic rocks of distinctive lithology and colour. Thus the succession begins with dark grey and green schists, followed by dark schists with minor grey quartzite, all in characteristically thin-bedded sections. Northeast of Lardeau settlement, schists derived from volcanic rocks overlie the metasedimentary succession and are overlain by grey schists and green micaceous quartzite (Lower Broadview Formation, Fyles, 1964, p. 31).

Stratigraphic Relations and Age

Although structural relations are complex the Lardeau Group lies with apparent concordance upon the Badshot–Mohican Formations beneath, and within this map-area it is structurally concordant with the Milford Group above. Beyond the map-area to the west, however, other workers (Read, 1966; Wheeler, 1968, p. 57) have recently suggested a profound unconformity between rocks of the Milford and the underlying Lardeau Group.

The age of the Lardeau Group ranges from post-Lower Cambrian to pre-Upper Mississippian, although the age of any particular lithological unit within it is unknown in this area. Apparent correlatives of the Lardeau Group in Nelson west-half area to the south yield ages of Middle Cambrian to Ordovician (Little, 1960, p. 35–42). In addition, Devonian rocks are present above these strata just south of the 49th Parallel (Park and Cannon, 1943, p. 22).

In the absence of faunal information in this district, specific correlation of units mapped between the southwest and northeast corners of the map-area is impossible. For example, there are striking contrasts in lithologies and in thickness in the Lower Cambrian rocks of this map-area between the northeast and the southwest parts. If similar variations occur between units of the remainder of the lower Paleozoic in these two localities, then the futility of unit-for-unit correlation on a lithological basis can be seen.

Milford Group

A narrow band of Milford Group occurs in the southwest corner of the map-area where it may be as much as 4,500 feet thick, consisting dominantly of black argillite and slate with some chert and limestone. No conglomerate was found near the base of the Milford though it is common in the region to the northwest (Walker and Bancroft, 1929; Fyles and Eastwood, 1962; Read, 1966; Wheeler, 1968). An extensive description of this group in the area of Mount Milford and southward is given by Cairnes (1934, p. 38–43).

The age of the group extends from Late Mississippian (Walker and Bancroft, 1929, p. 13; Fyles and Eastwood, 1962, p. 32) to Pennsylvanian and/or Permian (based on collections by Wheeler, GSC unpubl. rept. C10-65-EWB of E. W. Bamber). These outcrops probably also include a narrow slice of Mesozoic Slocan Group, hence Cairnes' (1934, p. 43) report of Mesozoic age for the upper part of this unit (Wheeler, pers. com.).

Kaslo Group

These rocks occur only in the very southwest corner of the map-area. They consist dominantly of volcanic rocks and related intrusions with minor intercalated sediments. Cairnes (1934, p. 43–49) gave an extensive description of these rocks in immediately adjoining localities.

The Kaslo Group is considered to be Triassic (op. cit., p. 49).

The Paleozoic–Precambrian Boundary

Within Lardeau map-area, west of the Purcell Divide, the Hamill quartzite and pebbly grit lie concordantly on Horsethief Creek phyllite or slate. South of the headwaters of Little Glacier Creek, east of upper Duncan Lake, some orthoquartzite layers are interbedded with typical Horsethief Creek phyllite and grit. Thus there is no recognizable break in sedimentation at this locality. In most localities, however, there is a profound change of rock type between the Hamill and Horsethief Creek Groups. Where these rocks are severely deformed at and west of the Purcell Divide any evidence of a disconformity has been destroyed.

In the eastern Purcell Mountains–Rocky Mountain Trench area the Cranbrook Formation rests concordantly upon Horsethief Creek rocks in any one exposure. Although quartzite predominates in the Cranbrook Formation it is often red to purple

as well as the more common white. There are interbedded quartz-pebble conglomerates and sometimes grit containing white detrital mica. The Horsethief Creek also, in places, contains red or purple slate and white pebble-conglomerate. The only difference is that Horsethief Creek rocks often have a green chloritic, argillaceous matrix and are interbedded with drab shale and slate whereas Cranbrook conglomerate beds have a quartz sand, or rarely, a carbonate matrix and are more friable. No great difference in these sediments is visible in many of the outcrops. However there can be no doubt that Cranbrook Formation thins southward from Lead Mountain, where it is apparently 2,000 feet thick, to Steamboat Mountain where it is no more than a few tens of feet thick at most. On Mount Forster the Jubilee Formation overlaps the Cranbrook and rests directly upon Horsethief Creek rocks. At the north end of Columbia Lake in Stanford Range (Walker, 1926, p. 21; Henderson, 1954, p. 51) Jubilee Formation also rests upon the Horsethief Creek Group. Henderson suggests a 'high' in this locality and westward at the end of the Precambrian (op. cit.). Nevertheless, southward from these localities in the Windermere district the Lower Cambrian strata once again appear and thicken rapidly to the south (Leech, 1954, 1958). This is summarized diagramatically in Figure 5. Thus the Middle and/or Upper Cambrian Jubilee Formation overlaps Lower Cambrian strata in the vicinity of the Windermere High. Similarly, the Lower Cambrian strata overlap Windermere strata to rest upon different formations of the Purcell to the south (Rice, 1941, p. 29; Leech, 1954). There does not appear to have been extensive folding or metamorphism in the interval between the deposition of the Windermere and the Lower Cambrian.

The Paleozoic of Lardeau Map-Area and Environs

Eastern Zone

The character of the Purcell landmass at the end of the Precambrian can be deduced from the distribution, changing thickness, and character of the Lower Cambrian sediments. Jubilee Formation (Middle and/or Upper Cambrian) rests either directly on, or is separated from Horsethief Creek Group by only a few tens of feet of Lower Cambrian in the southern Steamboat, Mount Forster, and Law Creek localities. It must, therefore, be deduced that Lower Cambrian rocks were not deposited or were eroded from this area before deposition of the Jubilee Formation. The thin strata of the Cranbrook and Eager Formations on Jubilee Mountain thicken rapidly northward. Coarse- to medium-grained clastics are found in the Cranbrook Formation, thus there must have been an emergent landmass undergoing fluvial deposition in the general Windermere area in Early Cambrian time. The marine fauna in the overlying Eager Formation, or its equivalent, and the transgression of the upper beds over the underlying quartzite show the encroachment of marine conditions at the end of the Lower Cambrian. Very similar relations in the Lower Cambrian are found eastward in Stanford Range (Henderson, 1954) and southward in Canal Flats area (Leech, 1954). There the Lower Cambrian progressively thickens southward from the Windermere area, and marine-fauna-bearing strata of the Eager Formation are again found in considerable thickness above the Cranbrook quartzites. Near the divide of the Purcell Mountains, at about 49°30′N, there is a considerable thickness of Lower Cambrian strata (6,000 feet, though some of this may be of younger age (Rice, 1937, p. 21)). Here the Lower Cambrian rests directly on units of the Purcell as old as Creston Formation. It may be deduced from these

stratigraphic patterns that a landmass existed in the Windermere district and its environs during early Early Cambrian time (*see* Figs. 5 and 6). Although an extensive landmass was emergent during much of the Early Cambrian, by the end of that epoch only a very limited area in the Windermere district remained emergent, an area here called the Windermere High. Much of the remainder of the ancestral Purcell anticlinorium, developed at the time of the East Kootenay Orogeny (White, 1959; Leech, 1962), was depressed below sea level and was receiving sediments at this time. From the Early Cambrian to the Devonian the Windermere High was not an emergent landmass and was not undergoing active erosion, but it nevertheless exerted an important influence on each successive formation in the sequence.

Windermere High is preferable for the local part of the Purcell anticlinorium, rather than Windermere Arch or Purcell Arch, for parts of the original anticlinorium were receiving sediments at the beginning of the Paleozoic. The Paleozoic rocks in the locality of the Windermere High rest on Windermere rocks so that this part of the Purcell anticlinorium was receiving sediments long before the Paleozoic. The Windermere High is thus of limited duration and of local extent only, and wherever information is available, Paleozoic sediments appear to thicken outward from the high (*see* Fig. 6). Wheeler, however, has taken a somewhat different view and considers the 'Purcell platform' in a different sense. He considers the platform to have been a periodically emergent arch (Wheeler, 1966, p. 31–32) essentially coincident with the ancestral Purcell anticlinorium formed at the end of the East Kootenay Orogeny. In a broad regional sense and from Purcell to Tertiary time this is correct and the Windermere High is an event in this long history.

The Jubilee Formation is divided into two main units, a lower very thinly bedded dolomite and an upper massive dolomite. Both thin progressively from Jubilee Mountain to Mount Forster, each unit being about one half as thick on Mount Forster as on Jubilee Mountain. Similar paleogeographic conditions were presumably found in the southern Stanford Range for similar changes in thickness are found there (Henderson, 1954) and in the Hughes Range to the south (Leech, 1954). Presumably no emergent nearby landmass was undergoing active erosion to produce coarse clastics at the time of deposition of the Jubilee. Only a few scattered quartz grains can be found in basal Jubilee beds even where the Jubilee is thin, and even where it rests directly on Horsethief Creek strata, an ideal source of grit or pebbles. The relation of this and succeeding formations to the Windermere High is summarized in Figure 6.

This figure shows diagrammatically the variations in lower Paleozoic strata in the region of the Windermere High. It is not palinspastic and does not reflect true original distances between the various sections. It follows, as well, that the shape or extent of the 'high' is not known. Nevertheless certain consistencies are evident. There are regular variations from Jubilee to Steamboat Mountains and to Mount Forster. Similar sections occur in the Stanford Range notwithstanding the fact that the Rocky Mountain Trench is crossed in going from Mount Forster. The McKay Group on Mount Forster consists of fine black shale, intraformational limestone-pebble conglomerate and minor blue limestone; no grit or sand occurs. Although the group thickens rapidly to Steamboat Mountain (2,500 feet) and to Brisco Range beyond (4,000 feet) similar rock types are to be found in these localities. Where the Beaverfoot Formation rests on Jubilee strata, on the ridge between Law and Horsethief Creeks, and the McKay Group is absent, no sand, grit, or pebbles are found. Similar relations are found to the southeast in Stanford Range.

From Brisco Range southwestward toward the Windermere High the main strata of the Beaverfoot Formation (Ordovician–Silurian) overlap the Glenogle Shales, the Mount Wilson Quartzite and the Whiskey Trail Member at the base of the Beaverfoot Formation. The Beaverfoot Formation progressively thins to Law Creek, yet shows no coarse clastics. The conclusion must be that throughout the lower Paleozoic (except for the Lower Cambrian) the Windermere High remained submergent and was not subject to active denudation. Examination of Horsethief Creek strata or Lower Cambrian strata anywhere in this region shows the type of sediments produced in active denudation. No such debris was supplied to the lower Paleozoic formations after Early Cambrian time, and no emergent shoreline existed in this region between the Early Cambrian and the Devonian.

The influence of the Windermere High following deposition of the Beaverfoot Formation cannot be deduced. Although basal Devonian strata appear to rest with some erosional unconformity on the Beaverfoot on Mount Forster, this is also true in Brisco Range and reflects the sub-Devonian hiatus present throughout the southern Rocky Mountains.

Western Zone

West of the Purcell Divide both Windermere and Lower Cambrian strata thicken rapidly and no profound unconformity divides these successions. It must be deduced, therefore, that in this southwestern zone no profound change of conditions, resulting from major orogenic activity, occurred between the Precambrian and the Cambrian. In this zone the thickness of the Lower Cambrian strata alone exceeds the total thickness of all sediments in the northeastern zone, from the Lower Cambrian to the Devonian.

The Lower Cambrian reflects a break in sedimentary rock type between the thick clastics and volcanics (Irene Formation, Rice, 1941) of the Windermere below and the fine clastics and volcanics of the Lardeau Group above. The Lower Cambrian (Hamill Group) is characterized by orthoquartzite and marble albeit with much semi-pelite and impure quartzite.

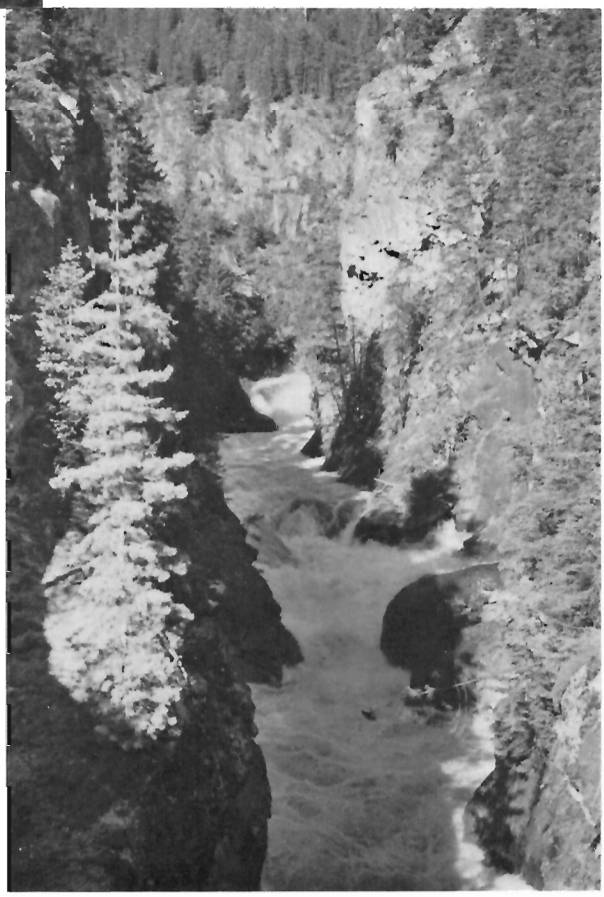
The unit has been derived from an emergent terrain to the east and southeast, for in Lardeau map-area the base of the westernmost Hamill Group, just north of lower Carney Creek, consists of pebbly and feldspathic quartzite. This unit probably represents an extensive fluvial deposit marginal to an elevated source area to the immediate east and southeast. The zone of deposition of coarse clastics gradually transgressed eastward so that basal units there are coarse and upper units in the west become progressively finer grained with more admixed pelitic material. As with the Eager Formation farther east, here too the sediments immediately following the quartzite sequences consist of very fine clastics and limestone, the latter with archaeocyathid faunas.

As already pointed out the succeeding strata assigned to the Lardeau Group and ranging in age from post-Lower Cambrian(?) to pre-Mississippian (Milford) cannot unfortunately be compared unit for unit with the strata in the northeast. Norford (1969, p. 41) has suggested that these strata represent an offshore shaly facies of the Ordovician and Silurian of the western Rocky Mountains. This cannot be substantiated in Lardeau map-area on a unit-for-unit comparison between these two regions. It may be suggested, however, that the strata between the Lower Cambrian and the Mississippian represent not an offshore shale facies but a deeper facies, characterized by thick

PLATE II

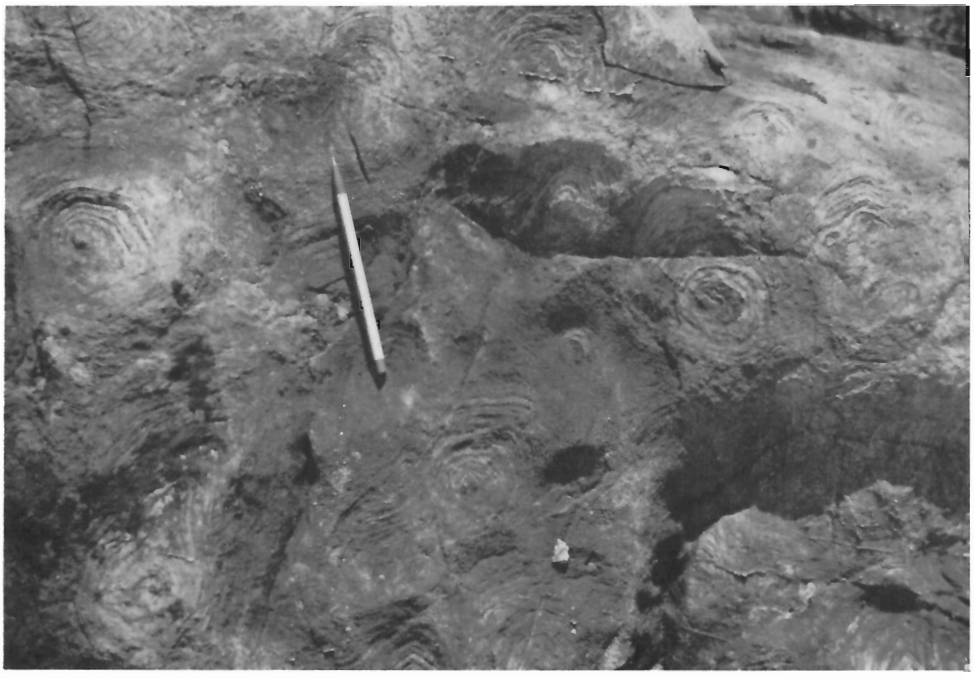
A. Conrad Glacier, Horsethief Creek Group pencil slates in foreground.

158445

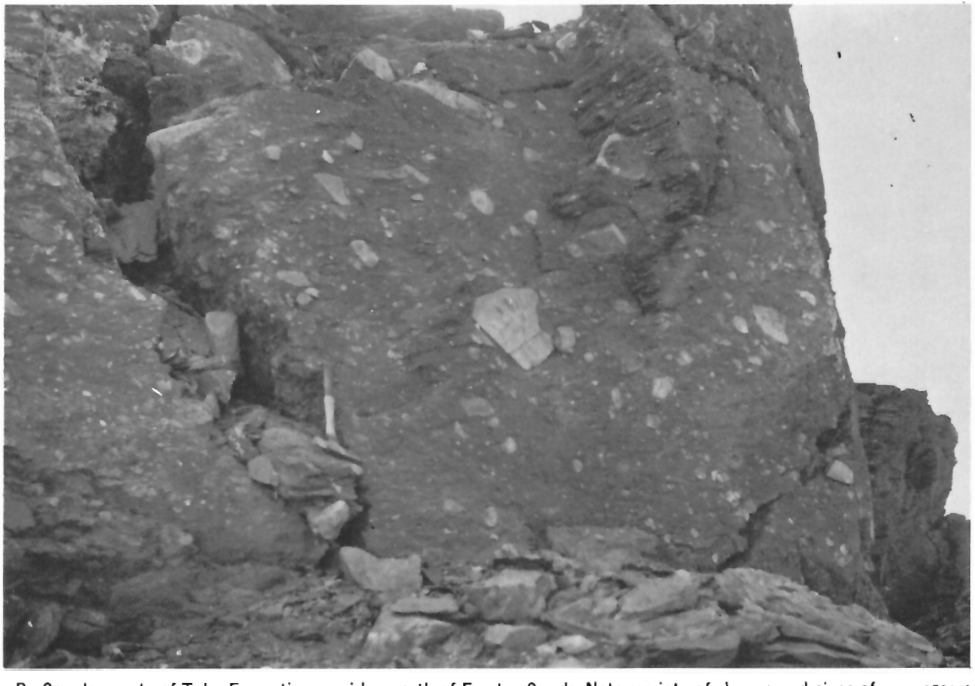


B. Fry Creek Canyon cut through quartz monzonite of Fry Creek Batholith a short distance above mouth of creek.

158444



A. Algal growths in dolomite of Mount Nelson Formation, from Bruce Creek, below Mount Slade. 158456



B. Conglomerate of Toby Formation on ridge north of Forster Creek. Note variety of shapes and sizes of cobbles and boulders. Large angular block of Mount Nelson dolomite. 158448

