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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

BULLETIN 196

GLACIAL GEOMORPHOLOGY AND PLEISTOCENE HISTORY OF CENTRAL BRITISH COLUMBIA

H. W. Tipper

Ottawa, Canada 1971

GLACIAL GEOMORPHOLOGY AND PLEISTOCENE HISTORY OF CENTRAL BRITISH COLUMBIA

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By

H. W. Tipper

DEPARTMENT OF
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PREFACE

For more than twenty years the author of this report has been mapping the bedrock geology of central British Columbia and during this time he has developed a deep interest in the intriguing problems connected with the glacial history of the area. Many of his observations were used in the preparation of the Glacial Map of Canada, published in 1968, and it is desirable that this information be made available to the public in greater detail in order to provide a clearer understanding of the glacial history of this large and previously little known region.

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

OTTAWA, February 20, 1970.

BULLETIN 196 — Die glaziale Geomorphologie und die Geschichte von Zentral-Britisch- Kolumbien im Pleistozän

Von H. W. Tipper

Während des Pleistozäns war das ganze Zentralgebiet von Britisch-Kolumbien von Eis bedeckt. Zu Beginn der Epoche war die Ausbreitung der Eisdecke am grössten.

БЮЛЛЕТЕНЬ 196 — Гляциальная геоморфология истории плейстоцена центральной части Британской Колумбии.

Ховард Ватсон Типпер.

Вся центральная часть Британской Колумбии во время плейстоценовой эпохи была покрыта льдом. Предыдущие наступления ледников были наиболее значительными.

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GLACIAL GEOMORPHOLOGY AND PLEISTOCENE HISTORY OF CENTRAL BRITISH COLUMBIA

ABSTRACT

During the Pleistocene epoch all of central British Columbia was covered by glacier ice that molded and sculptured a multitude of features from which the glacial events can be interpreted. The Fraser ice sheet was formed by the accumulation of snow and ice in the Coast and the Cariboo Mountains whence it flowed into the Interior Plateau as coalescent ice sheets. The ice from the two sources met near Fraser River resulting in a southeasterly confluent mass and a northerly flowing sheet. The latter, together with ice from the northern interior, flowed northeasterly to the Rocky Mountains which blocked further advance. Deglaciation was a combination of frontal retreat, downwasting, and stagnation of large masses of ice.

Later readvance from the Coast Mountains and Cariboo Mountains produced tongues and lobes of ice that extended into the Interior Plateau but did not coalesce as an ice sheet.

Earlier glacial advances are believed to have been more extensive. At some time in early Pleistocene time, ice accumulated to form a thick central dome from which ice flowed radially over and through the Coast, Cariboo and Rocky Mountains.

RÉSUMÉ

A l'époque du Pléistocène, toute la partie centrale de la Columbie-Britannique était recouverte de glace de glacier qui a modelé et sculpté une multitude d'accidents topographiques permettant d'interpréter les phénomènes glaciaires. La calotte glaciaire Fraser a été formée par l'accumulation de neige et de glace dans la chaîne Côtière et les monts Cariboo, d'où elle s'est acheminée vers le plateau intérieur sous forme de calottes glaciaires coalescentes. Les glaces des deux sources se sont réunies près du fleuve Fraser engendrant une masse confluente à orientation sud-est et une calotte glaciaire se déplaçant vers le nord. Cette dernière, rejointe par les glaces interieures du nord, s'est dirigée vers le nord-est où les montagnes Rocheuses ont arrêté sa marche. La déglaciation a été causée par recul frontal, la fusion sur place et la stagnation d'énormes masses de glace.

Les poussées subséquentes à partir de la chaîne Côtière et des monts Cariboo ont produit des langues et des lobes de glace qui ont pénétré dans le plateau intérieur sans toutefois se réunir en calotte glaciaire.

On croit que les poussées glaciaires antérieures avaient été plus importantes. Vers le début du Pléistocène, les glaces se sont accumulées pour former un dome central épais à partir duquel rayonnaient des glaciers qui ont envahi et recouvert la chaîne Côtière, les monts Cariboo et les montagnes Rocheuses.

INTRODUCTION

GENERAL STATEMENT

The glacial features and Pleistocene history of British Columbia have been a source of interest and a subject of inquiry for many geologists and naturalists since the first systematic geological investigations in the western Cordillera more than 100 years ago. Information pertinent to the glacial deposits was largely obtained incidental to the bedrock mapping or other activities. Few scientific investigations in British Columbia had as their aim the interpretation of glacial deposits and the elucidation of Pleistocene events; the few that took place are mainly in the last quarter century.

The central part of the province is no exception to this neglect. Except for one or two recent studies around Kamloops and Prince George little detailed information has been obtained on which to build a comprehensive interpretation of the glacial history. The present study is not a detailed investigation but aims mainly at assembling pertinent information, presenting new ideas and interpretations, and encouraging further investigations particularly in central British Columbia and generally in the Canadian western Cordillera.