PLATE IV

A. Conglomerate of Toby Formation a few miles southeast of locality of Plate III B.

158447

B. Jumbled breccia of Toby conglomerate on north side of Bugaboo Creek.

158458

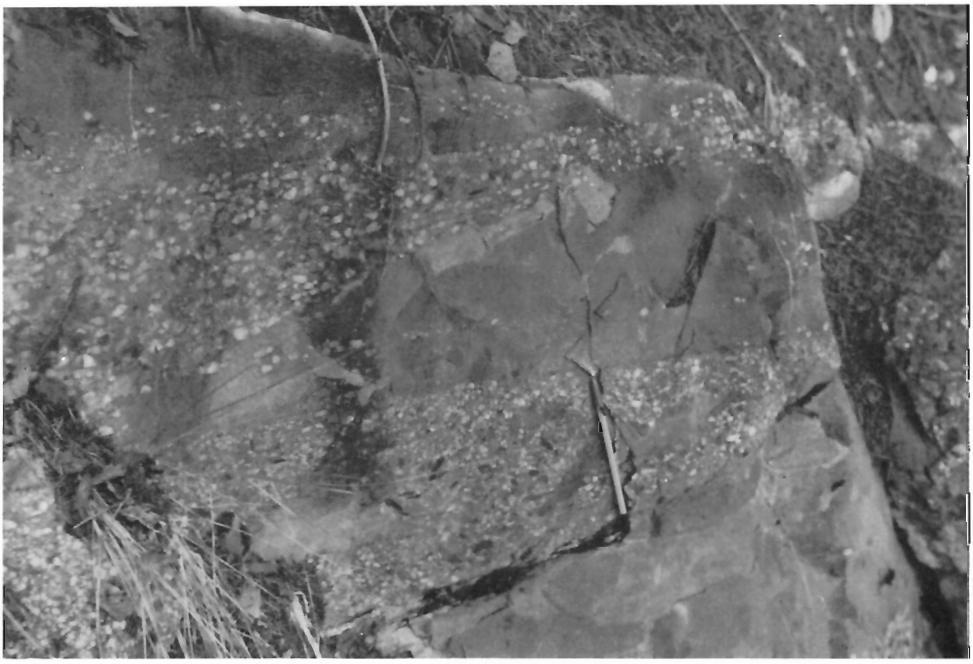
PLATE V

A. Toby conglomerate with matrix of vesicular andesite. Just north of upper Frances Creek.

158457

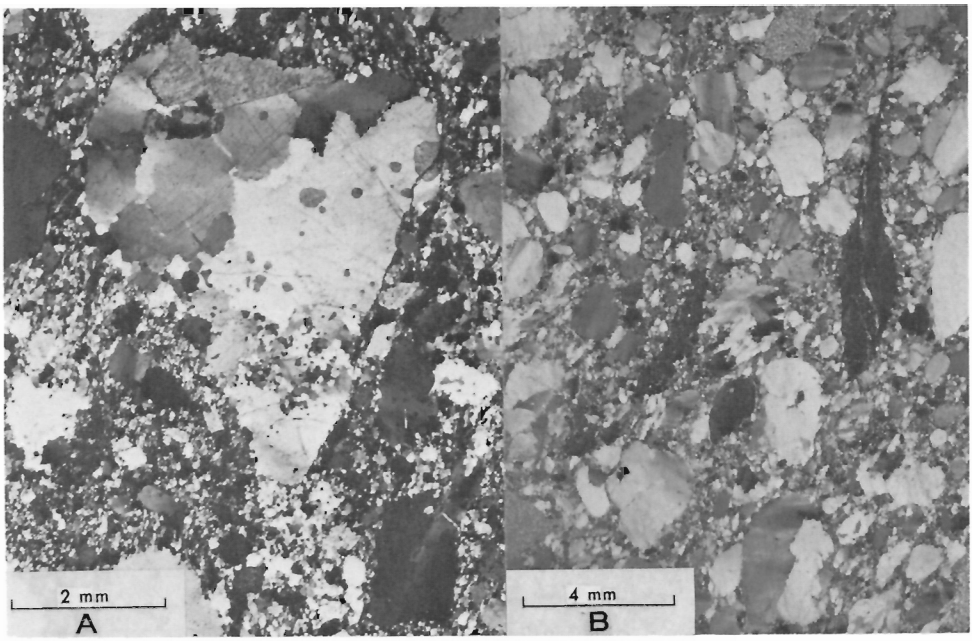
B. Deformed Toby conglomerate north of upper Carney Creek.

158441



A. Rapid variation in grain size of Horsethief Creek Group pebble-conglomerate and gritty quartzite. 158446

B. Pass between Horsethief and Glacier Creeks. Mount Monica at left showing north end of Blockhead syncline. Hamill Group quartzite on Mount Monica, highly pyritiferous Horsethief Creek Group slate on moraine in foreground. (August 1954) 152138



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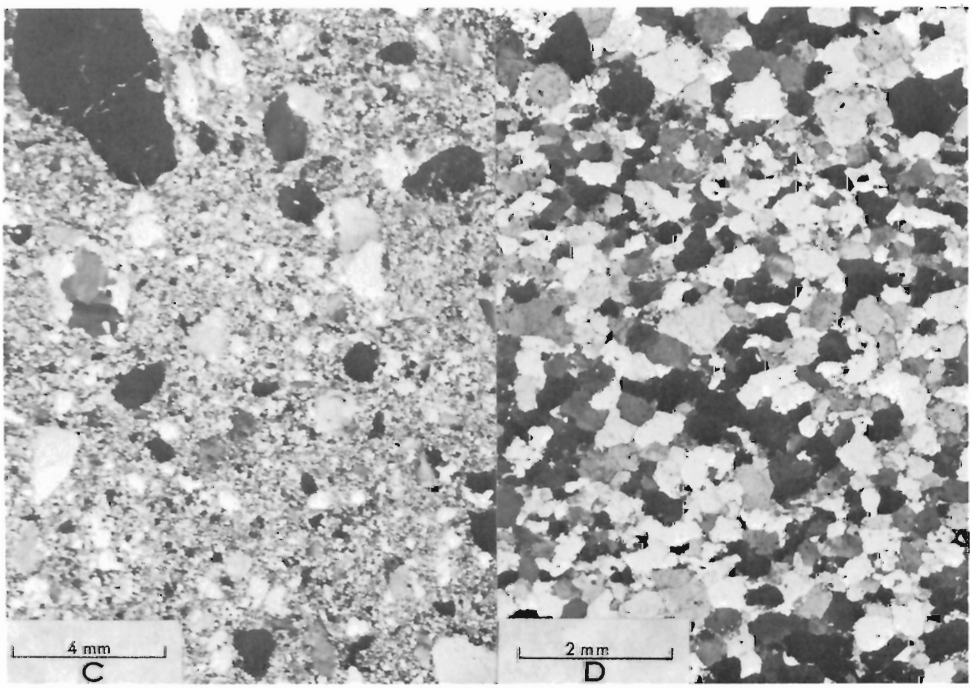
A. Horsethief Creek Group pebbly grit west of upper Stockdale Creek. Note 4 mm particle with potash feldspar and quartz (spec. 128RA-54).

B. Same, north of Bugaboo Creek, note variety of particles, quartz, quartzite (very fine), and argillite (spec. 452RA-57).



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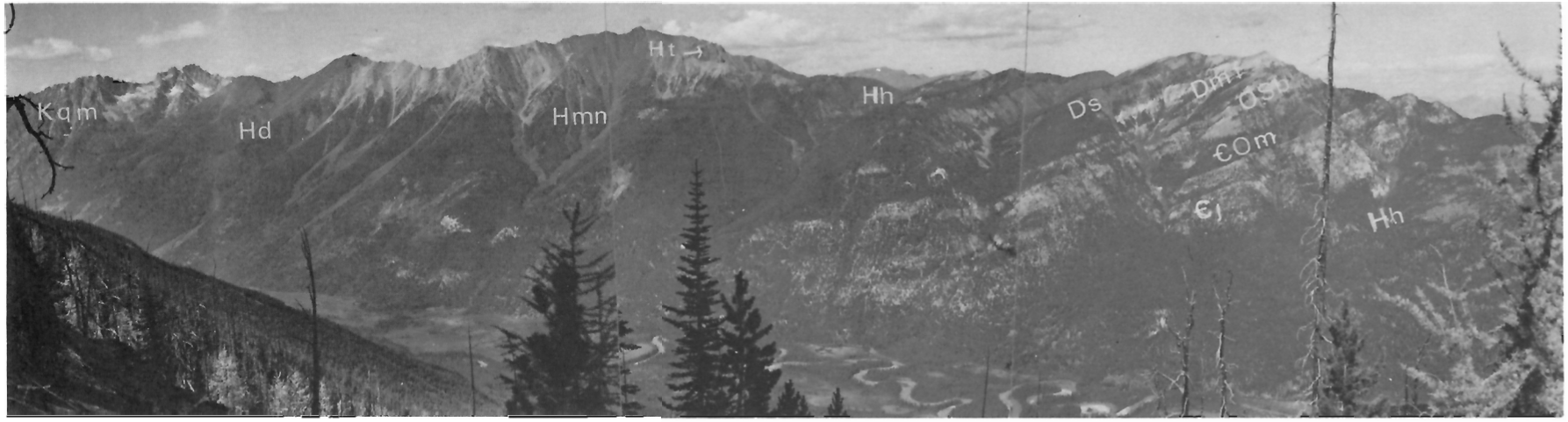
C. Horsethief Creek Group grit, matrix dominant (spec. 397RA-56).

D. Cranbrook orthoquartzite, south end of Steamboat Mountain (spec. 78RA-54).



158452

PLATE VIII. Panorama of lower Paleozoic section of Mount Forster, eastern Purcell Mountains. Hh – Horsethief Creek Group; Cj – Jubilee Formation; CO_m – McKay Formation; OSb – Beaverfoot Formation; Dmf – Mount Forster Formation; Ds – Starbird Formation; Ht – Toby Formation; H_{mn} – Mount Nelson Formation; Hd – Dutch Creek Formation; Kqm – Horsethief Creek Batholith (*see* cross-sections K–L and M–N, geological map).

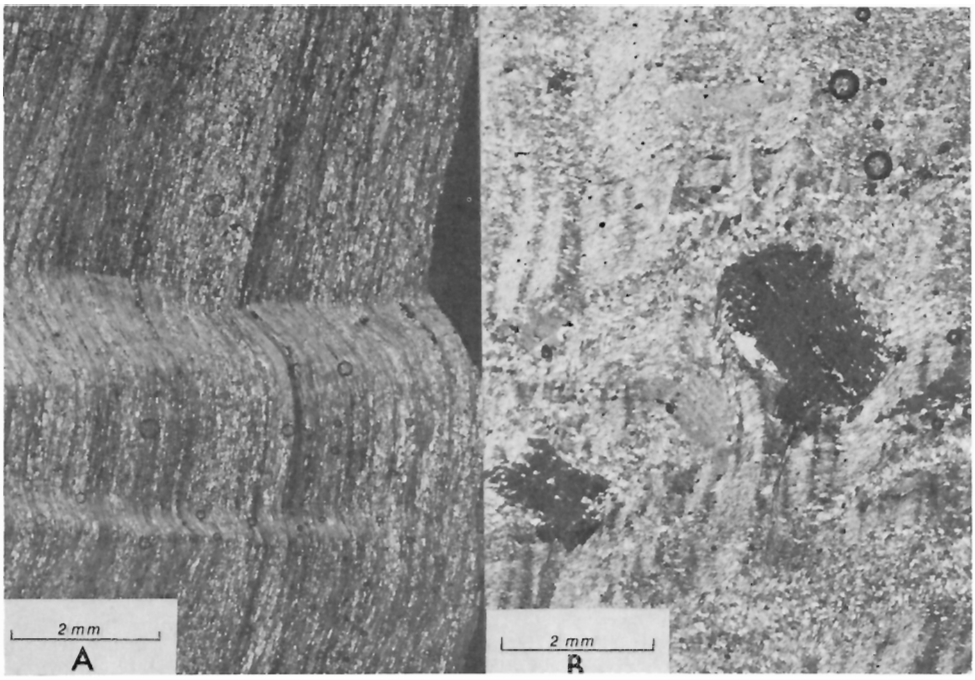
PLATE IX

A. Quartzite typical of Hamill Group. Locality near small cirque lake north of head of Clint Creek.

152163

152177

B. Hamill Group pebble-conglomerate on crossbedded grit and quartzite, Blockhead syncline.



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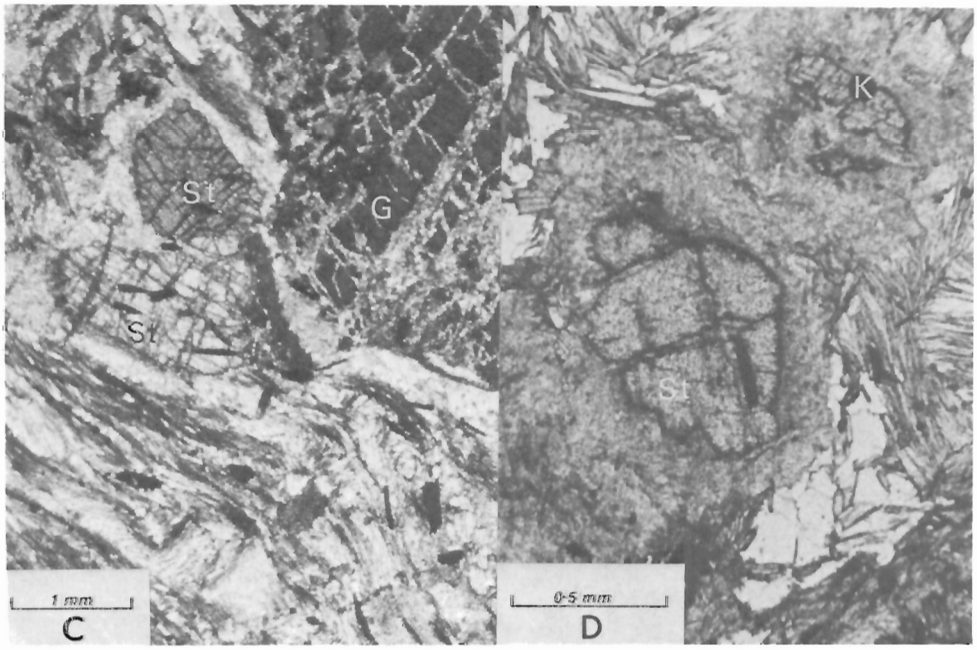
A. Crenulated phyllite of upper division of Aldridge Formation a mile north of the head of Doctor Creek (spec. 8RA-53).

B. Schist with biotite porphyroblasts, north of east end of Fry Creek Batholith (spec. 27RA-53).



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C. Staurolite (St) and garnet (G) in schist east-southeast of Mount Willet.

D. Kyanite (K) in same schist. Both staurolite and kyanite show pinitic alteration around periphery, garnet is similarly altered along fractures (spec. 210RA-55).

PLATE XI

A. Cleavage in Creston slate and quartzite, north of big bend of Findlay Creek. Note difference in orientation of cleavage in the two lithologies.

158440

B. Eastward overturned folds in Kitchener-Siyeh Formation, looking south from a point north of Mount St. Maur. Cliff about 20 feet high.

158439

PLATE XII

A. Fold in Creston Formation quartzite and argillaceous quartzite on Findlay Creek south of Mount St. Maur.

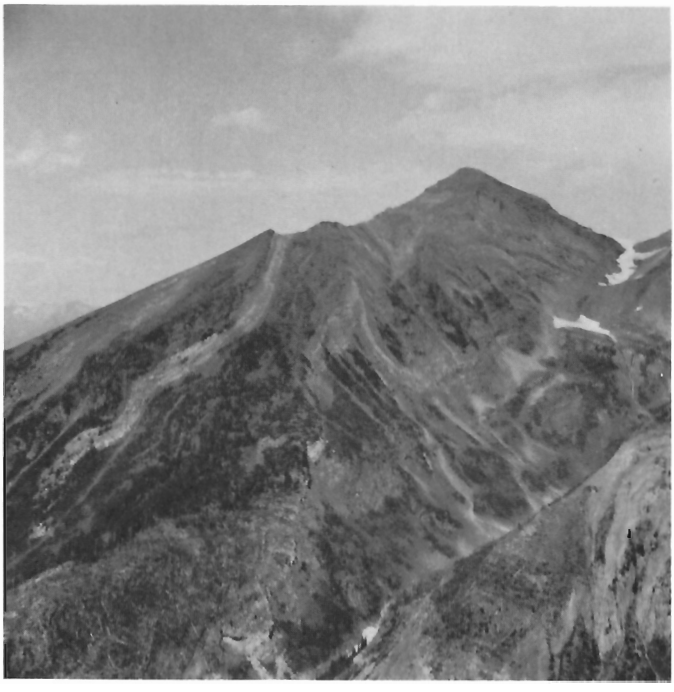
158438

B. Detail of Fry Creek quartz monzonite intrusive into Creston Formation at head of Morigeau Creek.

158442

PLATE XIII

Northwest-trending folds in Horsethief Creek Group on west side of Four Squatters. There is a sudden change of folding intensity at this locality in contrast to the folds eastward over the top of the range. Upper photograph has been taken a few miles northwest of the lower. Snowpatch in left background of lower photo is same as patch in right background of upper photo.



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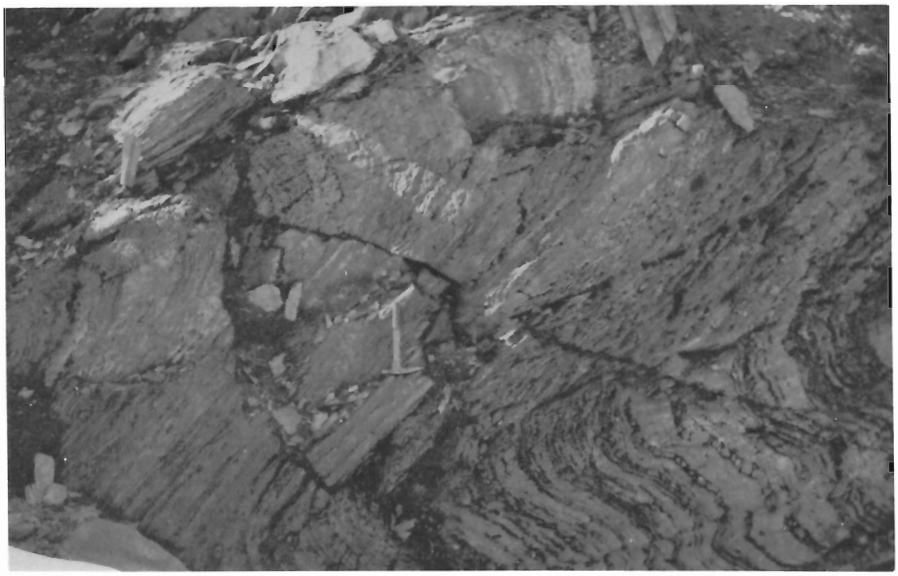

A. Westward overturned fold in Badshot–Mohican Formations about 3 miles east of Mount Lavina. Axial planes strike 320 degrees and dip 20 degrees east, axis strikes 320 degrees and plunges 6 degrees north. 158455

B. Isoclinal, recumbent folds with very gently west-dipping axial planes, above and west of village of Lardeau. This locality would be in the hinge zone of the Kootenay Lake anticline according to Fyles (1964, Fig. 16 or *see* Fig. 13 this report). 158443

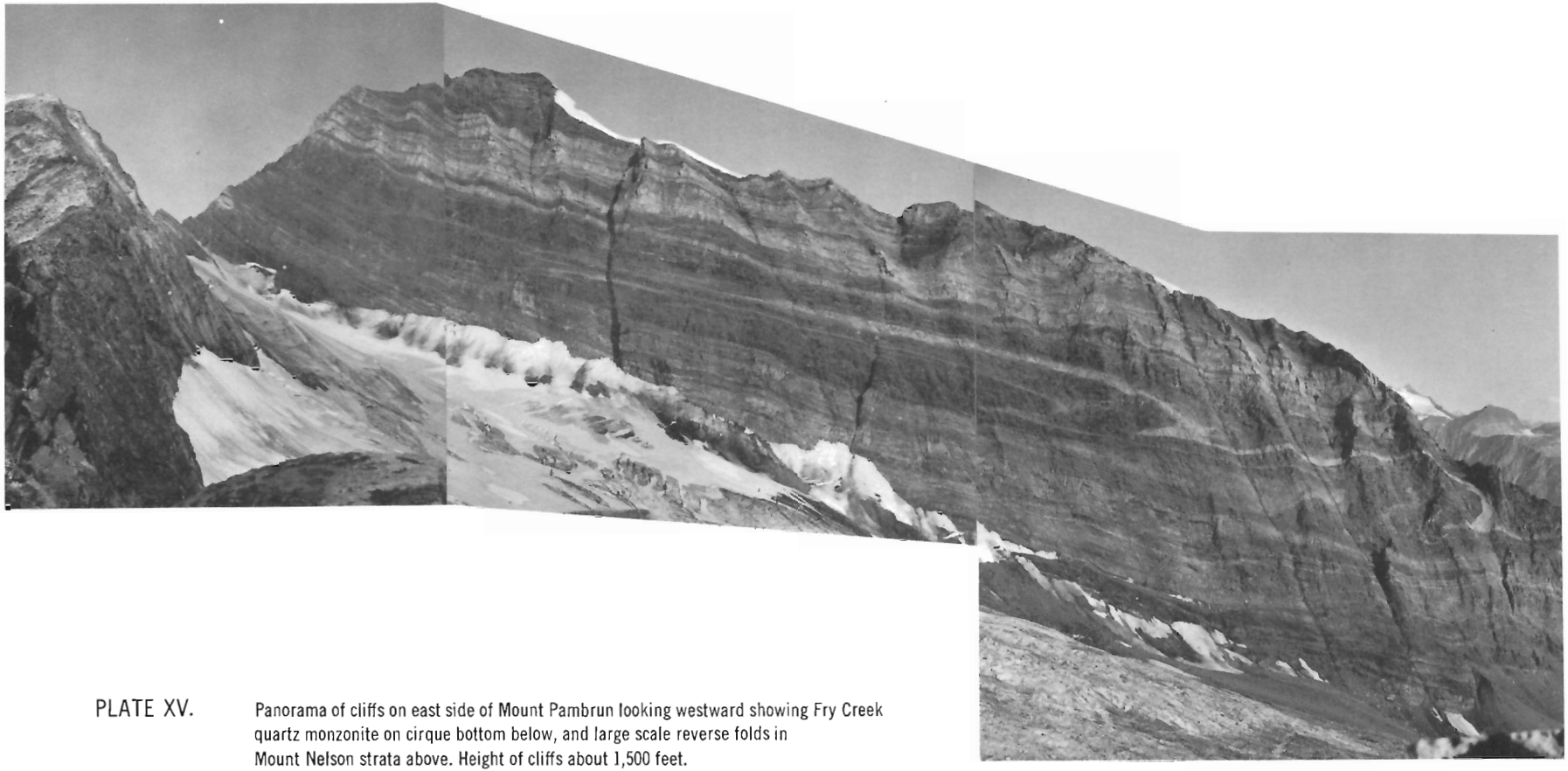

PLATE XV. Panorama of cliffs on east side of Mount Pambrun looking westward showing Fry Creek quartz monzonite on cirque bottom below, and large scale reverse folds in Mount Nelson strata above. Height of cliffs about 1,500 feet.

158459

pelitic and semipelitic deposits containing thick successions of volcanic rocks. These are eugeosynclinal and occur farther west in Lardeau map-area than an outer shale facies.

The northeastern zone, perhaps as far west as Blockhead syncline and eastward to the main ranges of the Rocky Mountains, consists of the offshore shaly facies and central carbonate facies. The outer shaly facies and its deposition has been much modified by the Windermere High in Lardeau map-area, east-half. If an 'outer shale facies' has been deposited it has been eroded away. West of the present Purcell Divide, the basin of deposition dropped off rapidly into a deeper zone. Thus the Purcell Divide marks approximately the outer limit of miogeosynclinal deposition in the lower Paleozoic.

Considerable evidence exists that extensive deformation occurred in the interval represented by the end of deposition of Lardeau Group rocks and the beginning of deposition of the Milford succession (*see* Chapter V). In Milford and later rocks eugeosynclinal conditions continued, much similar to the pattern of deposition found in the preceding Lardeau Group rocks. Other than the basal conglomerate of the Milford Group no succeeding successions of coarse late- or post-tectonic clastics are found in the succession, contrary for example to those of the Windermere strata deposited following the East Kootenay Orogeny. This fact must be taken into account in assessing the extent and intensity of a pre-Milford orogeny.

Chapter IV

INTRUSIVE ROCKS

Moyie Intrusions

Moyie Intrusions occur throughout the Purcell succession but are concentrated at two general stratigraphic horizons, the upper part of the lower division of the Aldridge Formation and the central part of the upper division of the Aldridge. In all, they account for several hundred feet of thickness in the Aldridge Formation. They are rare and generally not more than a few tens of feet thick in the succeeding formations of the Purcell. They have not been seen in either Dutch Creek or Mount Nelson Formation.

Moyie Intrusions are massive and cliff forming and generally are conformable with the enclosing Aldridge strata. Rarely they may be seen to jump abruptly to another stratigraphic level a few tens of feet up or down. Dykes that may have been 'feeders' are seen very rarely, even in this mountainous terrain. One such dyke about 30 feet wide, can be followed for about 2 miles along the high ridge trending northeast from Mount St. Maur.

In hand specimen these rocks are dark coloured, coarse- to medium-grained metadiorite or meta-quartz diorite. Most pyroxene is altered to hornblende, and much plagioclase to albite. Few textures and minerals of the original diabase remain.

Contacts are sharp, although often much sheared as though strain during later folding had been concentrated at the sill–sedimentary rock contact. Similarly the outer zones, particularly of large sills are often sheared during later deformation.

Moyie Intrusions lie conformably within the Purcell strata and were apparently emplaced before deformation of the Purcell. This implies that the Moyie Intrusions predate at least the minimum age of the East Kootenay orogenic disturbance (Leech, 1962, p. 2–4). Hunt (1962, p. 438) reported K/Ar ages on hornblende for Moyie Intrusions and a whole-rock age on Purcell lava hornfels from 1,050–1,110 m.y. Ages of sedimentation for Purcell-equivalent rocks in the Big and Little Belt Mountains in Montana range back to at least 1,325±15 m.y. (Obradovich and Peterman, 1968, p. 744; Rb/Sr isochron using samples from a number of formations). Thus the above ages for the sills are probably of the right order of magnitude. Older ages of 1,580 and 1,400 m.y. by K/Ar on hornblende from Moyie Intrusions reported by Hunt (op. cit.) predate the above dates of sedimentation.

Feldspar Porphyry Intrusions

These intrusions are confined to the immediate vicinity of the north end of Kootenay Lake, and are the felsite intrusions of Fyles (1964, p. 36–38). They occur

as conformable to semiconformable sill-like masses mainly in the Lardeau Group, although one lithologically identical six-foot sill was noted in Milford Group rocks in the southwest corner of the map-area. Thicknesses are commonly a few inches to a few tens of feet, rarely more.

The rock is white to rusty on weathered surface and white to buff on fresh surface. It is commonly porphyritic with phenocrysts of plagioclase (oligoclase) and microcline averaging 1 to 2 mm in a very fine grained allotriomorphic matrix of quartz and feldspar. Phenocrysts form up to one half the rock. When seen in thin section the microcline shows good grid twinning, sometimes in very irregular grains that replace plagioclase. Plagioclase similarly occurs in grains up to 4 mm. Quartz is rare as phenocrysts, but may be seen in strained, elongated mosaics of individual grains. The groundmass in a very fine allotriomorphic mass of quartz and feldspar with grain size about 0.02 mm. Biotite forms a very small proportion of the rock, up to 5 per cent, but usually much less. Biotite may be chloritized and calcite is rarely associated with plagioclase as an alteration product. Apatite, epidote, and magnetite (?) are found as accessories.

These intrusive layers are commonly massive and as they lack mafic minerals they show no internal layering. Very rarely, mafic clots show a lineation roughly parallel with fold axes in the enclosing sediments. Although the intrusions commonly parallel the compositional layering and the parallel foliation of the enclosing rocks they can, nevertheless, in some localities be seen to cut gently across the layering. Sill-like masses branch in places and clearly cut the enclosing strata. Boudinage structure is developed to some degree in many sills with boudin necks parallel with the strike of lineation in the enclosing rocks (Fig. 7).

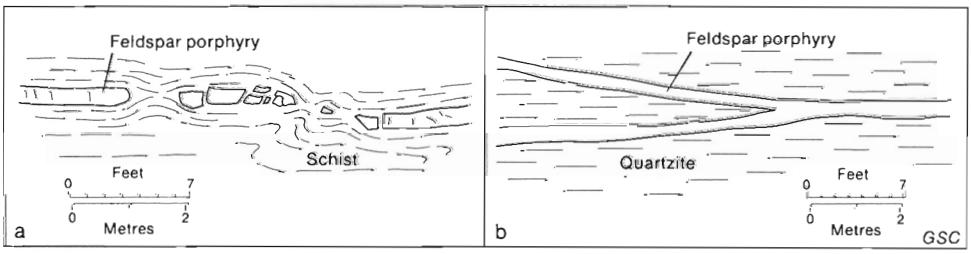

FIGURE 7. Characteristic forms of feldspar porphyry intrusions.

Clearly these intrusions postdate the principal deformation (Phase I) and Fyles (1964, p. 63) considered them to have been intruded at a late stage in the second phase of deformation. They clearly are not coincident with the zone of maximum regional metamorphism which culminates east of the area in which sills are common (*see* Chapter V). If the one sill noted in the Milford Group belongs to these intrusions then they are at least post-Milford in age. No isotopic age determinations have been attempted.

Semiconcordant Intrusions

These intrusions occur on, or west of the Purcell Divide and although they clearly crosscut strata locally and are intrusive, the long axes of the two main bodies are concordant with the trend of structures in the enclosing strata. It may be of course, that this

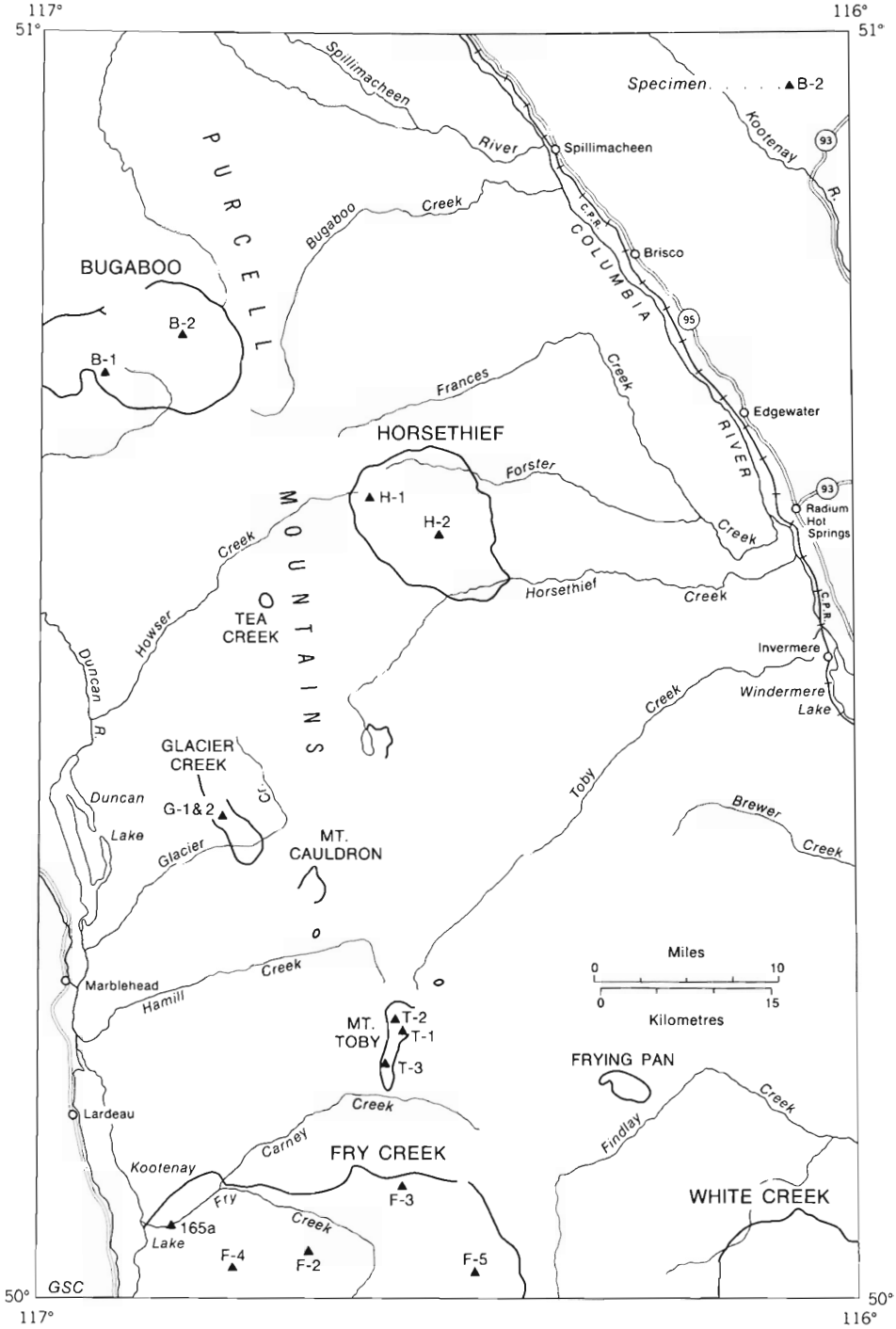

FIGURE 8. Location and names of intrusions and of specimens selected for chemical analysis and/or K/Ar age determinations (Note—Fry Creek Batholith specimens in Tables 5 and 6 not on this figure are located south of 50°00′ lat.).

concordance is due in part to their emplacement within or near the contact of the competent Hamill quartzite succession.

Intrusions assigned to this group are shown on Figure 8. They consist of the Glacier Creek stock, about 15 square miles in extent, Mount Toby stock, about one half that size, Cauldron Mountain stock, and several small bodies, one east of Tea Creek, one south of Cauldron Mountain, and one northeast of Mount Toby. Another may exist northeast of the junction of Rory and Howser Creeks, but this locality was not visited. Areally all these are relatively minor and comprise no more than a few square miles.

Mount Toby Stock

The lithology of this stock is quite different from that of any other mass within the map-area, and is similar to the Adamant Pluton studied by Fox (1969). Rock types range from pyroxene syenodiorite through hornblende and biotite–hornblende granodiorite. The range of compositions found are shown in Figure 9, and in Table IV.

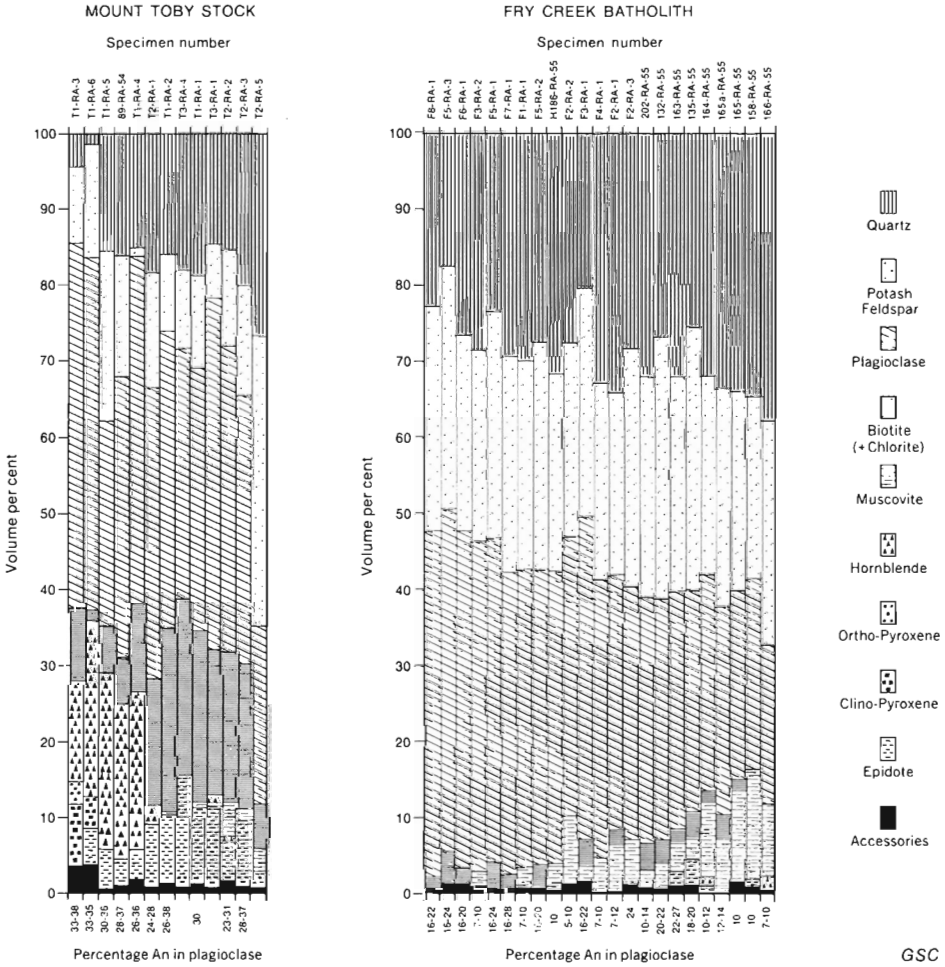

FIGURE 9. Graphic representation of modes of Mount Toby Stock and Fry Creek Batholith.