SOURCE OF INFORMATION

For more than twenty years the writer has been mapping bedrock in central British Columbia and during this time more than 45,000 square miles have been systematically investigated as part of a program of detailed reconnaissance bedrock study. The areas that the writer has mapped wholly or in part are indicated in Figure 1. In the course of this work, both in the field and in airphoto studies, it was inescapable that a compelling interest in the intriguing glacial phenomena should lead to the assembling of glacial data and the development of ideas to explain the features. Interpretations from these areas is the main source of information, obtained largely from air photographs supplemented by some specific examinations in the field and casual observations incidental to the bedrock studies.

Original manuscript submitted: 5 March, 1969
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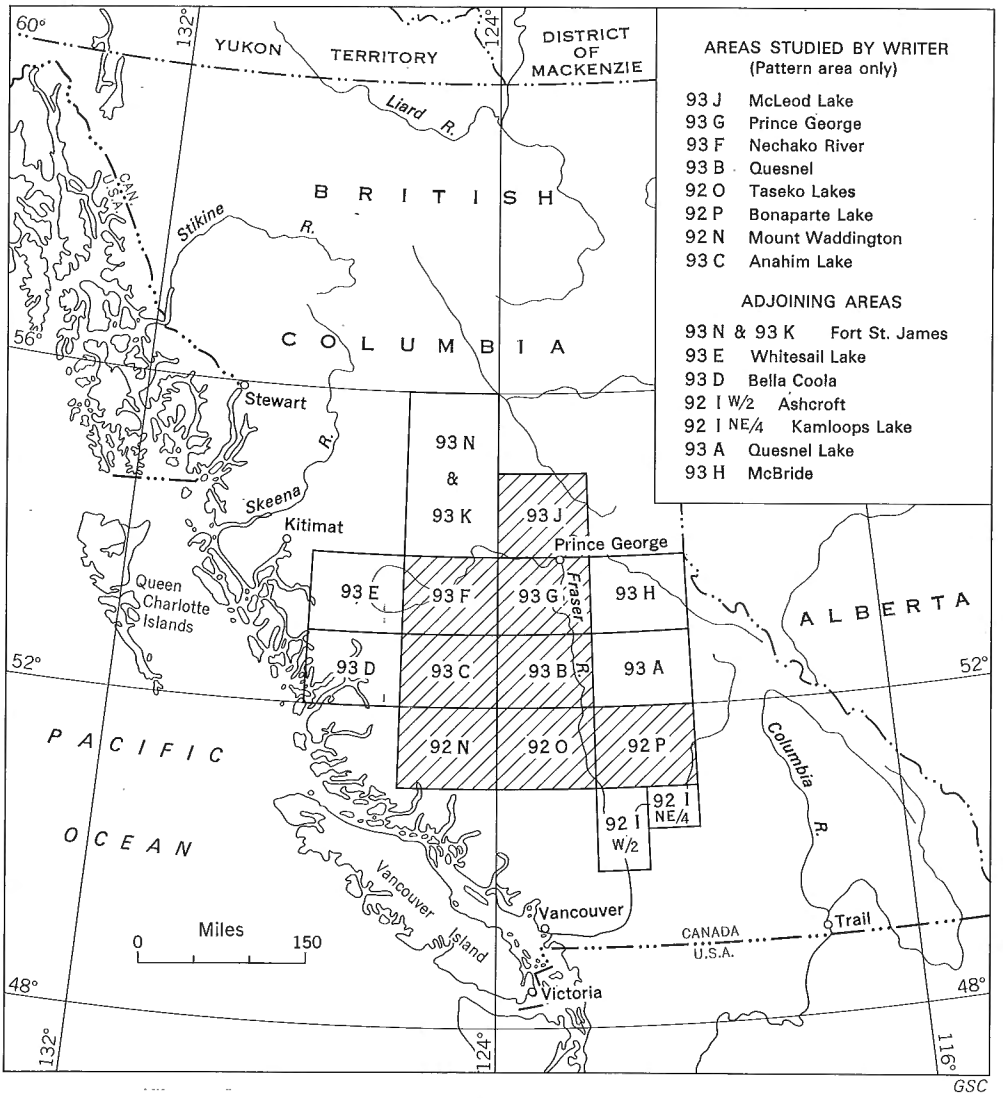

Figure 1. Index map of areas referred to in this report.

In adjoining areas further corroborating information has been gleaned from air photographs, from some ground observations by the writer, and from observations of colleagues at the Geological Survey. This information has permitted the development of a picture broad enough to encompass an area representative of the interior of the province extending from centres of accumulation to near the margins of the ice fields and ice lobes.