TABLE IV *Modal and chemical analyses of Glacier Creek and Mount Toby stocks*

INTRUSION	GLACIER STOCK											TOBY STOCK												
	Quartz diorite				Granodiorite				Quartz monzonite			Syenodiorite		Quartz diorite	Granodiorite								Quartz monzonite	
Sample number	H204-RA-55	H76-RA-55	H78-RA-55	H77-RA-55	173_a-RA-55	H60-RA-55	174-RA-55	H201-RA-55	173_b-RA-55	G1-RA-1	G1-RA-2	T1-RA-6	T1-RA-3	T1-RA-4	T3-RA-1	T1-RA-2	T2-RA-2	T2-RA-1	T3-RA-4	89-RA-54	T2-RA-3	T1-RA-1	T1-RA-5	T2-RA-5
MODE (VOLUME PER CENT)																								
Quartz	7.8	13.4	17.7	16.3	5.3	15.85	18.4	19.0	24.0	29.3	29.3	1.5	4.65	15.0	14.7	15.85	15.3	18.3	18.0	16.0	20.2	18.7	15.55	26.6
K-feldspar	1.9	2.1	1.6	2.75	11.4	11.55	12.7	7.4	30.11	22.0	20.75	14.85	10.0	1.1	7.2	10.25	12.7	15.2	10.4	16.0	14.4	21.1	22.35	37.9
Plagioclase	35.2	41.7	40.7	28.65	28.5	29.15	30.0	26.5	32.4	30.4	33.5	46.35	47.95	45.85	45.8	39.25	40.0	38.1	32.9	35.4	35.0	35.45	27.10	23.6
Biotite (+ chlorite)	19.8	14.0	23.1	33.04	13.0	12.4	19.25	24.0	9.3	11.5	11.95	1.6	9.65	11.35	19.3	24.2	19.9	16.9	23.2	6.0	19.2	22.75	5.9	5.8
Muscovite	1.3	0.2	0.4	—	—	—	—	0.7	—	—	—	—	—	—	—	—	4.6	—	—	—	1.2	—	—	2.3
Hornblende	20.3	23.2	6.2	4.1	30.5	25.4	8.25	14.0	2.5	0.1	—	22.45	13.1	20.8	1.4	0.1	0.8	2.4	—	20.5	0.3	—	22.8	—
Orthopyroxene	—	—	—	—	—	—	—	—	—	—	—	4.15	3.0	0.1	—	—	—	—	—	—	—	—	0.05	—
Clinopyroxene	1.1	2.8	—	0.2	10.5	1.0	—	0.3	—	—	—	—	7.95	—	—	—	—	—	—	0.1	—	—	—	—
Epidote	8.5	1.1	7.7	11.4	—	3.5	10.0	11.8	0.8	5.9	3.65	4.6	—	3.95	10.9	8.85	5.0	8.2	14.7	3.6	8.7	10.2	5.15	2.3
Calcite	1.0	—	—	—	—	—	—	0.3	—	—	—	—	—	—	—	0.2	—	—	—	—	—	—	—	—
Opaque acc.	1.5	0.4	0.8	2.5	0.2	0.75	0.7	0.5	0.1	0.4	0.55	2.15	2.35	0.95	0.5	0.6	1.6	0.7	0.6	0.6	0.7	0.5	0.55	0.6
Non-opaque acc.	0.8	1.1	2.0	0.8	0.6	0.4	0.7	0.5	0.8	0.3	0.3	0.35	1.3	1.1	0.2	0.7	0.1	0.2	0.2	0.54	0.3	0.85	0.55	0.1
Per cent An	36–50	33–37	32–50	30–50	27–32	25–40	35–38	30–46	24–29	24–36	22–38	33–35	33–38	26–36	—	26–38	23–31	24–28	—	28–37	28–37	30	30–36	—

WEIGHT PER CENT										
SiO_2	67.6	69.6	53.7	55.1	61.1	61.3	60.6	62.4		61.7
TiO_2	0.39	0.34	1.5	1.1	0.86	0.89	0.78	0.85		0.7
Al_2O_3	15.6	15.6	17.9	16.7	15.1	61.3	16.4	16.6		16.9
Fe_2O_3	2.2	0.89	3.6	3.2	2.6	2.2	2.2	2.0		2.0
FeO	1.53	2.35	4.7	5.76	3.72	3.88	4.37	3.8		4.05
MnO	0.06	0.05	0.20	0.18	0.11	0.09	0.11	0.09		0.09
MgO	2.2	1.7	3.6	4.7	3.6	2.1	2.6	2.1		2.3
CaO	2.7	2.4	7.5	6.5	4.8	4.2	4.5	4.1		4.3
Na_2O	3.0	2.9	4.0	3.2	3.3	3.4	3.2	3.4		3.6
K_2O	3.8	3.9	2.5	2.5	3.1	3.4	3.4	3.5		3.5
P_2O_5	0.19	0.14	0.4	0.42	0.27	0.31	0.28	0.3		0.21
H_2O	0.64	0.73	0.51	0.57	0.75	0.75	0.62	0.73		0.61
CO_2	0.07	0.15	0.08	0.04	0.21	0.04	—	0.23		—
TOTAL	99.98	100.95	100.20	100.00	99.50	98.90	99.10	100.10		100.00
NORM										
Q	25.35	27.1	1.3	5.1	13.8	14.7	13.3	15.4		12.4
OR	23.0	23.5	14.9	15.0	18.7	20.7	20.6	21.0		20.9
AB	27.5	26.5	36.0	29.0	30.2	31.3	29.4	31.0		32.6
AN	12.0	11.0	23.6	24.0	17.5	19.4	20.8	18.7		19.8
WO	—	—	4.5	2.3	2.0		0.1			0.2
HEM.	—	—	—	—	—	—	—	—		—
EN	6.2	4.8	10.0	13.2	10.2	6.0	7.4	6.0		6.5
FS	0.3	2.6	3.0	5.5	3.0	3.5	4.4	3.5		4.1
MT	2.25	0.9	3.8	3.4	2.8	2.3	2.3	2.1		2.1
IL	0.6	0.5	2.1	1.6	1.2	1.3	1.1	1.2		1.0
AP	0.4	0.3	0.8	0.9	0.6	0.7	0.6	0.6		0.4
C	2.4	2.8	—	—	—	1.0	—	0.5		—

Rapid chemical analyses by colorimetric methods by analytical chemistry section, Geological Survey of Canada.
Modes determined by counting at least 1,000 points on one or more thin sections.
Plagioclase determinations on flat stage.

In hand specimen the pyroxene syenodiorite is buff-brown, equigranular, and fine to medium grained. A rude, apparently primary foliation is shown by the alignment of plagioclase laths. Granodiorite is a coarser grained, dark grey rock with grains of hornblende as much as several millimetres long, and patchy feldspar. Near the border of the mass, particularly in the southern 'tail', the granodiorite shows a distinct gneissic banding and is almost an augen gneiss with small augen of feldspar wrapped by a finer groundmass of quartz, feldspar, and biotite.

Under the microscope the pyroxene syenodiorite is seen to consist of strongly oriented plagioclase laths of An_{33-38}. Both clino- and orthopyroxene occur. Orthopyroxene is strongly pleochroic *pink* to *green*, and clinopyroxene often shows outer zones altered to hornblende. The granodiorite consists of subhedral plagioclase laths mixed with anhedral microcline, interstitial clusters of mosaic quartz, and large, ragged, anhedral grains of biotite and hornblende. Mafic minerals are scattered in occurrence and hornblende is commonly 3 to 4 mm, a few of which show cores of clinopyroxene. Irregular intergrowths of hornblende, biotite, quartz, epidote, and sphene are also common in some specimens. In the more gneissic varieties plagioclase may also show slightly deformed carlsbad and albite twinning and potash feldspar exhibits strong grid twinning. Biotite occurs in shreds and rough laths and hornblende is much altered to biotite. Epidote occurs with biotite and quartz in streaks. Accessory minerals consist of apatite, coarse sphene, allanite, zircon, and opaques.

Contacts are steep to vertical and the stock is clearly intrusive into its surroundings, with a strong contact metamorphism (*see* Chapter V). A few large inclusions of quartzite exist in part of the southern 'tail.' Internal structure is conformable to the outer configuration of the mass.

Glacier Creek Stock

Rocks of this mass consist dominantly of hornblende–biotite granodiorite with a mafic-rich border zone in some localities. Modal and chemical compositions are shown in Table IV. Rock types range from quartz diorite to granodiorite and quartz monzonite. The other small plutons of this group are similar in mineralogy and composition to the Glacier Creek rock (Fig. 8).

In hand specimen the granodiorite is typically fine to medium grained, grey to dark grey, and equigranular. Toward the centre of the mass there is an increase in potash feldspar content and the granodiorite grades to quartz monzonite.

In thin section the granodiorite is seen to be equigranular, hypidiomorphic, and fine to medium grained. Plagioclase consists of 0.5- to 1.0-mm laths commonly showing a strong preferred orientation. It is often zoned from An_{45} to An_{25} and cores sometimes show a slight alteration to epidote. Most potash feldspar consists of interstitial grains up to 0.5 mm with good grid twinning. Quartz commonly occurs as discrete anhedra 0.3 to 0.5 mm long but sometimes forms wormy intergrowths with hornblende. Hornblende occurs as irregular, skeletal, or poikilitic grains, rarely with cores of clinopyroxene. Epidote occurs as 0.5 mm anhedra and biotite as ragged, dispersed grains. Accessories include sphene, apatite, allanite, zircon, and opaques.

The more leucocratic quartz monzonite is medium to coarse grained, sometimes with small phenocrysts of potash feldspar. Such potash feldspar consists of perthitic microcline with small inclusions of quartz, plagioclase, and biotite. Plagioclase consists

of subhedral laths zoned from An_{38} to An_{22} and shows little preferred orientation. Pyroxene is not found and hornblende occurs in ragged, irregular grains. Biotite, the dominant mafic mineral, occurs in clusters with epidote and it often contains zircon.

The contact zone is usually vertical and is abrupt against the enclosing Hamill quartzite. In places a contact breccia zone as much as 20 feet wide is followed by 200 feet or more of rusty weathering biotite quartzite. Outside this zone the grey quartzite typical of the Hamill Group is little changed. The breccia consists of angular fragments of metamorphosed Hamill quartzite, 1 to 20 cm long set in a dark grey, fine-grained granodiorite or quartz diorite. In places there is no contact breccia, but the granodiorite contains a few large blocks of quartzite.

Discordant Intrusions

These masses are clearly emplaced athwart the regional structures and cut or deform all earlier northerly or northwesterly trending folds or faults. In addition they superimpose a contact metamorphic aureole on earlier regional metamorphism. Most of these intrusions are oval and consist dominantly of quartz monzonite, leucocratic to biotite-bearing, and equigranular to porphyritic. There are a few variants from this, consisting of granite at one end of the scale and granodiorite at the other (Table V). Lithologies found are similar to the more leucocratic varieties in White Creek Batholith to the south of the area (Reesor, 1958), but the more mafic and inclusion-rich border zones so prominent in White Creek Batholith are not found to any extent in these masses. The principal batholiths (Fig. 8) are Bugaboo Batholith (50 square miles), Horsethief Batholith (60 square miles), and part of Fry Creek Batholith (120 square miles of a total area of 180 square miles). Smaller ones consist of the northeast limit of White Creek Batholith in the southeast corner of the map-area, Frying Pan stock in upper Findlay Creek, and Lake of the Hanging Glacier stock south of the headwaters of Horsethief Creek.

Bugaboo and Horsethief Batholiths

Bugaboo Batholith is divided into two lithologically distinct units consisting of a western fine- to medium-grained, uniform textured hornblende–biotite granodiorite and an eastern quartz monzonite. The latter consists of a number of textural variants ranging from a medium-grained, leuco-quartz monzonite of uniform texture to very coarsely porphyritic biotite quartz monzonite. In this type, potash feldspar grains as much as 2 or 3 cm long may form as much as 10 per cent or more of the rock. In places swarms of aplite and pegmatite dykes may be seen in cliffside exposures. It is possible that mapping at a larger scale would allow the portrayal of several different textural and compositional phases in the eastern part of the intrusion. Table V shows some modal and chemical analyses of selected specimens from Bugaboo Batholith. Clear age relations between the two main phases are in some doubt. However, inclusions of granodiorite in quartz monzonite similar in aspect to the western granodiorite indicate the probability that the quartz monzonite is later.

The contacts of Bugaboo Batholith are steep and abrupt. Dyke swarms may be seen intruding the metasediments at some localities, e.g., Cobalt Lake. Rarely a few inclusions of metasediments may be seen within a few feet of the contact. Internal primary foliation was seldom noted in these leucocratic rocks.

TABLE V *Modal and chemical analyses of Bugaboo, Horsethief, and Fry Creek Batholiths*

INTRUSION	BUGABOO BATHOLITH											HORSETHIEF BATHOLITH					
	Quartz diorite	Granodiorite					Quartz monzonite				Gran-ite	G-Dte	Quartz monzonite				
Sample number	271-RA-55	B1-RA-1	B1-RA-2	H239-RA-55	H240-RA-55	272-RA-55	B2-RA-1	B2-RA-2	B2-RA-3	276-RA-55	269-RA-55	H186-RA-55	H2-RA-2	H1-RA-1	H2-RA-1	132-RA-54	135-RA-54
MODE (VOLUME PER CENT)																	
Quartz	24.6	23.0	27.8	19.3	19.0	13.2	29.7	36.25	30.85	20.0	23.25	31.5	33.3	48.65		26.9	25.4
K-feldspar	1.7	14.35	10.45	13.1	17.2	20.1	20.3	31.05	29.65	43.4	48.56	25.8	16.4	17.15		34.3	34.3
Plagioclase	46.2	42.55	41.6	43.1	53.4	39.8	31.5	31.05	29.65	26.8	19.06	38.8	41.5	26.35		30.7	29.7
Biotite (+ chlorite)	11.5	9.7	8.5	6.2	7.3	8.5	3.55	2.5	1.1	7.3	3.43	0.4	5.0	4.85		2.8	3.4
Muscovite	5.4	—	—	1.5	—	5.1	3.5	4.35	2.75	1.2	1.12	3.0	2.4	—		3.5	2.6
Hornblende	—	3.55	2.2	5.8	—	—	—	—	—	—	—	—	—	1.0		—	—
Orthopyroxene	—	—	—	—	0.45	1.9	—	—	—	—	—	—	—	—		—	—
Clinopyroxene	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Epidote	0.4	5.35	6.65	6.2	—	5.1	0.25	—	0.55	0.1	2.0	—	0.65	0.45		—	3.40
Calcite	—	—	—	0.2	—	2.0	0.1	0.25	0.2	—	—	—	—	.1		—	0.4
Opaque acc.	1.40	1.3	0.95	1.6	1.75	1.2	0.25	0.6	0.05	0.1	0.12	0.3	.3	.85		0.4	.6
Non-opaque acc.	0.4	1.1	0.45	2.7	0.9	2.2	0.85	0.8	0.45	1.2	1.81	0.2	.4	.55		1.7	.5
Per cent An	32–48	24–36	20–37	24–40	30–36	28–46	20–24	20–25	25–30	20–30	18–24	10	18–25	20–24		20–22	18–20

WEIGHT PER CENT								
SiO_2	63.9		72.8				73.0	70.0
TiO_2	0.58		0.15				0.15	0.25
Al_2O_3	17.2		15.0				14.6	16.1
Fe_2O_3	3.3		0.51				0.27	0.88
FeO	1.53		.65				1.08	1.12
MnO	0.14		.04				0.05	0.03
MgO	2.5		.42				0.73	0.92
CaO	4.2		1.2				1.3	1.3
Na_2O	3.4		3.5				3.7	3.4
K_2O	2.6		4.8				4.6	4.8
P_2O_5	0.32		0.07				0.12	0.04
H_2O	0.67		.39				.31	0.51
CO_2	—		.06				.08	—
TOTAL	100.34		99.59				99.99	99.40
NORM								
Q	20.9		29.07				27.8	25.8
OR	15.5		28.07				27.5	28.8
AB	31.0		31.75				33.5	31.0
AN	19.0		5.5				5.5	6.3
WO	—		—				—	—
HEM.	0.7		—				—	—
EN	7.0		1.2				2.0	2.6
FS	—		0.56				1.2	0.8
MT	2.4		0.52				0.3	.9
IL	0.8		0.2				.2	.4
AP	0.6		0.15				.3	.1
C	2.1		2.3				1.7	3.3

Rapid chemical analyses by colorimetric methods by analytical chemistry section, Geological Survey of Canada.
Modes determined by counting at least 1,000 points on one or more thin sections.
Plagioclase determinations on flat stage.

TABLE V (Conc.)

INTRUSION	FRY CREEK BATHOLITH																				
	Quartz monzonite																				
Sample number	F1-RA-1	F2-RA-1	F2-RA-2	F2-RA-3	F3-RA-1	F3-RA-2	F4-RA-1	F5-RA-1	F5-RA-2	F5-RA-3	F6-RA-1	F7-RA-1	F8-RA-1	158-RA-55	162-RA-55	163-RA-55	164-RA-55	165-RA-55	165$_a$-RA-55	166-RA-55	202-RA-55
MODE (VOLUME PER CENT)																					
Quartz	30.0	34.05	27.2	28.1	19.95	28.55	32.9	23.5	27.4	7.6	26.7	29.4	22.7	34.7	32.1	32.1	31.8	34.1	33.8	37.8	32.3
K-feldspar	27.55	24.2	25.75	31.45	30.25	25.15	25.9	29.9	30.0	32.1	25.5	28.5	29.1	23.5	28.2	28.2	26.1	25.8	28.6	29.0	28.9
Plagioclase	39.15	33.40	36.95	33.35	35.95	43.3	35.6	42.6	39.0	44.8	44.7	39.5	46.1	24.7	38.90	31.4	25.0	22.3	25.6	20.8	30.9
Biotite (+ chlorite)	—	2.2	—	—	3.55	0.15	—	3.3	2.8	3.4	1.8	1.9	1.4	0.2	2.0	1.8	1.5	1.5	3.1	0.2	3.4
Muscovite	2.45	5.85	9.0	6.05	1.90	1.8	5.4	0.1	0.3	0.7	0.4	0.3	0.2	14.5	3.5	3.6	9.7	12.0	7.0	9.6	2.3
Hornblende	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.8	—
Orthopyroxene	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Clinopyroxene	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epidote	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0	1.9	1.8	1.1	—	—	—	—
Calcite	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.2		—	1.3	—	—	—
Opaque acc.	0.55	0.05	0.2	0.15	0.85	0.8	0.1	0.3	0.5	1.2	0.5	0.4	0.5	—	0.7	0.5	1.2	0.2	—	0.1	0.6
Non-opaque acc.	0.3	0.25	0.9	0.9	7.55	0.25	0.1	0.3	—	0.2	0.4	—	—	0.7	2.9	0.6	3.6	3.2	1.9	0.7	0.8
Per cent An	7–10	7–12	5–10	24	16–22	7–10	7–10	16–24	16–20	16–24	16–20	16–28	16–22	10	10	22–27	10–12	10	12–14	7–10	10–14

WEIGHT PER CENT								
SiO_2	76.0	73.5	71.2	72.9	72.3	71.7	69.6
TiO_2	0.05	0.11	0.24	0.09	0.29	0.18	0.32
Al_2O_3	14.0	16.1	15.2	15.0	15.5	16.9	16.3
Fe_2O_3	0.46	0.43	0.89	0.75	1.0	0.91	1.3
FeO	.25	.55	.71	.23	0.7	.51	0.73
MnO	.02	.07	.02	.07	0.03	.01	.04
MgO	.12	.43	.26	1.2	0.22	.18	.17
CaO	.32	.51	1.7	0.51	1.6	1.6	2.0
Na_2O	4.3	3.5	4.0	3.9	4.0	4.4	4.0
K_2O	4.0	4.5	4.0	4.4	4.3	4.0	4.1
P_2O_5	—	0.02	0.06	0.12	0.14	0.07	0.09
H_2O	0.22	0.54	0.26	.37	.19	.16	.3
CO_2	—	—	0.06	.05	.01	.04	.03
TOTAL	99.78	100.30	98.56	99.60	100.30	100.80	99.00
NORM							
Q	30.1	31.8	27.22	28.82	27.18	25.14	24.9
OR	23.5	26.8	24.25	26.24	25.53	23.52	24.7
AB	38.25	31.6	36.75	35.26	36.01	39.22	36.5
AN	1.5	2.4	8.0	1.76	7.05	7.44	9.5
WO	—	—	—	—	—	—	—
HEM.	—	—	—	—	—	—	0.2
EN	0.4	1.2	0.7	3.36	0.61	0.5	0.5
FS	3.5	0.5	0.06	—	0.03	.06	—
MT	0.45	0.5	0.97	0.51	1.05	.94	1.1
IL	0.1	0.2	0.4	.13	0.4	.25	0.4
AP	—	—	0.15	.25	0.29	.15	0.2
C	2.15	5.0	1.5	3.48	1.83	2.79	—

Rapid chemical analyses by colometric methods by analytical chemistry section, Geological Survey of Canada.
Modes determined by counting at least 1,000 points on one or more thin sections.
Plagioclase determinations on flat stage.

Horsethief Batholith consists dominantly of porphyritic biotite quartz monzonite containing large, euhedral potash feldspar phenocrysts as much as 5 cm or more long. Locally, variants may be found without coarse potash feldspar. The western tenth of this batholith consists of a very coarse grained granite characterized by pink potash feldspar with euhedral cores and irregular boundaries; quartz occurs in irregular, coarse patches of milky, anhedral grains. Plagioclase occurs in porcelaneous, euhedral grains and biotite as shiny, black tablets. In all, it is a very distinct rock, much different from the porphyritic quartz monzonite, although the two rock types appear to grade into each other.

Although mineral proportions and grain sizes vary, the minerals seen in thin section vary little between phases or between Bugaboo and Horsethief plutons. Plagioclase occurs in subhedral laths 1 to 2 mm and is zoned from An_{35} to An_{25} in granodiorite, but is more commonly An_{20-25} in quartz monzonite. Microcline may be perthitic and usually shows good grid twinning. It occurs as interstitial anhedral grains or as separate, large, subhedral grains including quartz, plagioclase, and biotite. Quartz occurs as anhedra in clusters up to 5 mm or as 1 to 2 mm grains. It shows even extinction. Quartz in the coarse Horsethief granite consists of unstrained, large patches of coarse, irregular grains containing planes of dusty inclusions. Biotite occurs in large, fresh to ragged grains up to several millimetres in size. It may be associated with muscovite in some varieties of quartz monzonite. Hornblende, where present, occurs as small subhedral grains commonly 1 mm in size. In thin section accessory minerals are seen to be epidote, allanite, apatite, and opaques.

Black sand placer concentrations containing the columbium-bearing minerals pyrochlore and euxenite are found below the outwash areas of active glaciers in the high peaks of Bugaboo and Horsethief Batholiths. A large block of porphyritic quartz monzonite taken from Horsethief Batholith and representative of much of this pluton was crushed and a heavy concentrate was separated and examined. All minerals found in the placer concentrate were found in the common quartz monzonite of the pluton: pyrochlore–microlite, euxenite–polycrase, uraninite, anatase, lepidocrocite, epidote, allanite, magnetite, ilmenite, rutile, sphene, apatite, fluorite, and zircon. Cassiterite and molybdenite were also found in some of the black sand concentrates. Since the glaciers act as a mechanical grinder and the outwash streams as a sorting device, all minerals found in the fresh rock are found in the placer sands. There is no opportunity for weathering. It is not unlikely that similar minerals are found in plutons such as White Creek and perhaps Fry Creek, but large active glaciers are not present in these masses and products of denudation are much more extensively weathered.

Fry Creek Batholith

This pluton is characterized by leuco-quartz monzonite of medium grain size and uniform texture in contrast to similar plutons characterized by the coarse, potash feldspar phenocrysts. Locally, different phases are present, for example in the northwest corner. There, a coarse muscovite quartz monzonite shows some evidence of post-crystalline cataclasis, as well as a tourmaline-bearing phase. Elsewhere local porphyritic quartz monzonite occurs over small areas. The typical Fry Creek granitic rock is a white, white weathering, medium-grained, fresh, leuco-quartz monzonite, containing a little muscovite or muscovite and biotite. The pluton shows less lithological variation than similar plutons in the area.

Figure 9 and Table V show modal and chemical compositional variations. Inclusions are rare even near the boundary, and pegmatites and aplites, although present, are not common. The mass is sharply intrusive and contacts are vertical to moderately outward dipping (Pls. XII B and XV). It clearly crosscuts several regional metamorphic zones and disrupts northwest-trending, regional structures (*see* Chapter V). Internal foliation is uncommon except in the northwest quadrant of the pluton.

In thin section, a hypidiomorphic, medium-grained texture is seen to predominate. Plagioclase occurs in 1 to 3 mm subhedral grains and varies from albite to oligoclase, An_{8-10} and An_{15-28}. Microcline, sometimes showing hair perthitic intergrowths, is 2 to 4 mm and shows good grid twinning and includes plagioclase and quartz. It also occurs as fine, anhedral, interstitial grains. Quartz is anhedral, 1 to 2 mm in size, and sometimes weakly strained. Muscovite occurs as stubby flakes as much as 2 mm and biotite, if present, occurs as small grains as much as 1 mm and is pleochroic from tan to dark brown. Accessories are zircon, apatite, sphene, and tourmaline.

In contrast, rocks in the northwest zone of the batholith, approximately west of the junction of Carney and Fry Creeks, are commonly foliated, thus muscovite in 2- to 8-mm wisps parallels elongate quartz lenses. Quartz is often granulated and strained, and in places shows an incipient mortar texture. Tourmaline in some localities consists of large prisms or very large skeletal grains as much as 12 mm in size. Clearly this part of the batholith and this part alone shows evidence of some post-crystalline deformation. It lies approximately opposite the regional amphibolite metamorphic zone (Fig. 11) and may indeed have been affected by Phase II deformation in the metamorphic rocks to the north (Fyles, 1964 and *see* Chapter V).

Other Plutons

A few square miles of the northeastern tip of White Creek Batholith projects into the southeastern corner of Lardeau map-area. It consists generally of the porphyritic biotite quartz monzonite unit of White Creek Batholith (Reesor, 1958, p. 40). Mafic-rich units are absent from the periphery of the batholith in this locality.

Frying Pan stock and Lake of the Hanging Glacier stock (Fig. 8) are two small intrusions of porphyritic quartz monzonite similar in aspect to that found in Bugaboo, Horsethief, and White Creek Batholiths.

Age Determinations

Table VI summarizes the K/Ar isotopic age dates available from the larger plutons in this map-area. Two nearby specimens from Glacier Creek biotite–granodiorite yielded biotite ages of 127 m.y. (spec. G-1-RA-1) and 145 m.y. (spec. G-1-RA-2). Thus the minimum age must be considered to be at least 145 m.y., or Late Jurassic. Two specimens from Mount Toby stock yielded K/Ar biotite ages of 232 m.y. (spec. T-1-RA-1) and 179 m.y. (spec. T-3-RA-1). A further determination by K/Ar on hornblende gave an age of 162±8 m.y. (spec. T-2-RA-1) (Wanless *et al.*, 1968, p. 45). The validity of the earlier biotite ages is open to doubt and the hornblende age perhaps more likely represents the age of consolidation of this mass.

Plutons of the discordant group (Bugaboo, Horsethief Creek, and Fry Creek) have yielded K/Ar ages ranging from early- to mid-Cretaceous (Table VI). Some anomalies

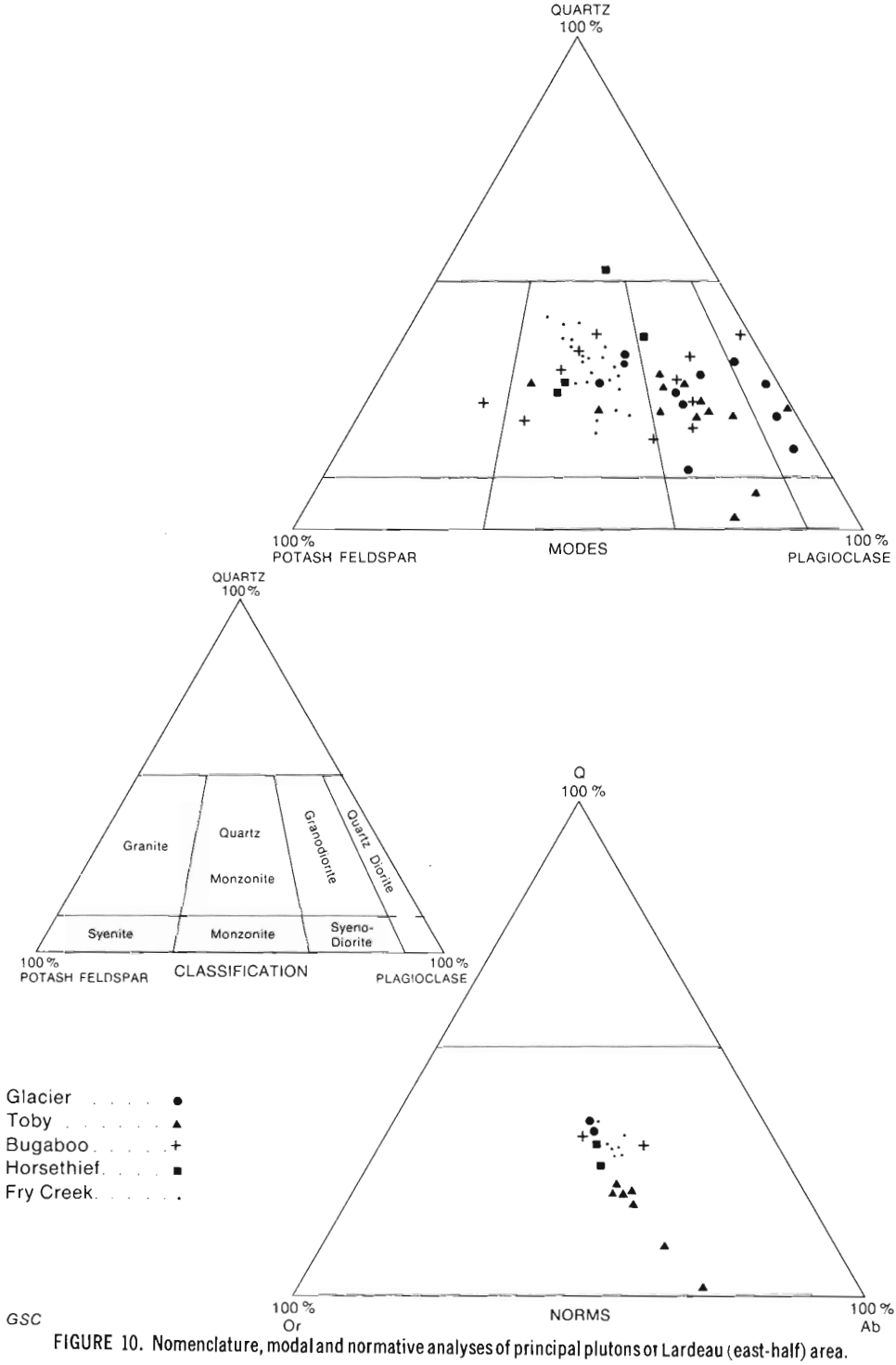

FIGURE 10. Nomenclature, modal and normative analyses of principal plutons of Lardeau (east-half) area.

TABLE VI *K-Ar ages from plutons of Lardeau map-area, east-half*

Sample number	Reference number	K Per cent	Ar^{40}/K^{40}	Radiogenic argon Per cent	Rock type	Age (m.y.)
			Glacier Creek Batholith			
G-1-RA-1	61–18	7.86	0.00770	100	Biotite granodiorite	127
G-1-RA-2	62–15	8.08	.00880	100	Biotite granodiorite	145
			Toby Stock			
T-3-RA-1	62–14	7.80	0.0110	100	Hornblende–biotite augen granodiorite gneiss	179
T-1-RA-1	62–13	8.09	.0144	100	Biotite granodiorite	232
T-2-RA-1	66–49	1.62	.0099	87	Gneissic granodiorite	162 (H)
			Bugaboo Batholith			
B-1-RA-1	61–20	7.77	0.00601	100	Biotite granodiorite	100
B-2-RA-1	62–17	8.10	.00798	100	Leuco-quartz monzonite	132
B-2-RA-1	62–18	8.83	.00839	100	Leuco-quartz monzonite	138 (M)
			Horsethief Creek Batholith			
H-2-RA-1	62–16	8.19	0.00648	100	Porphyritic quartz monzonite	108
H-1-RA	62–19	7.83	.00565	100	Coarse biotite granite	205
			Fry Creek Batholith			
1955-165a	60–18	7.78	0.00360	80	Leuco-quartz monzonite	45
1955-165a	60–19	7.53	.00265	81		63 (M)
F-8-RA-1	62–12	7.94	.00452	100	Leuco-granodiorite	76
F-1-RA-1	62–8	8.51	.00499	100	Leuco-quartz monzonite showing some evidence of late shearing	83 (M)
F-3-RA-1	62–11	8.01	.00514	100	Fresh leuco-quartz monzonite	86
F-3-RA-1	62–10	8.05	.00546	100	Fresh leuco-quartz monzonite	91 (M)
F-2-RA-1	62–9	8.90	.00584	100	Fresh leuco-quartz monzonite	97 (M)

M= muscovite; H= hornblende; all others biotite.
References: GSC Paper 62-17, 63-17, 67-2A.

in these determinations are evident from the geological relations. Possibly only concordant ages from biotite–muscovite pairs can be looked upon as indicating minimum ages of the plutons. Thus, Bugaboo Batholith yielded a biotite age of 132 m.y., and a coexisting muscovite 138 m.y., and Fry Creek for a similar pair gave ages of 86 m.y. on biotite, and 91 m.y. on muscovite. Ages in the deformed zone of northwestern Fry Creek pluton gave, for a mica pair, biotite 45 m.y., and muscovite 63 m.y. Although the 'absolute' value shown here must be questioned, it does confirm a later event in this part of the mass. An age of 100 m.y. for biotite from the western part of Bugaboo Batholith appears to indicate a younger age for this part of the mass than that of the quartz monzonite to the east. This is not confirmed by intrusive relations between the two units, quite the contrary, and this 'age' should be considered a minimum only and in no way an age of consolidation. Similarly no geological confirmation can be deduced for the age of 205 m.y. on the western, coarse granite of Horsethief Batholith and 108 m.y. on the porphyritic quartz monzonite to the east. There is no textural or structural evidence to indicate such a wide difference in age between these rock types.

Similar ranges in K/Ar ages on biotite and muscovite were obtained in White Creek Batholith (Gabrielse and Reesor, 1964). Later Rb/Sr isochron and mineral studies were undertaken (Wanless *et al.*, 1968, p. 375–386). A Rb/Sr isochron on the leucocratic rocks of White Creek yielded an age of 111±5 m.y. (op. cit., p. 381). Mineral studies indicate important events at 85 m.y. and 65 m.y., confirming at least some of the K/Ar scatter of ages as apparently important thermal events. The apparent lack of relationship in the Rb/Sr isochron between leucocratic rocks and mafic-rich, border zone rocks is as yet unexplained.

The larger plutonic masses of this and immediately adjoining areas do not appear to be simple, uniform intrusions, simply emplaced at one time in the complex deformational history of this region. This group of intrusions is generally younger than the more melanocratic group discussed above. Within each group considerable variations exist in rock types as well as in apparent age of consolidation.

Summary and Discussion

Available modal and normative analyses for the plutons within this map-area are plotted in Figure 10. The plots show a range in composition from quartz diorite to quartz monzonite if the granitoid rocks are taken as a group. No one body displays the full range of compositional variations, in fact each pluton, however small, shows distinctive variations from other plutons even within a generally similar group. In general, the group of plutons in this map-area displays all the lithological variations to be found in the surrounding region, with the exception of alkaline or quartz-poor varieties.

Plutons of more basic composition and higher total content of mafic minerals appear to be the earliest in the sequence. With their high mafic content they also show clearly a primary and, in some cases, a secondary structure and appear to be closely involved in the structural deformation of the enclosing rocks. They yield older isotopic ages.

In contrast, the mafic-poor intrusions are clearly later than all structures in the surrounding rocks. They yield younger ages, are dominantly quartz monzonites and seldom show internal structural features primary or secondary. They clearly superimpose a metamorphic aureole on both low- and intermediate-grade, regionally metamorphosed rocks.

Chapter V

METAMORPHISM AND STRUCTURE

Regional Metamorphism

Regional metamorphism within the map-area increases progressively from northeast to southwest. It rises gradually through a shale–argillite–slate belt, covering the northeast half of the area, to phyllites of the lower greenschist facies along a central-western belt. The level of metamorphism rises more rapidly in the southwestern part of the map-area through a biotite and a garnet zone, into lower almandine–amphibolite facies characterized by staurolite and staurolite–kyanite bearing mineral assemblages.

The divisions shown (Fig. 11) are based on the examination of pelitic rocks or the pelitic matrix of coarse, clastic rocks. Divisions are dependent upon reconnaissance sampling so that although the trends and the general location of critical changes of metamorphic mineral assemblages are as portrayed, the location of zone contacts should not be considered as precise.

Shale–Argillite–Slate Zone

Rocks of all ages from the upper part of the Purcell System to the mid-Paleozoic occur in this belt. In hand specimen and in outcrop, rocks within the northeast half of the map-area show little evidence of metamorphic recrystallization. In thin section shales and slates and the pelitic fraction of grits and pebbly conglomerates are seen to consist of an extremely fine mesh of clayey material. Toward the southwest boundary of the zone this material shows evidence under the microscope of recrystallization to chlorite and/or muscovite. Nevertheless, grain size remains in the order of 0.01 mm or less. Primary sedimentary textures are clearly distinguishable in the clastic rocks. In Windermere rocks clastic plagioclase retains its original composition which ranges from An_{25} to An_{40}. Along the eastern slope of the Purcell Mountains coarse, clastic muscovite may commonly be recognized in Windermere rocks.

In practice the zone of demarcation between the slate belt and the lower part of the greenschist facies is based largely on grain size and the clear recognition of recrystallization to a muscovite–chlorite–albite–quartz mineral assemblage. This occurs over a broad zone so that the demarcation between the slate–shale belt and the next higher belt is necessarily arbitrary.

Chlorite–Muscovite–Albite–Quartz Zone

Pelitic rocks characterized by this assemblage cover a broad zone straddling the Purcell Divide from the southeast to the northwest part of the map-area. In thin

section the shaly fraction of the rocks can be seen to be clearly recrystallized to chlorite and/or muscovite with albite and quartz to a grain size of 0.05 mm and larger. Reaction between matrix and clasts is evident and deformation of clasts is more evident even though primary textures are still identifiable in the coarser, clastic rocks. Cleavage and foliation are more intensely developed. In outcrop, pelitic and semipelitic rocks show a clear phyllitic sheen on foliation surfaces. Grain size gradually increases southwestward to a point at which biotite appears along a relatively well-defined line as porphyroblasts up to 2 mm or more. Common mineral assemblages found in this zone are listed in Table VII.

Biotite- and Garnet-bearing Zones

Biotite appears abruptly in pelitic rocks along a line trending northwest from upper Carney Creek to the mouth of Howser Creek (Pl. X). It occurs as porphyroblasts up to 2 mm or more in size. Similarly, garnet appears in pelitic and semipelitic rocks a little farther to the southwest. This zone forms an arrow-shaped pattern on the map (Fig. 11) that broadens southward and narrows to a point near the head of Duncan Lake. Assemblages encountered in these rocks are listed in Table VII.

Staurolite and Staurolite–Kyanite Zone

Although some specimens of the inner part of the garnet zone contain plagioclase of composition about An_{25} insufficient information was available to delineate the beginning of the almandine–amphibolite facies. A fairly well defined staurolite and/or staurolite–kyanite (Pl. X) zone has been marked on Figure 11 instead. Assemblages present are shown in Table VII.

It is not uncommon for rocks in the northern part of this zone to show the effects of post-porphyroblast deformation and partial retrograde metamorphism. Biotite, garnet, and staurolite porphyroblasts commonly contain straight lines of inclusions rotated up to 90 degrees to the strong foliation in the matrix. Biotite, e.g., near the mouth of Duncan River, has been completely chloritized. Both staurolite and kyanite, southeast of Mount Willet, show rims of pinitic alteration (Pl. X).

General Comments

1. There is a marked increase in grain size and the development of muscovite and chlorite downward in the stratigraphic section in the Purcell System. There is a large proportion of Moyie Intrusions in the Aldridge rocks and perhaps some of the metamorphic effect may be due to emplacement of sills. However, the obvious contact effect near a sill extends at most a few tens of feet. Biotite porphyroblasts developed as a contact metamorphic mineral near sills are commonly completely chloritized. Thus it may be deduced that the general regional low greenschist facies metamorphism postdates the emplacement of the Moyie sills. Further, in the vicinity of White Creek Batholith muscovite-bearing pelitic layers show evidence of refolding within the structural aureole of the batholith. Thus, it may also be concluded that the regional greenschist metamorphism predates the emplacement of the granitic intrusions (*see* discussion of contact metamorphism, below). Therefore the gradual increase in the effect of lower greenschist metamorphism detected in these rocks appears to be related to the increasing depth of the Purcell strata.