Finally the writer has drawn on all published information contained in geological reports of areas, from soil maps, from glacial geology reports on specific regions and problems, and from any publication with pertinent facts or ideas relative to the glacial deposits and history of central British Columbia. The comments and suggestions of many members of the Geological Survey have been helpful, constructive, and encouraging but the responsibility for the information and ideas presented here rests with the writer.

PURPOSE OF THE STUDY

The Glacial Map of Canada published by the Geological Survey of Canada (Prest et al., 1968) presents trend lines, outlines of glacial lakes, meltwater channels, and other glacial information for central British Columbia. Much of this information was obtained from the manuscript maps of the writer. It is desirable to present this information in greater detail, to provide a clearer understanding of the glacial deposits and their significance, and to provide a preliminary or reconnaissance glacial map of a large area in an otherwise little known region.

The writer has developed certain ideas or hypotheses on the nature of the glaciation and deglaciation of central British Columbia. These ideas are presented in the hope that they will be examined and constructively criticized, leading eventually to detailed studies that may provide complete and accurate interpretations of the glacial history.

PHYSIOGRAPHY

PHYSIOGRAPHIC SETTING

Central British Columbia is, in general, an elongate basin or trough trending northwesterly with rugged mountains on the northeast and southwest sides. To the northwest the trough is terminated by rugged mountains and to the southeast by a somewhat less-rugged, uplifted, and dissected plateau. The interior of this trough is characterized by low to moderate relief, gently undulating to hilly topography, and a lack of glacier-clad rugged mountains.

Major streams of the area under consideration flow southerly, but ignoring the stream valleys, the hypothetical surface formed by extending the interstream surfaces would slope in a general northeast direction convergent to the northeast.

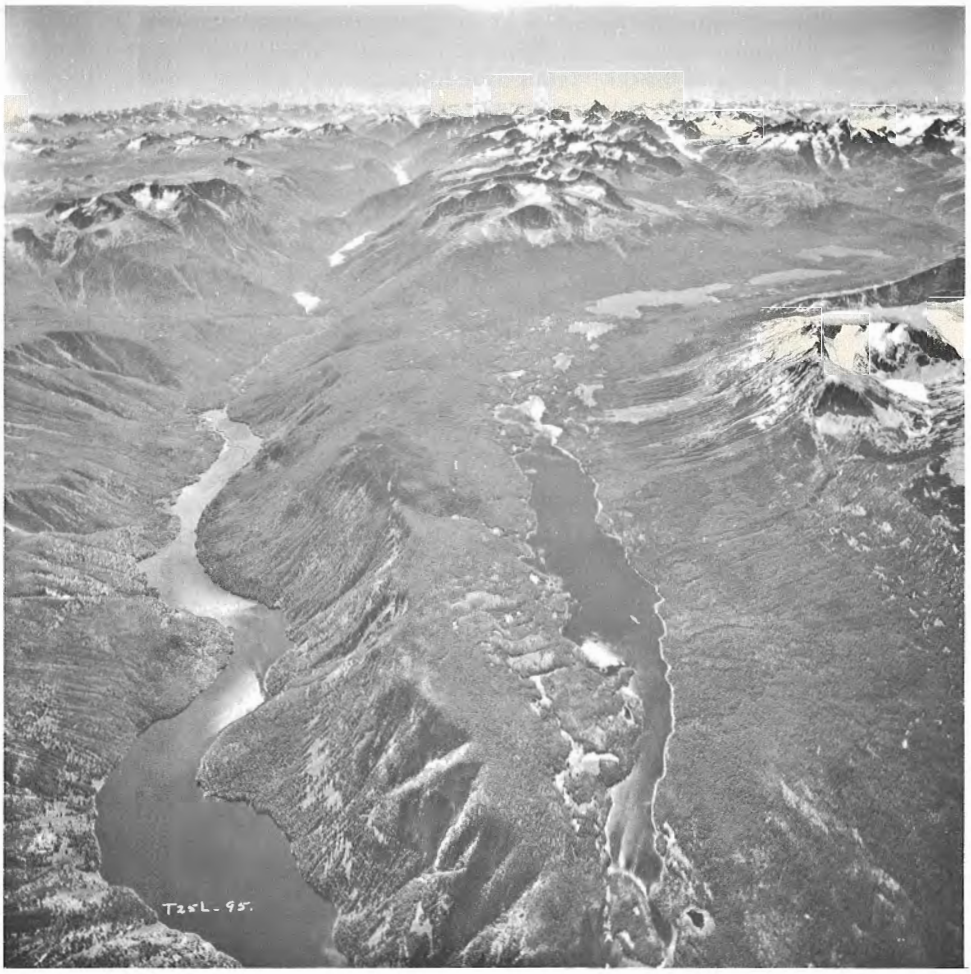

Figure 3. Coast Mountains view southerly along Lonesome Lake valley. Anahim Lake and Mount Waddington map-areas. The mountains on the horizon are the site of ice accumulation during the Fraser Glaciation. Monarch Mountain is the sharp peak on the horizon, right to centre. The lakes in the right half of the photograph are on an extension of the Interior Plateau surface into the mountains and Lonesome Lake valley in the left half of the photograph has been cut below this surface. EMR photo T25L-95

DRAINAGE SYSTEMS

Most of the area under consideration is drained by Fraser River system including Chilcotin, Blackwater, Quesnel, and Nechako Rivers. The extreme northeast part is drained northerly to the Peace River and the westerly part has several rivers that drain to the Pacific Ocean.

Fraser River System

The Fraser River system is complex. The southern part, which includes Chilcotin and North Thompson Rivers and the part of the Fraser River south of 51 degrees N., represents streams that have eroded headward and steadily deepened their channels and deeply incised themselves into the plateau surface. The Chilcotin River, for example, at its junction with Fraser River is 1,800 feet below the Fraser Plateau surface but 90 miles towards its source, it is flowing on this surface. Similarly the North Thompson River flows in a deep trench cut into the Shuswap Highlands.

The northern part of the Fraser River system has a different aspect. The main tributaries of the Fraser, namely Quesnel, Blackwater, Narcosli, Willow, and Nechako Rivers as well as many smaller creeks, flow northerly, northwesterly or northeasterly into Fraser River. With the Fraser River flowing southerly, this forms a classical barbed drainage system. Lay (1940, 1941) advanced the hypothesis that the Fraser River was once a northward flowing system discharging through McGregor River-Parsnip River valleys into the Peace River drainage. The writer considered this theory when studying the Tertiary deposits of the Quesnel and Prince George map-areas and found Lay's ideas essentially correct. The sedimentary structures in Miocene river gravels clearly indicate a northward flow of water in Miocene time.

The writer believes that capture of the north flowing Fraser River was effected by the ancestral Chilcotin River or a tributary thereof and that it took place between the mouth of the present Chilcotin River and Soda Creek north of Williams Lake. This part of the Fraser River from Soda Creek to Chilcotin River is youthful in character with steep valley walls and a narrow valley bottom. North of Soda Creek the Fraser River Valley widens to a broad valley in which the Fraser River meanders. The current is strong and the meanders are being incised into the valley bottom. The valley broadens northward to Prince George which in itself would characterize a northward flowing stream. Chilcotin River or a tributary thereof apparently worked headward from the present mouth of Chilcotin River and intersected the northward drainage of the ancestral Fraser River. This capture probably occurred in late Pliocene time and was later than the Miocene-Pliocene plateau lavas and older than the last major glacial episode.

Westward Flowing River Systems

Along the Coast Mountains, there are several streams, Deane, Atnarko, Klina Klini, and Homathko Rivers and Moseley Creek, that have their headwaters in the Interior Plateau but flow westerly across the rugged Coast Mountains to the Pacific Ocean. Whereas the headwaters of these