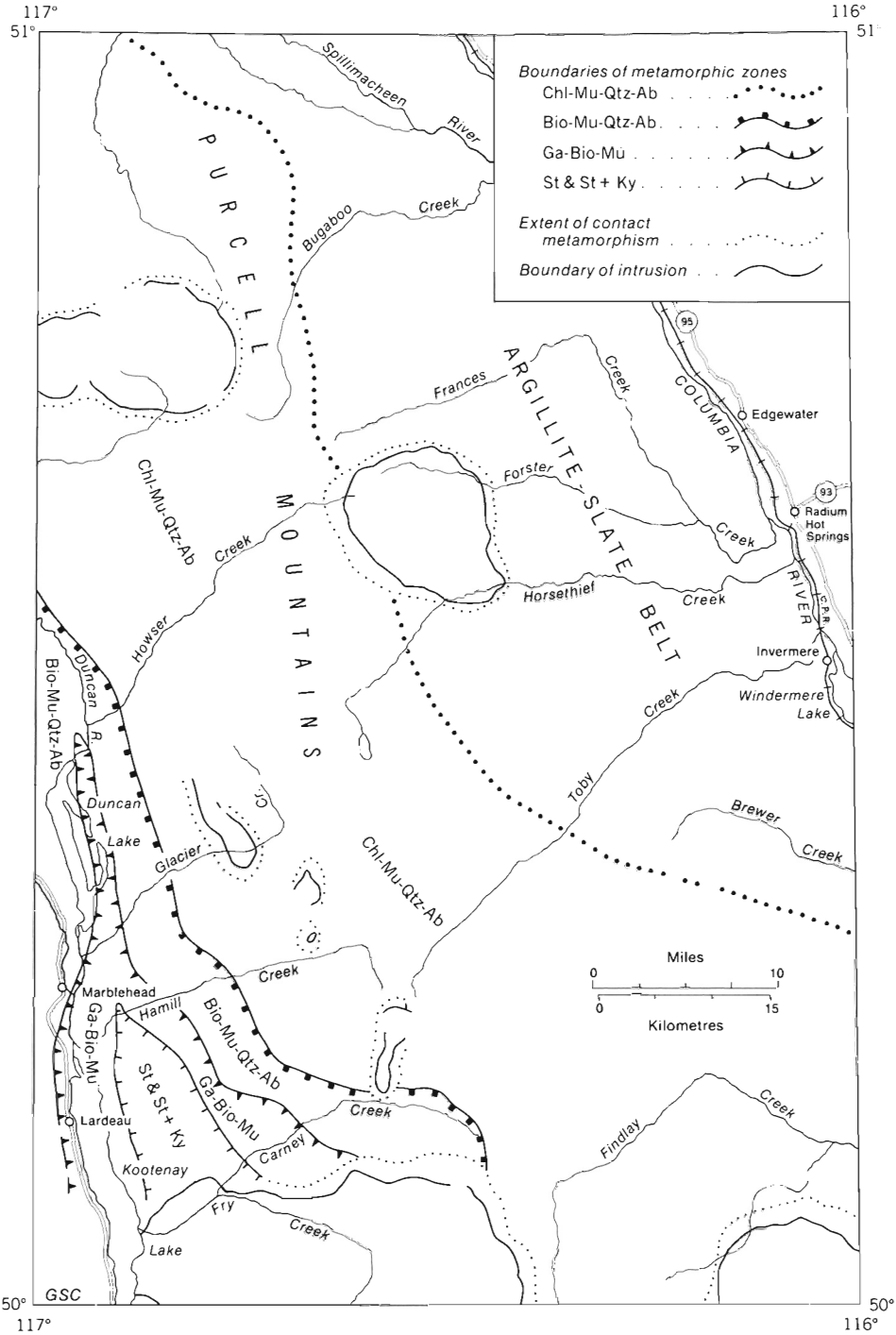

FIGURE 11. Regional and contact metamorphic zones in Lardeau (east-half) map-area (typical mineral assemblages in pelitic and semi-pelitic rocks in Table 7).

TABLE VII *Metamorphic mineral assemblages (Zones as in Fig. 11)*

Ab:	albite	Do:	dolomite	Pl:	plagioclase
An:	andalusite	Ep:	epidote	Q:	quartz
Bi:	biotite	Ga:	garnet	Se:	sericite
Cc:	calcite	Hb:	hornblende	Si:	sillimanite
Cd:	chloritoid	Ky:	kyanite	St:	staurolite
Ch:	chlorite	Mu:	muscovite	Tr:	tremolite
Co:	cordierite				

Lithology	Pelites and semipelites	Others
Regional Metamorphism		
Below Biotite Zone	Ch-Se-Q Se-Q Ch-Q Ch-Mu-Ab-Q Mu-Q-Ab Mu-Q	Ch-Cc-Q Cc-Q
Biotite Zone	Bi-Mu-Ab-Q Ch-Mu-Ab-Q Mu-Q Cd-Bi-Q-Ch	
Garnet Zone	Ga-Mu-Bi-Ab Mu-Bi-Q Ga-Ch-Mu-Ab-Q Ga-Bi-Pc-Mu (Q) Cd-Mu-Ga-Q	Mu-Bi-Ga-Ep Tr-Cc-Q Do-Q
Staurolite; and Staurolite-Kyanite Zone	St-Ga-Bi-Mu-Pc (Q) Mu-Bi-Ca-Q St-Ga-Ky-Bi	Hb-Pc-Q-Ep
Contact Metamorphism		
Contact zones of intrusions	Ga-St-An An-Si-Bi-Pc-Q St-Bi-Mu-Q-Pc Ga-Co-St-Mu An-Mu-Bi-Q An-Co-Mu-Bi (Q) Ga-Si-Mu-Bi-Q	

2. No recognizable evidence exists of a difference in grade of metamorphism across the Windermere–Purcell unconformity. Thus on the north side of Bugaboo Creek, slates in the Mount Nelson Formation below the unconformity are as fine grained and as little altered as Horsethief Creek Group slates above the unconformity. The matrix of grits and fine pebble-conglomerates in this locality appears to be more susceptible to recrystallization than the fine, dense slates of either the Horsethief Creek or the Mount Nelson. They contain recognizable muscovite and/or chlorite and the peripheral zones of clasts show some reaction with the matrix. They therefore show more extensive recrystallization than the Purcell rocks below the unconformity.

3. There is a general increase in metamorphic grade southwestward in the map-area. Metamorphic mineral zones trend generally north–northwest and transect lithological units. The highest grade zone (lower almandine–amphibolite facies) occurs in a narrow belt that disappears northward within the map-area. It is notable that this level of metamorphism diminishes in the extreme southwest corner of the map-area. It is also notable that the level of metamorphism begins to diminish below the top of the Lardeau Group. Thus it must be concluded that any metamorphism that affected the Lardeau rocks before deposition of the Milford Group was very low grade and in this zone has been overprinted by a much more intense post-Milford metamorphism.

Contact Metamorphism

Contact metamorphic aureoles have been developed around the peripheries of granitoid intrusions within this area. Commonly the recognizable effect of this metamorphism extends from about a thousand feet to several thousand feet from the contact. The zones are narrowest in the vicinity of steep-walled intrusions, e.g., the southeast contact of Bugaboo Batholith, and widest in those localities in which the contact slopes at a moderate angle outward from the pluton as on the northern contact of Fry Creek Batholith near Mount Pambrun (Pl. XV, and geological map). The contact aureole for each pluton has been approximately located at the outer limit of the development of biotite in the enclosing sediments.

Some of the principal assemblages in pelitic rocks in contact zones are listed in Table VII. They are characterized by andalusite and/or cordierite; staurolite is often present and sillimanite is found in a few localities. In those localities in which a granitic pluton has been emplaced into rocks characterized by low greenschist facies (muscovite–chlorite–albite–quartz), there can be no doubt that the contact metamorphism has been superimposed upon and postdates the regional metamorphism. However, along the western part of the northern contact of Fry Creek Batholith the precise dividing line between regional and contact metamorphism cannot be marked on the basis of the reconnaissance information available. There is, nevertheless, a clear difference between the regional and the contact metamorphism. The regional metamorphism is characterized by staurolite and staurolite–kyanite, the contact metamorphism by andalusite, cordierite, and staurolite. Further, porphyroblasts belonging to the regional assemblage commonly contain lines of inclusions rotated to a high angle to the enclosing foliation. Staurolite and kyanite show peripheral alteration to pinite. In the contact zone inclusions in biotite, staurolite, and andalusite are aligned

parallel with foliation in the enclosing schist. Clearly porphyroblasts in the different environments have grown under different conditions and the contact metamorphism is later than the regional almandine–amphibolite metamorphism.

Structure

The geological map summarizes, in brief, the structural patterns in this map-area. For purposes of discussion the area may be subdivided into three main regions based, in part, upon stratigraphic succession and, in part, upon structural style. From northeast to southwest these consist of the Brisco–Vermilion Ranges characterized by lower Paleozoic strata and upright folds; the Purcell anticlinorium, from the Rocky Mountain Trench westward to the Mount Cauldron syncline, characterized by Purcell and Windermere strata and upright to northeasterly overturned folds; and finally the southwest area from the Mount Cauldron syncline to the Selkirk Mountains along the southwest fringe of the map-area (the Kootenay Arc). This zone consists largely of lower Paleozoic pelites, semipelites, carbonate rocks, and quartzites in contrast to the lower Paleozoic of the Brisco Range which is dominated largely by pelites, limestones, and dolomites. This structural zone is characterized by rapidly increasing grade of metamorphism and increasingly complex folding.

These structural zones will be discussed successively from northeast to southwest followed by a brief consideration of some of the structural problems of the area.

Brisco and Vermilion Ranges

The fold structures of the Brisco Range are outlined by vertical to steeply inclined strata of the lower Paleozoic succession. Folds are upright and although modified by much faulting, are continuous structures throughout the Brisco Range in this map-area. Plunges vary from northwest to southeast, and axes of small-scale folds may plunge up to 30 degrees. Such plunges are only of local importance, and the net plunge of the structures is very little throughout the length of the Brisco Range within this map-area. Dips of the limbs of large isoclinal folds do not diverge far from the vertical, and consistent directions of overturning are not evident in this part of Brisco Range. Local overturns may be either southwest or northeast (*see* cross-sections CD and IJ, Map 1326A, *in pocket*).

Slaty cleavage is well developed only in the shaly portions of McKay strata and in Glenogle Shales in the axial zones of anticlines. In the more competent strata of the Beaverfoot Formation, most commonly preserved in synclines, local faulting is dominant. Most synclines show steep faults in or near their axial zones. In some places part or all of a limb of a fold is cut out by such faults, e.g., east of the Rocky Mountain Trench between Brisco and Spillimacheen. Faults trend northwesterly parallel with the major folds. A few north- or northeast-trending cross-faults occur throughout this section of the Brisco Range. They are steep to vertical and offset one or both limbs of a major fold structure.

Fold and fault structures of the Brisco Range trend slightly more northwesterly than the Rocky Mountain Trench and as a result fold after fold and fault after fault are truncated by this structure. For example, the Kindersley Creek anticline, in McKay strata north of Spillimacheen, forms the central part of the Brisco Range a few miles southeast at the east border of the map-area.

The faults of the Brisco Range are closely associated with the fold structures. They dip steeply, often parallel with the axial planes of steep isoclinal folds, and movement is often a few tens of feet to, at most, a few hundred feet. Only one large fault is found in the Brisco Range in this area; the northward extension of the Redwall Fault from the Stanford Range (Henderson, 1954, p. 36–38). This fault is marked by extensive red oxide-stained breccia and extends from Redstreak Mountain through Radium Hot Springs northwesterly into the Rocky Mountain Trench. It brings Jubilee strata against Beaverfoot strata and represents a vertical displacement of several thousand feet. Although Henderson suggested considerable strike slip movement along the Redwall Fault no evidence for or against this possibility could be deduced in this map-area. The significance of the Redwall Fault in the formation of the Rocky Mountain Trench cannot be determined from the available evidence. It may be observed, however, that the trench truncates faulted folds equally both north and south of the Redwall Fault; patterns are not different on either side of this large fault. The Purcell front has overridden the structures of the Brisco Range.

The Purcell Anticlinorium

The Purcell anticlinorium is the dominant structural feature of the map-area and extends from the Rocky Mountain Trench westward to about the Mount Cauldron syncline. From this point westward, in an area of rapidly increasing grade of metamorphism, structures differ markedly in style and belong to the Kootenay Arc (Fyles, 1962, 1964). The Purcell anticlinorium is essentially a fold belt dominated by broad, open folds in successions of relatively competent strata (Pl. I and cross-section QR, on Map 1326A, *in pocket*) and by more complex, tighter folds in less competent, thinner bedded successions (Pl. XI B). Although the average plunge of folds is a few degrees northward there are many local reversals and small folds plunge either north or south from locality to locality. Folds are commonly modified by local faulting. The gross structural pattern of this part of the map-area is portrayed by the map patterns and cross-sections (*see* Map 1326A).

Folds

The easternmost, major, structural feature within this zone consists of the Purcell boundary syncline. It parallels the Rocky Mountain Trench and is marked, respectively, by the lower Paleozoic rocks of Jubilee and Steamboat Mountains and by the Windermere rocks immediately north of Windermere Lake. This structure is followed westward by an anticlinal zone, then by the Mount Forster syncline. Structures in this eastern Purcell zone are characterized at all scales by synclines with steep-dipping to eastward-overturned western limbs (for example, *see* cross-sections CD, KL, and the eastern ends of MN and OP, Map 1326A, *in pocket*). It is worth noting that this characteristic structural form is found in all rock successions of the eastern Purcell Mountains from the Purcell rocks in lower Findlay and Dutch Creeks, as well as the Windermere and mid-Paleozoic rocks of the Mount Forster syncline, the lower Paleozoic strata of Jubilee Mountain, and the Horsethief Creek Group of the northeast slope of the Purcell Mountains immediately to the west. There is no change in fold style upward in the stratigraphic column through a succession of unconformities ranging from the Winder-

mere (at the base of Toby Formation) through the lower Cambrian, and through a number of disconformable successions in the lower Paleozoic, ranging to the Devonian.

In outcrop the typically overturned fold, particularly in pelitic or semipelitic strata, exhibits a good development of cleavage (Pls. XI, XII). Figure 12a shows the cleavage–bedding relations in a fold typical of this part of the Purcell anticlinorium. Tops can be determined locally by primary sedimentary features such as crossbedding, ripple-marks, graded bedding, and stratigraphic successions. These features substantiate the relations shown in Figure 12a between cleavage and bedding. Thus, in isolated outcrops overturned strata can be identified by nearly horizontal cleavage in steeply dipping beds. Departures from this systematic relationship are found only in the vicinity of Moyie sills, granitic intrusions, and large faults.

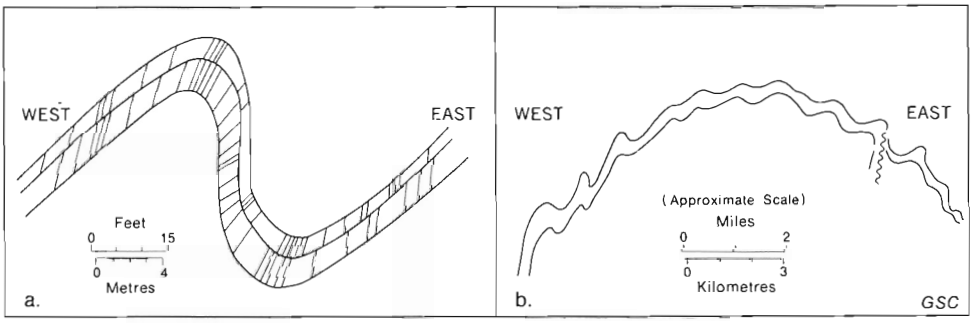

FIGURE 12. Structures in Purcell anticlinorium
(a) Cleavage–bedding relations in northeast overturned fold in Horsethief Creek Group slate.
(b) Anticlinal culmination showing step-like subsidiary folds, diagrammatic, but representative of Four Squatters anticline.

West of the Mount Forster syncline fold axial planes are generally upright, in contrast to those in this syncline and eastward in which fold axial planes dip west at moderate angles (*see* cross-sections on Map 1326A). Westward in the Purcell anticlinorium folds become increasingly vertical and isoclinal. Thus Blockhead Mountain syncline has limbs that may be slightly inclined from the vertical either to the east or west. In the Horsethief Creek Group, rocks of the northwest part of the map-area subsidiary folds rise to major culminations and descend to large synclinal depressions (*see* Map 1326A). Thus in local outcrops, depending upon location on the east or west side of a major anticlinal culmination, folds show alternately steeply dipping east limbs and gentle west limbs, or steep west limbs and gentle east limbs (Fig. 12b). Such subsidiary folds can be seen to have amplitudes of 500 to 1,000 feet on a mountain side. They can be disharmonious and vary rapidly in shape normal to the axis along the axial plane (Pl. XIII). Plate XIV also shows the sudden steepening and tighter folds of the west limb of a major anticlinal culmination on the mountain slope into Duncan River. This culmination arches over the Four Squatters in a series of open, upright folds. East of the Four Squatters, subsidiary fold shapes are the reverse of those on the west side; anticlines have steep, east limbs and gently west dipping west limbs as shown diagrammatically in Figure 12b.

Faults

Faults are common at all scales in this zone and are easily recognized in the gently dipping successions of the central Purcell arch. Most such faults are vertical to near vertical, north-trending, normal faults with west side down. Movement, often only a few feet, is seldom more than a few tens of feet. Without more detailed stratigraphic control the maximum movement cannot be measured accurately. Faults are usually recognized by local shearing and/or by brecciation in more competent strata.

Rocky Mountain Trench Fault

Three faults of quite different character and of great significance are recognized. The first, the Rocky Mountain Trench fault, is not seen but is implied by contrasting structural and stratigraphic relations on either side of the trench. It presumably dips westward and brings rocks as old as Horsethief Creek Group opposite rocks as young as Beaverfoot Formation. It is the latest major structure present and truncates structures along both the Purcell front and the western Brisco Range. The extent of this movement is unknown but considering only eastward displacement, and noting that at the north boundary the trench truncates the Kindersley Creek anticline, that on the east boundary of the map-area lies in the centre of the Brisco Range, then movement could have been at least 7 miles and was probably much more. Although strike slip movement up to a few miles may have been possible, movement of several tens of miles seems unlikely (Leech, 1966, p. 321). Leech (op. cit.) points out that extensive strike slip movement along the trench could not have taken place at its southern or northern limits. Perhaps, as he suggests, the extensive linear continuity of this feature results not from strike slip movement in Mesozoic or later deformation but rather from rejuvenation during this orogeny of an older basement linear.

It has been pointed out above that similar paleogeographic conditions existed on either side of the Rocky Mountain Trench during early Paleozoic and probably Windermere time (Windermere High, Fig. 6, *in pocket*). No extensive strike slip movement along the Rocky Mountain Trench has separated these two localities, in which thickness variations and facies changes are common to all the lower Paleozoic strata across the present locus of the Rocky Mountain Trench.

Mount Forster–Steamboat Fault

Another important fault in the Purcell anticlinorium in this map-area is the Mount Forster–Steamboat fault. Upward movement from the west is indicated by stratigraphic relations along this steeply dipping fault. Movement is in the order of several thousand feet, for in one locality the upper part of the Mount Nelson Formation is brought up against the Upper Devonian Starbird Formation. At its southern end it is sharply curved and brings the entire northern keel of the Mount Forster syncline upward with respect to the southern part of the fold. The fault is cut off by the Cretaceous Horsethief Batholith.

This fault postdates the Mount Forster syncline as well as the syncline on Steamboat Mountain. The latter is broken and deformed at the northern end of Steamboat Mountain. The fault predates the emplacement of the Horsethief Batholith. Its southerly continuation from the batholith has not been noted. It thus appears, at least on the basis of information available from this reconnaissance, that this fault differs from

Hall Lake and others of this type farther south. Although direction of movement is similar, the Mount Forster–Steamboat fault is concave northwestward, not southeastward, as in Hall Lake and other similar, possibly much older faults, to the south.

Hall Lake Fault

At the southeast corner of the map-area an important fault projects into the area from Canal Flats map-area (Leech, 1954) and is cut off by White Creek Batholith. On this fault there is extensive movement of several thousand feet, in which the lower part of the upper part of the upper Aldridge is brought upward on the north against Creston Formation on the south. This may be a continuation of the Hall Lake fault found south of White Creek Batholith (Reesor, 1958, p. 28).

The Southwest Region

This locality, within the Lardeau map-area, constitutes the central part of the Kootenay Arc (Fyles, 1962, 1964) and consists of complex structures in lower Paleozoic rocks in upper greenschist and amphibolite facies of metamorphism. The structure in this region has been studied and reported on by Fyles (1964, p. 41–64), and little can be added in this study to the excellent, detailed portrayal of the structure given by him.

Briefly, Fyles recognized two main phases of folding with scattered, sporadic development of later folds considered to be relatively less important than the two earlier phases. An idealized composite cross-section by Fyles portrays the pattern of folding across the area in the zone between Duncan and Kootenay Lakes (Fig. 13). Phase I folds are isoclinal and are refolded coaxially by Phase II folds. Fyles considered that, "Direct evidence of a time lapse between the formation of Phase I and Phase II structures has not been found, and the parallelism of Phase I and Phase II fold axes is taken as evidence that the two are closely related parts of one protracted deformation" (op. cit., p. 61). The pattern of major Phase I folds before Phase II deformation is unknown but, "... the distribution of the formations over an area larger than Duncan Lake area, in which progressively younger rocks lie to the west and older ones to the east, may be interpreted to mean that Phase I folds rose step-like toward the Purcell anticlinorium on the east" (op. cit., p. 63–64). Although the regular step-like rise to the east of Kootenay–Duncan Lake is interrupted by the major

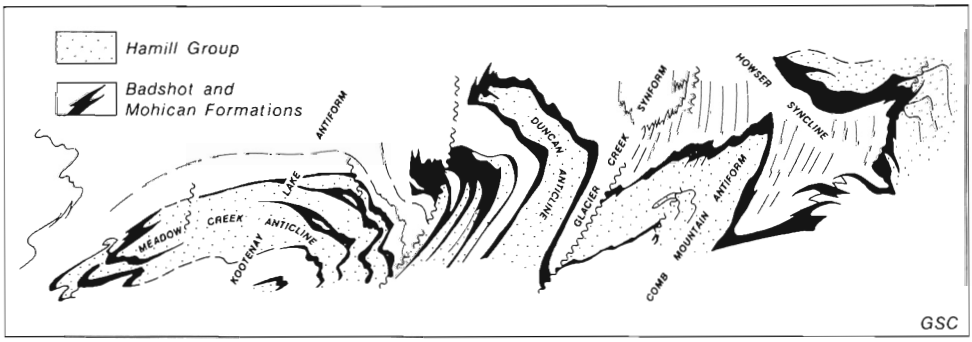

FIGURE 13. Diagrammatic cross-section in a zone between Duncan and Kootenay Lakes (after J. T. Fyles, 1964, p. 62, part of Fig. 16).

Cauldron Mountain and Blockhead Mountain synclines, there appears to be a regular step-like rise to the first major anticlinal culmination in Horsethief Creek strata, extending from the Four Squatters southerly to Fry Creek Batholith. The stratigraphic rise, at least on a smaller scale, can be seen on the western slope of the Four Squatters and the corresponding step-like descent can be seen on the east side. Clearly the intensity of folding increases progressively westward from the Cauldron Mountain syncline, and the style of folding characteristic of the Duncan area extends no farther east than the belt of Hamill quartzite extending north and south of Mount Simpson. Within the zone of the Kootenay Arc the metamorphic gradient increases rapidly, the folds become progressively more isoclinal and the refolding of Phase I folds becomes a characteristic pattern.

According to Fyles the Phase II folds "... may be regarded as dragfolds suggesting movement of the east up in relation to the west" (op. cit., p. 64). It perhaps could be suggested that Phase I folds represent the initial stage of folding in the deformation of the Purcell Mountains, the isoclinal style and intensity of folding reflecting both position on the flank of the fold belt, the thin-bedded pelitic, semipelitic and calcareous stratigraphic succession, and the higher grade of metamorphism. Phase II folds then represent further rise of the mountain belt to the east. Metamorphism within the amphibolite zone continued during Phase II folding, for garnet, staurolite, and kyanite here show no post-crystalline deformation although inclusions in garnet show rotation during growth. Phase II folding apparently outlasted recrystallization north of the amphibolite zone and there metamorphic minerals show cataclasis.

Faulting is related to, or postdates Phase II folds (Fyles, 1964, p. 60–61). They strike generally parallel with the fold structures and dips are steep to vertical.

Contact Zones of Plutonic Intrusions

The contacts of granitic intrusions are commonly very sharp with a superposition of a contact metamorphic aureole on the slates and greenschists of the enclosing rocks. In many localities the structural aureole of the Cretaceous plutons is equally clearly superposed on older regional structures. Thus, south of the eastern part of Bugaboo Batholith, slates of the Horsethief Creek Group, beginning about 3 miles south of the contact, show a faint development of a crenulation foliation parallel with the contact; at 2 miles this foliation becomes much more marked. It increases in intensity of development as the contact is approached until it is the major structural feature in the rocks. Similarly, northeast of Bugaboo Batholith small folds that trend east–west parallel with the contact are developed; these cross earlier northwest-trending structural features.

On a large scale Fry Creek Batholith has modified the regional structural trends all along its northern boundary and strata that a short distance north trend northerly, here trend east–west. Strata are tilted into conformity with the trend of the batholithic contact. On Mount Pambrun the plutonic rocks have risen upward along a fairly continuous stratigraphic horizon, and in doing so have dragged the overlying strata into great reverse drags that show relative movement of the underlying strata southward and upward (Pl. XV).

White Creek Batholith, in the southeastern corner of the map-area, similarly modifies regional structures around its periphery (*see also* Reesor, 1958, p. 28). In this area it truncates the probable continuation of Hall Lake fault.

In all the peripheral zones of the Cretaceous plutons there can be no doubt that their time of intrusion postdates both the regional structure and metamorphism. In the case of the older plutons, here labelled Jurassic, their structural relationships are not as well defined. Their long axes lie northerly (Mount Toby intrusion) and northwesterly (Glacier Creek stock) in conformity with the local trend of the enclosing structures. Metamorphism is intense for a short distance around the circumference of the plutons.

The relationship between emplacement and deformation is particularly interesting in the Mount Toby intrusion. It is tadpole-shaped with a bulbous northern end. The northern part is structurally massive, but the southern tail exhibits a strong post-crystalline deformation with a good development of lineation approximately parallel with fold axes in the surrounding strata. Thus the orientation of the mass as a whole appears to be governed by the fold trend in the surrounding rocks and was emplaced synchronous with the major folding. A part of the narrow, southern zone apparently recrystallized synchronously with the deformation of the surrounding rocks, whether as a second phase of folding or as a continuation of a single, major phase of deformation cannot be deduced from the information available. Nevertheless, the implication is clear that in contrast to the Cretaceous plutons the emplacement and crystallization of these plutons is approximately synchronous with deformation in the surrounding rocks. Does the time of consolidation of Mount Toby stock (about 162 m.y.) thus date approximately the culminating, major phase of deformation of the enclosing rocks? The evidence, although perhaps far from unequivocal, suggests the culminating deformation in this part of the fold belt was about Middle Jurassic.

Structural Problems

The Rocky Mountain Trench

Although only a short segment of the Rocky Mountain Trench is found through the northeast corner of the map-area, a few observations are warranted. The trench closely follows the trend of an eastward, overturned syncline in Windermere strata north of Windermere Lake, then along the east side of the synclines on both Steamboat and Jubilee Mountains outlined by lower Paleozoic strata. In contrast, the trench rapidly truncates a series of folds and faults along the west border of Brisco Range. Thus the typical, eastward, overturned fold of the eastern Purcell Mountains appears to override, along a reverse fault, both the folds and the related faults in the western Brisco Range on the east side of the trench.

The Mount Forster–Steamboat fault is one of major reverse displacement and clearly deforms both the eastward, overturned Mount Forster fold and the syncline on Steamboat Mountain (*see also* McCammon, 1965). It is cut off by the inferred fault along the Rocky Mountain Trench since it does not continue the short distance across the trench into Brisco Range. Therefore, it must be concluded that the trench structure postdates fold and fault structures of the eastern Purcell Mountains, as well as the Brisco Range. The extent of this movement has been suggested above to be not less than 7 miles.

Leech (1966, p. 307–329) has summarized the salient features of the Rocky Mountain Trench throughout its length. He presents considerable stratigraphic data (op. cit., p. 321) to show that no strike slip movement occurred south of this map-

area following the emplacement of allochthonous terrain across the line of the trench in about Paleocene time. In this map-area and its immediate environs in the Stanford Range to the east, similar conditions of deposition of lower Paleozoic strata (and Windermere?) up to and including the Devonian, along what might be designated the Windermere High, indicate that extensive strike slip movement has not occurred in this region. There may have been extensive shortening of the east–west-trending Windermere High, but no extensive (in the order of tens of miles) lateral displacement occurred coincident with this shortening.

Deformation Prior to the Culminating Mesozoic Orogeny

The basal Windermere unit, the Toby Formation, lies with a regional unconformity upon the underlying Purcell. The stratigraphic variation and distribution of this formation indicate clearly deposition upon a terrain of varying relief, one that had undergone a considerable period of deformation. The unequivocal recognition of pre-Windermere structures is not, however, as easy as might be assumed from the stratigraphic relationships. In work at this scale recognition of possible fold structures related to this deformation has not been possible, partly because of the lack of detailed coverage, but partly also because of the ubiquity and intensity of Mesozoic structures that affect all rocks from the Purcell to the Upper Devonian.

Pre-Windermere faults are implied, though not definitely proven in a number of localities. Between Farnham Creek and Lake of the Hanging Glacier a thick layer of Toby conglomerate lies on Mount Nelson and a thin layer on Dutch Creek Formation. Possibly the Mount Nelson Formation was downfaulted to the east before deposition of the Toby Formation. This movement is opposite to that of the later (Mesozoic) faults in this part of the area in which the west side is commonly down-dropped. Similarly north of Bugaboo Creek, a thick succession of Toby Formation, in places a jumbled breccia (*see* Pl. IV B), is followed eastward by localities in which Toby Formation is hardly recognizable, forming only a few pebbles in a slaty matrix. Again local faulting may have controlled the stratigraphic variation in Toby conglomerate.

South of the junction of Toby and Jumbo Creeks, Horsethief Creek Group lies directly on Dutch Creek Formation, yet 3 miles to the north Toby conglomerate lies on Mount Nelson Formation. Other possible stratigraphic indications of pre-Toby faulting are to be found, yet no unequivocal case of a fault truncated by the Windermere unconformity was found during this study. The problem of the certain identification of not only pre-Windermere faults but folds and other structures as well remains a fruitful field for future investigations, particularly in the localities mentioned above.

Although the Windermere High was in existence, there appears to have been no deformation of Windermere rocks before the deposition of the Lower Cambrian. Although recent evidence (Read, 1966; Wheeler, 1968) suggests the likelihood of pre-Milford Group deformation in the lower Paleozoic rocks of the Lardeau Group, no evidence of this has been recognized in this map-area.

Summary

Within Lardeau east-half map-area, the Precambrian is represented by extensive sedimentation over a long period, marked by an orogenic interruption, the East Kootenay Orogeny. The Paleozoic was similarly a period of extensive sedimentation, with some associated volcanism in the west, followed by restricted orogenic activity before the

deposition of the Milford Group. The Mesozoic, however, in Lardeau map-area is marked by the culminating orogeny with associated emplacement of granitoid plutons. Early Mesozoic sedimentary and volcanic strata, although found immediately west and southwest of this area, are limited to the southwest corner of Lardeau map-area.

Stratigraphic bracketing of the time of the culminating Mesozoic orogeny is not available in this map-area. However, Little (1960, p. 109), on the basis of stratigraphic information in Nelson west-half map-area a few miles to the southwest, considered that the deformation occurred in late Jurassic time.

Within Lardeau map-area there are two phases of folding in the southwest region (Fyles, 1964). The possibility exists that the second phase has affected the northwest corner of Fry Creek Batholith. If this is correct, the emplacement of Fry Creek pluton is bracketed by these two phases of deformation and the age of 97 m.y. (Table VI) gives a maximum age for the second phase of deformation. The pluton is unaffected east of the Carney Creek–Fry Creek junction; no cataclasis is apparent in granitic rocks near Mount Pambrun. If Phase II folds are present east of Cauldron Mountain syncline they are present only as minor features in the structural hierarchy.

Two granitic sequences are present in Lardeau east-half, the leucocratic post-kinematic intrusions, and the melanocratic syn- to late-kinematic intrusions. Toby Creek stock, belonging to the latter group, possibly gives some evidence of the age of culmination of the principal folding of this area. Thus the age of 162 m.y. for hornblende in this intrusion may indicate a Middle Jurassic age for the culminating orogenic activity here (Phase I folding). Although this is entirely possible, the isotopic dating of these events is far from exhaustive and combined study of structure, metamorphism, and isotopic age dating in this southwest region of Lardeau map-area remains a fruitful field for future geological investigations.

Chapter VI

ECONOMIC GEOLOGY

Although mineral properties in Lardeau map-area are small, and production is short lived, they are, nonetheless, numerous and many have been located in this area since the turn of the century. Most properties have been investigated for silver–lead–zinc, although a few copper prospects are found, and a few quarries are operated, mainly for barite.

Silver–lead–zinc-bearing properties are concentrated in two areas. The first consists of vein deposits in competent Mount Nelson strata and many prospects are to be found in the region of exposure of Mount Nelson Formation. Deposits of most economic interest are those rich in silver, usually occurring as argentiferous tetrahedrite in veins, or those deposits that show replacement, usually local, of the dolomite. The Mineral King Mine, although now worked out, was an excellent example of the latter and Fyles' study (1960, p. 86) shows well the character and irregularity of the replacement. Exploration and location of such replacements are difficult and properties characteristically show a long history of intermittent exploration by a succession of owners. Similar silver–lead–zinc-bearing veins, with local replacement are to be found in the Horsethief Creek Group rocks, as for example the Ruth Vermont and similar properties southeast (and northwest) of upper Vermont Creek.

The second principal locale of mineral concentration is the southwest part of the map-area where mineralization is concentrated in, or near Lower Cambrian Badshot marble, and in particular along the Duncan anticline (*see* below).

Nonmetallic minerals are found mainly along the Rocky Mountain Trench; most common are barite, mined either for itself or as a byproduct of metal mining, magnesite, and silica in a few localities west of Brisco.

The main properties of Lardeau map-area, east-half, are listed below, first for the northeastern zone, east of the Purcell Divide and second the southwestern zone, west of the divide. In each zone properties are listed alphabetically and are located on Map 1326A (*in pocket*). The number in parentheses before a property indicates its location on the figure. Nonmetallic deposits are marked separately.

Northeastern Zone

(2) Atlas (Ag, Pb, Zn)

Reference. Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1966, p. 236–237.

This property is optioned by Purcell Range Mines Limited, 801, 736 Granville St., Vancouver. Some diamond drilling and trenching has been done on the property. Galena and sphalerite occur in fractures mainly in light coloured, rusty spotted, micaceous quartzite of the Horsethief Creek Group.

(14) Delphine (Ag, Pb)

Reference. Minister of Mines, B.C., Ann. Repts. 1915, p. k94–k95; 1964, p. 135. Walker, 1926, p. 48.

This is an old property, re-examined in the mid-1960s by Western Beaver Lodge Mines Ltd., Suite 303, 1075 Melville St., Vancouver, B.C. Several old properties, the Tilbury and B.C. Group, occur above the Delphine to an elevation of nearly 9,000 feet (op. cit., 1915). Silver–lead-bearing minerals occur in narrow veins in Mount Nelson dolomitic limestone.

(3) Fe, Hil, etc. (Au, Ag, Pb, Zn)

Reference. Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1966, p. 236; 1967, p. 266.

Far East Minerals Ltd., 543 Granville St., Vancouver 2, hold 1,527 claims between the headwaters of Vowell and McMurdo Creeks. Values are mainly in veins in Horsethief Creek strata and form part of extensive scattered mineralization along a northwest-trending belt (*see* Atlas above, and Ruth Vermont, below).

(15) Hot Punch (Ag, Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1926, p. 241; 1949*, p. 199; also mentioned in Ann. Repts. between 1898 and 1918.

The property consists of six Crown granted (D. F. Jones and R. J. Edgar, 13302–106 Ave., Edmonton) and four recorded claims. Up to 1926 about 80 tons of ore had been shipped. The property was worked again in 1949. The upper adit is coved and the lower adit is about 300 feet long. Mineralization, mainly galena, is in quartz–siderite stringers and shear fillings in phyllite and limestone of the Mount Nelson Formation. Ore contains massive pyrite and some massive galena with stringers of sphalerite and scattered chalcopyrite and tetrahedrite.

(10) Jersey (Cu)

Reference. Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1965, p. 203.

Property optioned by COMINCO in 1965 for examination. It is in brecciated Jubilee dolomite near the contact with McKay Group strata just at the Mount Forster–Steamboat fault.

(8) Lead Mountain (Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1925, p. 221; 1954, p. 149; 1955, p. 73; 1956, p. 112; 1966, p. 237. Evans, 1933, p. 172.

The property consists of 12 claims held by Giant Mascot Mines Limited, 1131 Melville St., Vancouver. It consists of lead–zinc mineralization in Jubilee dolomite.

(6) Lead Queen (Ag, Pb)
(also (7) Steele Group)

References. Minister of Mines, B.C., Ann. Repts. 1915, p. 82, 98; 1919, p. 113; 1925, p. 225; 1926*, p. 240; 1927, p. 265; 1928, p. 276, 521; 1929, p. 284, 292. Walker, 1925, p. 227A.
Other references: Minister of Mines, B.C., Repts. for 1901–09; 1916–19.

This property was held as a Crown grant by Silver Queen Mines Limited, c/o A.L.P. Hunter, 702 Birks Bldg., Vancouver, B.C. About 350 tons of silver–lead ore were shipped before 1929. Mineralization consists of tetrahedrite, galena, and minor sphalerite in veins in Mount Nelson dolomite.

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* Denotes the main reference for a property.

Mag, Nimrod, Puzzler (Pb, Zn)

References. Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1967, p. 266; 1968, p. 266.

Property consists of 35 claims on Starbird Ridge on the north side of Horsethief Creek, 13 miles west of Wilmer, owned by G. Larrabee and operated by Cominco Ltd., 1199 West Pender St., Vancouver. Mineralization consists of galena and sphalerite in gash veins in carbonate rocks.

(20) Melody (Ag, Pb, Zn)
(Silver Spray)

References. Minister of Mines, B.C., Ann. Repts. 1921, p. 125, 165; 1925, p. 224; 1926–30; 1968, p. 267. Walker, 1926, p. 49.

The property consists of 23 claims in the vicinity of the old Silver Spray property. Mineralization occurs as fracture filling in an anticlinal zone in limestone. There may be local replacement and minerals consist of galena, and a little tetrahedrite and sphalerite. Copper carbonate is also mentioned.

(18) Mineral King (Ag, Pb, Zn, Cu, Cd and barite)
((17) Jumbo and (16) Lisa A)

References. Minister of Mines, B.C., Ann. Repts. 1959, p. 74–89; 1962, p. 88–89; 1967, p. 267–269. Other references: Minister of Mines, B.C., Ann. Repts. 1898–1905, 1915, 1920–30, 1950–58, and 1960–66. Walker, 1926, p. 49.

At the time of cessation of mining operations, this property was owned by Aetna Investment Corporation Ltd., 170 Donway West, Don Mills, Ont.

Mining was terminated in late 1967 after 14 years of operations during which 1,439,884 pounds of copper, 81,672,177 pounds of lead, 190,827,473 pounds of zinc, and 660,064 pounds of cadmium were produced (op. cit., 1967, p. 269).

While in operation, the mine was extensively studied and reported by Fyles (op. cit., 1959, p. 74–89; 1962, p. 88–89; 1967, p. 267–269). It is an excellent example of extensive and irregular replacement in Mount Nelson dolomite.

Two small properties showing similar characteristics of occurrence and mineralization are located north of Jumbo Creek, north of the mine. The Jumbo is owned by the same company (Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1967, p. 267) and the other is held by Colby Mines Ltd., 704, 535 Thurlow St., Vancouver 5 (op. cit., p. 267).

(12) Paradise (Ag, Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1927, p. 264, 407; 1949, p. 196–197. Walker, 1926, p. 46. Other references: Minister of Mines, B.C., Ann. Repts. 1899–1909, 1915–29, 1943–44, 1946–55, 1960, 1964, p. 84.

This property was owned by Sheep Creek Mines Ltd. at the last record of operation in 1964. The mine has been operated sporadically since 1901 and during the period of operation of the Mineral King, ore was trucked from the Paradise to the concentrator at the Mineral King.

The deposit consists of extensive replacement in Mount Nelson dolomite beneath a narrow slate bed. The ore contains pyrite, galena, and sphalerite, and the upper levels, long since worked out, consisted almost entirely of lead carbonate.

(11) Ptarmigan (Ag)

References. Minister of Mines, B.C., Ann. Repts. 1899, p. 667; 1900, p. 106; 1901, p. 1014; 1902, p. 136; 1903, p. 97, 104, 214; 1905, p. 143, 146; 1906, p. 135, 248; 1908, p. 249; 1909, p. 100; 1915, p. 97; 1919, p. 113, 146; 1920, p. 113, 139; 1955, p. 71; 1956, p. 111; 1957, p. 65; 1958, p. 53; 1959, p. 90; 1960, p. 85; 1963, p. 85; 1964, p. 135.