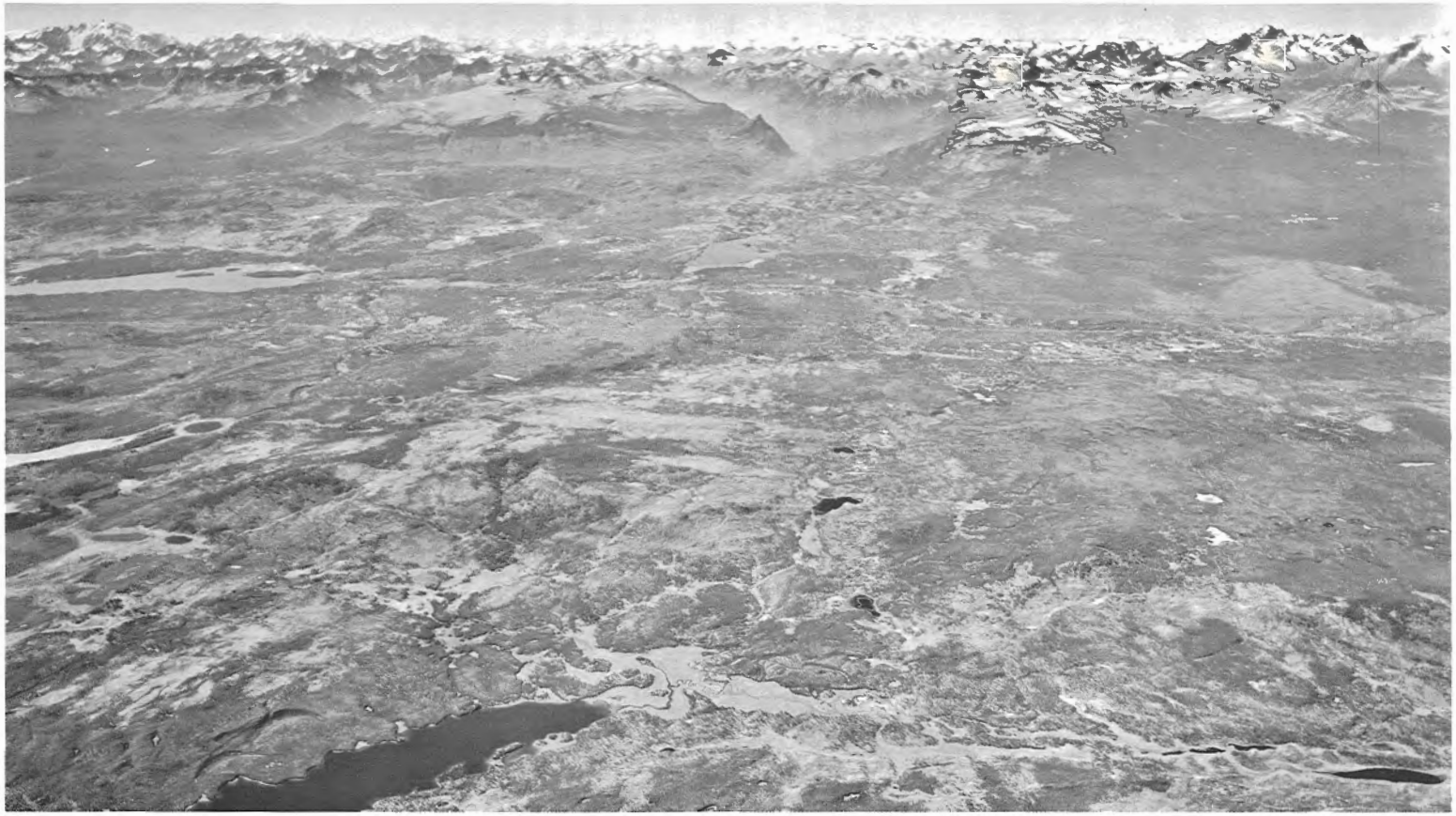

Figure 4. View southwesterly across Fraser Plateau into Coast Mountains. Anahim Lake and Mount Waddington map-areas. Klina Klini River valley extends into the mountains in centre background. Note abrupt front of mountains marking sharp transition from plateau to mountains. EMR Photo. T24R-183

streams are relatively gentle, slow streams in broad valleys, the course of the streams in the Coast Mountains is through precipitous canyons and tight valleys with steep gradients propelling the streams in a tumultuous rush to the ocean.

Whether or not these are antecedent streams is not known. The Coast Mountains are the site of Pliocene or younger upwarping and the streams could have maintained their course across this uplift. On the other hand, evidence for headward erosion, stream capture and reversal of flow is evident in several places, particularly the Klina Klini River. This river has a course in its headwaters that would indicate it was once the headwaters of a stream flowing eastward through Tatla Lake into Chilcotin River. Headward erosion from the main part of Klina Klini River intersected the older drainage at a point midway between Tatla Lake and Klina Klini post offices and diverted the stream to a northerly flow parallel to the Coast Mountains and thence westward through the mountains to the ocean. This piracy may only be a phase in the development of these western flowing river systems and serves only to obscure the true antecedent nature of these streams. The problem is not resolved.

Peace River Drainage

In the northeast a small area is drained northerly and eventually easterly into the Peace River system. Parsnip River is the main stream involved in this discussion. Tertiary sediments along its course indicate that the valley may be Eocene or older. It is possible that this northward flowing channel was at one time occupied by a river that included the area now drained by the upper Fraser River in its drainage basin.

PHYSIOGRAPHIC SUBDIVISIONS

Holland has outlined the physiographic subdivisions of British Columbia (Holland, 1964). Those of the central part of the province, shown in Figure 2, closely follow those of Holland and differ only in minor changes in boundaries, and other details. The subdivisions will be discussed briefly in the following section. For a comprehensive account, the reader is referred to Holland's report.

Coast and Cascade Mountains

The Coast Mountains form the western flank of the area, and were the main centre of ice accumulation on the western side of the interior basin. They are mainly underlain by a granitic and metamorphic complex with pendants of volcanic and sedimentary rocks. The Chilcotin Ranges, mainly sedimentary and volcanic rocks, flank the complex on the east.

The Coast Mountains are in general, rugged in many places reaching elevations in excess of 10,000 feet and culminating in Mount Waddington at 13,107 feet elevation (Fig. 3). Local relief is great, cirque glaciers are common, and several ice fields are present. The eastern margin forms a front of high ranges rising abruptly from the Interior Plateau, particularly from the Fraser Plateau subdivision (Fig. 4).

The Cascade Mountains are mainly in the State of Washington to the south and southeast. However they do extend into British Columbia and terminate against the Coast Mountains along Fraser River but are not pertinent to this discussion.

Rocky Mountains, Rocky Mountain Trench, and Columbia Mountains

The Rocky Mountains on the eastern margin of British Columbia are rugged with many peaks above 10,000 feet elevation, the highest being Mount Robson at 12,972 feet elevation. They are mainly folded and thrust-faulted Paleozoic and Mesozoic sedimentary rocks. Cirques and cirque glaciers are common.

Columbia Mountains lie southwest of Rocky Mountains and are mainly folded sedimentary and metamorphic rocks of Precambrian and Paleozoic age. These high, rugged ranges in many places exceed 10,000 feet in elevation; cirques and cirque glaciers are common on the higher peaks. Columbia Mountains are subdivided into three parts in the area being considered, Cariboo, Monashee, and Selkirk Mountains. Cariboo Mountains are of particular importance to this discussion as they are believed to have been an ice accumulation centre from which ice moved outward.

The Rocky Mountain Trench is a linear depression that flanks Rocky Mountains on the west and thus separates them from Columbia Mountains. The transition from the Trench to these mountains is abrupt, forming a prominent wall on either side for much of its length. Available information suggests it is a structurally controlled erosional feature but no one theory explains its origin throughout its length. The valley bottom of the Trench is 2 to 10 miles wide and is occupied by parts of major streams, Parsnip, Fraser, Canoe, and Columbia Rivers, with low divides between their headwaters.

Omineca Mountains, Skeena Mountains, and Hazelton Mountains

Between the Rocky Mountains and Coast Mountains at roughly latitude 55 degrees N, several groups of mountains, namely Omineca, Skeena, and Hazelton Mountains form a northern rim to the Interior Plateau. They are underlain by deformed Mesozoic and Paleozoic volcanic and sedimentary rocks that have been intruded by granitic and ultramafic plutons. The Rocky Mountains and Coast Mountains are, in general, higher and more rugged than these mountains and elevations greater than 8,000 feet are uncommon. Scattered small ice fields and valley glaciers are on the higher mountains. The southern parts of these mountains are lower and less rugged and merge with the rolling topography of the Interior Plateau.