This property is owned by the Selkirk Ptarmigan Mines Limited, H. K. F. Seel, Edgewater, B.C. It consists of about 3,000 feet of old workings completed by 1903. Since that time the property has been operated sporadically for silver occurring in argentiferous tetrahedrite. In the late 1950's ore was shipped by truck to the Trail smelter. Silver assays of the shipments ranged from 50 to 400 ounces per ton.

Mineralization occurs in fractures and shears in Mount Nelson dolomite and argillite. Tetrahedrite–pyrite ore occurs irregularly in veins within the shears, trending southerly and dipping steeply east.

(19) Red Ledge (Ag, Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1956, p. 110; 1959, p. 899.

A small project explored by Noel Routson and associates, Trentwood, Washington. It consists of showings of galena, sphalerite, and tetrahedrite in slate, argillite, and dolomite.

(4) Rocky Point Creek–Warren Creek (Cu)

References. Minister of Mines, B.C., Ann. Repts. 1920, p. 109; 1923, p. 198; 1924; 1960, p. 85; 1961, p. 83; 1967, p. 266; 1968, p. 265. Walker, 1925, p. 227A (Warren Creek Copper).

Properties consist of *HL, Bob, Liz* at elevation 6,000–7,000 feet at head of Warren Creek, operated by Carolin Mines Ltd., P.O. Box 1269, Merritt (op. cit., 1968).

St. Andrew Mining Co.—a series of 101 claims between headwaters of Warren Creek and Rocky Point Creek (op. cit., 1961).

Young—Pharaoh Mines Ltd., 1120, 505 Burrard St., Vancouver.

Old claims in the area consist of Copper King, Copper Queen, Gray Eagle, Marjory. Condor, and Amelia.

Mineralization is apparently "copper sulphides disseminated in quartz." (op. cit., 1924).

(1) Ruth Vermont (Ag, Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1929, p. 291; 1930, p. 234–236; 1936, p. E37–E41; 1956, p. 112; 1965, p. 203; 1966*, p. 230–235; 1967, p. 265.

The property is held by Copperline Mines Ltd., 407, 475 Howe Street, Vancouver. It is an old property and dates back to 1893 but has been examined and explored at intervals since then. The current exploration work began in 1965, and the property is now being prepared for operation (1969).

Sulphides are contained in veins in Horsethief Creek limestone and slate. The best sulphide zones occur just below the limestone or adjacent to fractures within the limestone. Minerals found are: galena, sphalerite, pyrite and arsenopyrite with small amounts of chalcopyrite, boulangerite, argentiferous tetrahedrite, scheelite, and carbonates (op. cit., 1966). The mineralization occurs near the crest of a large northwest-trending anticline.

* Denotes the main reference for a property.

(9) Silver Giant (Pb, Zn)

References. Minister of Mines, B.C., Ann. Repts. 1923, p. 195–196; 1926, p. 240; 1927, p. 261–263; 1949, p. 200–204; 1953, p. 154; 1954, p. 148; 1955, p. 72; 1956, p. 111; 1957, p. 65. Evans, 1933, p. 173A–175A.

When operations at this mine closed in 1957 the property was held by Giant Mascot Mines Limited. The first mineral discovery was in 1883 and operations and exploration have been sporadic ever since. The property was purchased by Baroid of Canada in 1960 for the mining of barite and its recovery from the tailings of the mining operation.

Ore occurred in Jubilee Formation near the contact with overlying McKay Group slates. Mineralization consisted essentially of disseminated galena in a barite gangue. Sphalerite and pyrite, and small amounts of chalcopyrite and bornite, as well as rare tetrahedrite and tennantite, are also present. The structure of the deposit is not well known, but appears to have been a west-plunging, overturned anticlinal nose. In the deeper levels, dolomites that dip 55 degrees west flatten rapidly to the west and southwest.

(13) Tatler, Great Northern, Copper King (Au, Ag, Pb, Zn, Cu)

References. Minister of Mines, B.C., Ann. Repts. 1901, p. 1014; 1902, p. 137; 1903, p. 245; 1920, p. 350; 1923, p. 199; 1924, p. 181; 1925, p. 223; 1968, p. 266. Walker, 1926, p. 50–51 (Phoenix Group).

The property consists of a mineral lease and 75 located claims owned by Jumbo Mines Ltd., 617, 402 West Pender St., Vancouver 3.

A number of older claims are located in the general locality at the head of Farnham Creek. Mineralization appears to be in Mount Nelson dolomite, northwestward along the same units in which the Mineral King is located (Walker, 1926, p. 51). Tetrahedrite and secondary copper minerals are mentioned by Walker.

Yornoc (Ag, Pb, Zn, barite)

References. Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1967, p. 266; 1968, p. 266.

Property consists of 31 claims owned by J. H. Conroy, Invermere, located at the head of Ben Abel Creek, at 7,500 feet elevation "... Galena, sphalerite, and chalcopyrite in a gangue of quartz and barite are found in fractures and replacements in dolomitic limestone" (op. cit., 1967).

Southwestern Zone

Although there are no active mines in this locality at the present, mineral exploration has been active in this district from the end of the last century to the present (*see* Fyles, 1964, p. 12–14). Extensive, relatively low grade mineralization extends over a considerable length in the Badshot–Mohican Formations in the Duncan anticline, from the peninsula in Duncan Lake almost to Fry Creek Batholith. The occurrence, localization, and origin of these deposits have been discussed recently by Fyles (1964, p. 65–70). This excellent discussion is readily available. It is interesting to note, in addition, that the principal mineralization in this locality coincides approximately with the regional metamorphic high, in the upper greenschist facies and lower amphibolite facies as shown here on Figure 11. In addition to being locally controlled along major

structural features (Fyles, 1964, p. 69–70) their concentration may also have been dependent upon the high level of metamorphism.

Properties are listed in alphabetical order below, and where extensively discussed by Fyles a reference only is given. All properties are located on Map 1326A.

(6) Argenta (Ag, Pb, Cu)

Reference: Fyles, 1964, p. 70–71.

(2) Duncan (Pb, Zn)

References: Fyles, 1964, p. 71–75. Muraro, 1962.

Fog (Pb, Zn)

Reference: Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1967, p. 258.

Property held by K.R.C., Inc., 1300 Elveden House, Calgary, Alberta. The claims include the Mag property (Fyles, 1964, p. 76–77) and are north of the Argenta claim.

(10) Hi–Lo (Ag, Pb, Zn)

Reference: Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1968, p. 260.

The property consists of 36 mineral claims held by Copper Horn Mining Ltd., P.O. Box 548, Penticton. It consists of minor sphalerite and galena in Badshot–Mohican Formation, north of Schroeder Creek.

(5) Lavina (Ag, Pb)

Reference: Fyles, 1964, p. 75–76.

(4) Mag (Pb, Zn)

Reference: Fyles, 1964, p. 76–77.

(9) Moonshine (Ag, Pb, Zn)

Reference: Fyles, 1964, p. 77.

(1) Omo (Pb, Zn)

References: Minister of Mines, B.C., Ann. Repts. 1918, p. 162; 1927, p. c283; 1929, p. 325; 1930, p. 257. Gunning, 1929, p. 51 (old International property).

A number of old prospects at about elevation 5,200 feet above the Duncan River. Mineralization consists of quartz veins with galena with some pyrite and minor sphalerite in Horsethief Creek Group rocks just below a pebble-conglomerate.

Pegleg (Molybdenite)

Reference: Walker, Geol. Surv. Can., Sum. Rept. 1928, p. 135A.

Property occurs on the south fork of Fry Creek (Gillis Ck?) 3 miles above the junction with Fry Creek. Mineralization occurs in an inclusion in granitic rocks 1,000 feet west above the creek. Minerals reported are molybdenite, garnet, fluorite, scapolite, and pyroxene.

(8) Sal (Pb, Zn)

Reference: Fyles, 1964, p. 78.

(7) St. Patrick (Ag, Pb, Zn)

Reference: Fyles, 1964, p. 79–80.

(3) Surprise (Ag, Cu)

Reference: Fyles, 1964, p. 80–83.

Vin (Pb, Zn)

Reference: Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1965, p. 197.

About 10 claims held by Cominco Ltd. on the north slope of Mount Lavina. They occur on the Duncan anticline and are presumed to carry disseminated galena and sphalerite.

(5) Placer Deposits (uranium–columbium)

Reference: Minister of Mines, B.C., 1955, p. 86; 1956, p. 142–143; 1968, p. 293.

This property was held by St. Eugene Mining Corp. Ltd., 2810, 25 King St. West, Toronto, and was explored in the mid-1950's.

Placer concentrations occur in the outwash gravels from glaciers in Bugaboo and Horsethief Batholiths. Leases are held on upper Bugaboo Creek, Vowell Creek, and Forster Creek. Test samples were concentrated on upper Bugaboo Creek in 1956, and although they were shipped no mining operation followed.

Columbium- and uranium-bearing minerals, uraninite, euxenite–polycrase, and pyrochlore–microlite are concentrated in the gravels. Similar placer concentrations occur in the upper east branch of East Creek. (*See also* discussion of accessory minerals of Bugaboo and Horsethief Batholiths, p. 78.)

Similar placer concentrations have been explored recently in lower Bugaboo Creek by Dillingham Corp. of Canada Ltd., 1500 West Georgia St., Vancouver (op. cit., 1968).

Nonmetals

In addition to the production of barite as a byproduct from metal mining (Mineral King) or from reworking of tailings (Silver Giant) there are a number of deposits worked for barite alone. Most of these are in, or near, the Rocky Mountain Trench region.

(4) Larrabee (barite)

References: Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1958, p. 86; 1960, p. 135; 1962, p. 147; 1963, p. 138. Walker, 1926, p. 51 (Bunyan property).

Property operated by Allan Mining and Exploration Co., 927 Third Avenue, NW, Calgary, Alberta. Small quarry exposes discontinuous pods of barite in Mount Nelson argillite. There is some secondary copper staining (malachite, azurite).

(1) Baroid of Canada (barite)

References: Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1960, p. 135; 1961, p. 141; 1962, p. 147; 1963, p. 138; 1964, p. 181; 1965, p. 259; 1966, p. 261; 1968, p. 296.

The Silver Giant property was purchased in 1960 by Baroid of Canada, Ltd., 44 King St. West, Toronto, Ontario. Most of the work has been directed toward recovery of barite from the tailings dump of the former operation. Between the years 1960 and 1968 more than 55,000 tons of barite have been recovered and shipped.

(3) Mountain Minerals, Ltd. (barite)

References: Minister of Mines, B.C., Ann. Repts. 1945, p. 130; 1952, p. 246–248; 1958, p. 84–85; 1960, p. 134–135; 1962, p. 147; 1963, p. 138; 1964, p. 200; 1965, p. 259; 1968, p. 296.

These properties are held by Mountain Minerals Ltd. of Lethbridge, Alberta, and have been mined since 1945.

Barite occurs in brecciated dolomite of the Beaverfoot Formation not far from the Mount Forster–Steamboat fault. A detailed description of the geological setting and of the deposits is given by McCammon (1965).

(2) A.P. Green Fire Brick Co. Ltd. (magnesite)

References: Minister of Mines and Petroleum Resources, B.C., Ann. Repts. 1962, p. 156–157; 1964*, p. 194–199.

Prospects are in two localities, near Dunbar Creek, and near Topaz Lake, both west of Brisco. Both were optioned by A.P. Green Fire Brick Co. Ltd., 2122 Eighth Avenue, SE, Calgary, Alberta and investigated in the early 1960's. No commercial production had taken place before 1964.

Magnesite occurs in scattered localities in Mount Nelson dolomites. A detailed study of the occurrence of the magnesite and its geological setting is given by McCammon (1965, p. 194–199).

(5) Kootenay Lake Marble

References: Minister of Mines, B.C., Ann. Repts. 1908, p. 97; 1929, p. 328; Fyles, 1964, p. 13.

The quarry, in Badshot marble is just north of Marblehead, north of Kootenay Lake. Marble was quarried for building stone as well as monuments until about 1930 (op. cit., 1964).

Mountain Minerals (silica)

Reference: Minister of Mines and Petroleum Resources, B.C., Ann. Rept. 1964.

Silica has been quarried by the same company operating the barite showings, west of Brisco, from exposures of Mount Wilson (Wonah) Quartzite (op. cit., 1964, p. 207).

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APPENDIX

Sections of Horsethief Creek Group

Section 1

Section along ridge between Law and Horsethief Creeks (thicknesses approximate).

Fault contact with Mount Forster Formation

	Thickness (feet)	
	of unit	above base
Grit, purple, medium-to coarse-grained	20	3,120
Slate, grey and brown	75	3,100
Quartz-pebble conglomerate with 75 per cent pebbles up to ¾-inch diameter, green chloritic matrix, many slabs of black slate in conglomerate; about 10 per cent interbedded slate	300	3,025
Grit, greywacke. fine quartz-pebble conglomerate, calcareous, limonitic, chloritic, siliceous matrix; about 30 per cent interbedded green slate	150	2,725
Paper slate, grey and brown	30	2,575
Feldspathic grit, brown weathering, limonitic	15	2,545
Paper slate, grey and green	25	2,530
Brown slate	10	2,505
Quartzite, brown weathering, grey	5	2,495
Limestone, 1- to 6-inch beds, brown weathering, light grey to white; regularly interbedded purple, green, and brown argillite and slate	125	2,490
Light purple slate	20	2,365
Greenish grey slate	10	2,345
Fine pebble-conglomerate, grit, and greywacke; some beds have brown limonite-stained chloritic and siliceous matrix, some have calcareous matrix with 30 per cent of 1/8-inch diameter quartz-pebbles	150	2,335
Paper slate, deep purple with some very bright green layers and patches	10	2,185
Slate, smooth, poorly cleaved, green	15	2,175
Coarse quartz-pebble conglomerate; some beds up to 90 per cent pebbles contain a few green quartzite pebbles as well as red jasper pebbles. Some beds of pebbly, feldspathic, green greywacke in sharp contact with the pebble-conglomerate	300	2,160
Grey paper slate	20	1,860
Slate, thinly cleaved, brown to muddy weathering, grading upward to greenish grey slate	200	1,840
White quartz-pebble conglomerate containing up to 80 per cent pebbles up to ½-inch diameter; matrix of medium-grained quartzite	20	1,640
Slate, very thinly cleaved, brown to reddish brown weathering, with very light grey lines up to 1/32 inch wide	15	1,620

	Thickness (feet)	
	of unit	above base
White quartz-pebble conglomerate and pebbly grit; matrix chlorite and quartz with brown flecks of limonite	20	1,605
Paper slate, green with dark grey lines to 1/16 inch wide, some calcareous, greenish grey slate interbeds	150	1,585
Quartz-pebble conglomerate, pebbles up to ¼-inch diameter form up to 75 per cent of the rock; brown, limonitic, and calcareous matrix	30	1,435
Grit, brown, with calcareous matrix	10	1,405
Slate, very thinly fissile, dark grey with some brown weathering bands ¼- to ½-inch wide	125	1,395
White quartz-pebble conglomerate consisting of 50 to 90 per cent pebbles up to ½-inch diameter with greenish, chloritic matrix; near base of a bed may be shale slabs up to 10 inches long; minor, angular, ½-inch pieces of brown weathering dolomite, some pieces to 6 or 8 inches; 5 to 10 per cent of rounded, or oblong, weathered, white feldspar grains. Upper part of section is finer pebbly grits and grits	220	1,270
Paper slate, very fissile, grey and black; some interbedded grey and black slate	250	1,050
Limestone, crystalline, black or brown to orange weathering, ½- to 2-inch beds; minor interbedded grey slate	75	800
Slate, intensely cleaved, interbedded reddish brown and black bands from ⅛ to 1 inch wide	125	725
White quartz-pebble conglomerate, grit and quartzite; rare graded beds with ¼-inch quartz-pebble conglomerate at base, grading to coarse grit, then to quartzite at top; brownish to pink weathering with many scattered specks of brown limonite; matrix slightly calcareous	150	600
Slate, well cleaved, grey and black; some banded grey and black slate in ½- to 1-inch beds	150	450
Slate, fissile, grey, in beds 6 to 8 inches thick; interbedded limestone, brown weathering, grey	60	300
Grit	10	240
Slate, black, sheared	5	230
Quartzite, grit, and quartz-pebble conglomerate, rusty to brownish weathering	50	225
Limestone, ¼- to 2-inch beds, coarsely crystalline, brown weathering, grey; interbedded with black shale in similar beds; mainly thin-bedded limestone near top	100	175
Shale, thin-bedded, fissile, grey and black	75	75
Conformable with Toby Formation below		
Toby Formation: Conglomerate, massive, dark grey weathering; contains unoriented pebbles, cobbles, and some boulders, mainly of quartzite, minor dolomite; matrix of argillaceous limestone at base, argillite toward top	25	
Regional angular unconformity		
Mount Nelson Formation: Brown weathering crystalline dolomite	10	
Dense white quartzite	100	

Section 2

Section at head of upper south fork of Jumbo Creek in cirque north of Blockhead Mountain.

Apparently conformable, sharp contact with overlying Hamill grits and quartzite of Lower Cambrian (?) age.

	Thickness (feet)	
	of unit	above base
Folded phyllite and slate, grey and greenish grey	1,000	5,400
Grits and pebble-conglomerates in beds 1 foot to 4 feet; minor beds (a few inches wide) of coarse pebble-conglomerate with quartz pebbles up to 1 inch diameter. Interbedded grey phyllites and black slates	1,200	4,400
Quartzite, grit, pebbly grit, feldspathic pebble grit, and feldspathic pebble-conglomerate, with all grain sizes from 1/16 to ¼ inch, but few particles over ¼ inch. These competent rocks vary from brown-flecked grey to green. Sections of competent rocks from 100 to 200 feet thick alternate with 50- to 75-foot sections of black to grey slate and phyllite	800	3,200
Phyllite, green, grey, almost silvery, pyritiferous, with conformable pods and stringers of quartz pyrite veins; phyllite, bright green, much folded on a small scale; phyllite, very light grey, alternating with some bright green phyllite and brown or grey weathering ¼- to 1½-inch limestone beds; some pods of brown weathering, white limestone	600	2,400
Phyllite, grey, much folded on small scale; minor green argillite, no limy beds, but all rocks contain much pyrite	500	1,800
Slates and phyllite, light silvery to dark grey, contain much pyrite, small scale folds up to 20-foot amplitude	700	1,300
Phyllite, greyish, containing much pyrite; interbedded brownish weathering grey limestone, individual laminae may be ⅛ to ¼ inch or limestone may be up to 2 feet (thinly banded); limestone, grey, crystalline, dark weathering, dolomite, cream coloured, discontinuous; black argillite	600	600

Conformable with Toby Formation below

Section 3

Basal section of Horsethief Creek above the Toby Formation beginning at elevation 7,100 feet, north above Rocky Point on Bugaboo Creek.

Section continues up ridge and consists of alternating slate, conglomerate, and grit (greywacke).

	Thickness (feet)	
	of unit	above base
Pebble-conglomerate	70	1,270
Black slate	150	1,200
Greywacke, grit, and pebble-conglomerate; no particles over 1/3 inch; some feldspar particles	100	1,050
Slate, black, and grit, rust flecked	50	950
Pebble-conglomerate, quartz pebbles less than ¼ inch, matrix grey, flecked with brownish rusty spots	30	900
Slate, black, well-developed slaty cleavage; minor beds of greywacke and grit to 3 feet thick	250	870
Slate, black and grey, black and dark grey weathering; minor fine greywacke near top of sequence	150	620
Quartzite, grit, and minor pebbly grit, brown specked, grey weathering; rare grey argillite	200	470
Slate, black, with well-developed slaty cleavage, bedding shown by thin, rusty to brown beds	100	270
Limestone, dark grey weathering interlaminated with ½- to 1-inch beds of grey quartzite with limy matrix	20	170
Quartzite, dark grey, buff to brown weathering calcareous matrix	60	150
Argillite, black, massive	20	90
Dolomite, grey, cream to light buff weathering; very thin bedded, ¼ inch or less	50	70
Limestone, black, grey weathering, dense	20	20

Conformable with Toby Formation below

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