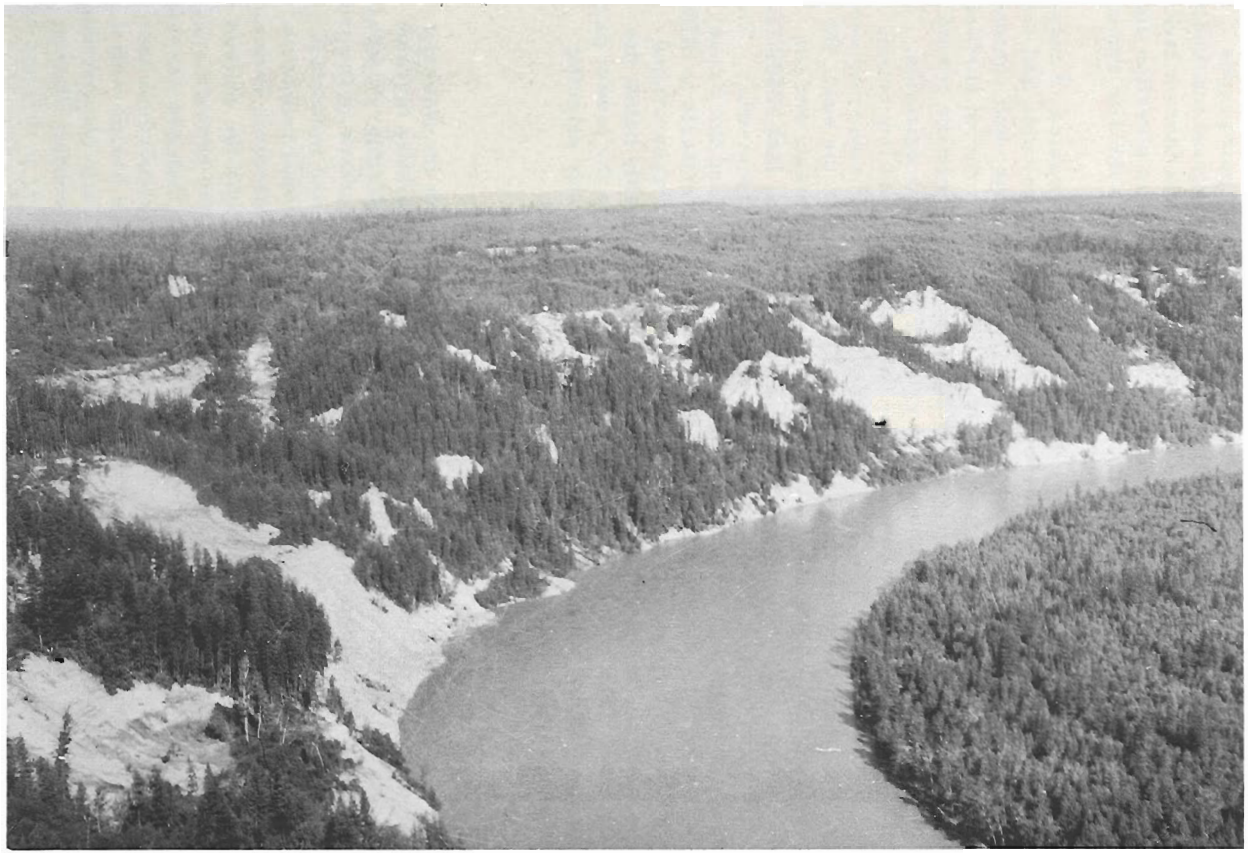

Figure 5. Nechako Plateau north of Quesnel, Prince George map-area. The surface is erosional, formed on Tertiary rocks of several ages and on Permian rocks. Fraser River has cut a channel into the surface. GSC Photo 119482

Interior Plateau

The central part of British Columbia is dominated by the Interior Plateau a northwest-trending elongate region, characterized by low to moderate relief. The mountain ranges described in the preceding paragraphs nearly enclose this region and form rugged barriers that contrast markedly in topography, elevations and relief. Only on the southeast is there a lack of mountains but even there the plateau generally increases in elevation and southward becomes a deeply dissected upland that completes the rim around the Interior Plateau.

The geology of the Interior Plateau is complex and varied. Fundamentally it is an area of deformed Mesozoic and Paleozoic volcanic and sedimentary rocks intruded by many plutons that vary in size, age, and composition. These rocks were reduced to a gently rolling to hilly erosion surface, probably in Cretaceous and early Tertiary time and in the Tertiary period volcanic rocks of differing composition, erupted in several episodes, blanketed the region and contributed further to a topography of low relief.

Holland (1964, pp. 66-74) subdivided the Interior Plateau into several parts, the Quesnel, Shuswap and Okanagan Highlands on the east, the Nechako, Fraser and Thompson Plateaus in the centre and west, and the Fraser Basin near Prince George. With the exception of the last subdivision, these are shown in Figure 2 but the boundaries are changed somewhat. The Fraser Basin of Holland is included in the Nechako Plateau and the Fraser Plateau as there do not appear to be sufficiently distinctive criteria to differentiate it. Holland considered the Fraser Basin to be a low area around Prince George lying below 3,000 feet elevation and presumably below the Nechako Plateau. The writer believes it merely represents the lowest part of the Nechako Plateau erosion surface and that the arbitrarily selected 3,000-foot contour hardly constitutes a significant boundary.

Nechako Plateau

The most northerly part of the Interior Plateau is the Nechako Plateau, an area of moderate to low relief, gently rolling to hilly terrane, and a few isolated, rounded mountains (Fig. 5). Here the (Tertiary?) erosion surface is not deeply dissected but exists as an irregular surface in the broad valleys between the hills and mountains. Most of the hills and mountains such as Quanchus, Fawnie, and Nechako Ranges, are erosional remnants or monadnocks (Holland, 1964) composed of Mesozoic or Paleozoic rocks. Tertiary volcanic rocks form rounded hills and in places floor the valleys with flat-lying or gently dipping lavas. In these instances the erosion surface appears to be above the Tertiary rocks although more than one erosion surface may be involved with Tertiary volcanics initially extruded on one. Around Prince George and to the west are three glacial lake basins with a flat topography that have been referred to as the Nechako Plain (Armstrong and Tipper, 1948, p. 285). On the east side, part of the Nechako Plateau has been designated as the McGregor Plateau (Holland, 1964, p. 69) and has a surface higher and more irregular than the erosion surface of the Nechako Plateau.

Figure 6. Fraser Plateau and Chilcotin River valley, Quesnel map-area. Plateau is underlain by flat-lying lavas with a thin till cover. Chilcotin River has cut a channel into the bedrock, possibly in part in pre-Pleistocene time. The surface of the lavas may be the original surface rather than due to erosion. GSC Photo 119448

Fraser Plateau

South of Nechako Plateau, a widespread accumulation of Tertiary volcanic rocks of several ages characterize the Fraser Plateau (Figs. 6, 7, 8, 9). Mesozoic and Paleozoic erosional remnants form scattered rounded hills. Early Tertiary volcanics, although possessing approximately concordant summit levels, are more dissected than the younger Tertiary lavas that flooded the lower Chilcotin River and the southeastern part of the Fraser Plateau. These late Tertiary lavas have only one or two major streams, the Fraser and Chilcotin Rivers, incised into them and for the most part are not greatly dissected. In the northwest part of the Fraser Plateau, three prominent mountain ranges, Rainbow, Ilgachuz, and Itcha, volcanic centres of late Tertiary and Quaternary age, rise above the plateau surface. Three small ranges of Mesozoic and Paleozoic rocks, Camelsfoot, Marbel, and Clear, lying within the southwest corner of Fraser Plateau, are not characteristic of the Fraser Plateau.

Thompson Plateau

The southernmost plateau region, the Thompson Plateau, is the most deeply dissected section of the Interior Plateau. The main rivers crossing this region are deeply incised and their tributaries have dissected

Figure 7. Fraser Plateau north of Alexis Creek, Quesnel map-area. Surface is partly a result of flat-lying Tertiary lavas and partly a result of Tertiary erosion. Typical flat to gently rolling terrain of the Interior Plateau. GSC Photo 119444

the (Tertiary?) erosion surface. This surface rises gradually to the south and the varying resistance to erosion of the many rock types of Paleozoic and Tertiary age has produced an irregular but rolling upland surface.

Quesnel, Shuswap, and Okanagan Highlands

The eastern flank of the Interior Plateau is a highland area and marks a transition from the flat to gently rolling topography of its central and western parts to the rugged peaks of Columbia Mountains. This highland region has been divided into three areas by Holland (1964, pp. 72-74) referred to as the Quesnel, Shuswap, and Okanagan Highlands and is underlain by folded and faulted Mesozoic to Precambrian sedimentary, volcanic and metamorphic rocks and granitic plutons of several ages. The hills and mountains are broad and rounded with moderate relief and are the remnants of an uplifted and dissected, gently rolling early Tertiary erosion surface.

PHYSIOGRAPHIC DEVELOPMENT OF CENTRAL BRITISH COLUMBIA

The topography of central British Columbia is the result of a long period of development extending at least to Late Cretaceous time and probably earlier. Much of the area, particularly the eastern part, has been

Figure 8. Fraser Plateau north of Chilcotin River, Quesnel map-area. Essentially a flat surface broken by a few rounded hills and deeply incised major streams such as Chilcotin River. EMR Photo T32R-40

undergoing uplift and erosion since mid-Triassic time. However, the development of the modern drainage system and topography can only be recognized with certainty as far back as latest Cretaceous time.

The major drainage channels of central British Columbia are believed to have had their beginning in latest Cretaceous time as evidenced by Late Cretaceous fossiliferous sedimentary strata along some of the major drainage systems such as Parsnip River (Muller and Tipper, 1962), Fraser and Quesnel Rivers (unpubl. information) and the Nechako River (Tipper, 1963). Eocene sedimentary rocks are common along almost all major drainage systems but except for a few small lacustrine deposits, are practically unknown in the interstream areas. Later Tertiary sediments are almost completely restricted to these same drainage systems. The presence

Figure 9. Fraser Plateau, southerly along Fraser River, Taseko Lakes and Bonaparte Lake map-areas. Fraser River dissects plateau surface and Coast Mountains are visible on horizon. Area viewed was overriden by late advance of Cariboo Mountain ice from the east (left). EMR Photo T23L-21

in the interstream areas of volcanic rocks representing several stages of Tertiary time refutes any argument that these sediments are only remnants of more widespread deposits.

Throughout central British Columbia many flat or gently sloping upland surfaces and many broad, flat-bottomed valleys represent the widespread erosion surfaces that developed during Tertiary time. During Eocene time much of British Columbia was reduced to an undulating erosion surface with a few erosional remnants or monadnocks. Subsequently the region was uplifted or upwarped, particularly on the east and south, and was dissected by the drainage system producing many highland or mountain areas with flat-topped or broad, round-topped mountains. Late Tertiary flood basalts were extruded onto this dissected erosion surface and either covered it or flowed into the valleys. Late Tertiary erosion stripped away the lavas

in places and, of more importance, the area of the Coast Mountains was uplifted in Pliocene or Pleistocene time, upwarping the flood basalts and the late Tertiary erosion surface that had developed. Complete dissection of the Coast Mountains and a partial dissection of the Interior Plateau was a late event, probably Pliocene or early Pleistocene. Pleistocene glaciation rounded off the prominences of the Interior Plateau and reduced the region to a rolling upland. Recent rejuvenation of the streams and very late cirque glacier action in the mountains have given parts of central British Columbia a youthful aspect.

This brief synopsis of the physiography of central British Columbia and its development serves to portray something of the general configuration of the region and its history. The Interior Plateau is essentially a broad, northwest-trending, irregular trough almost completely surrounded by high, rugged mountains from which ice flowed in Pleistocene time, accumulated in the Interior Plateau, and formed the Cordilleran ice sheet.

DESCRIPTION OF GLACIAL FEATURES

Central British Columbia possesses most features characteristic of a glaciated region and their presence is ample proof that all of central British Columbia was overridden by glacial ice. Several types of glacial features are well-developed and characteristic of the region, others are less important. In the following section many features are described and discussed and the writer's observations, conclusions and opinions regarding their significance are briefly outlined.

DRUMLINS, ROCK DRUMLINS, AND GLACIAL GROOVES

The development of drumlins, rock drumlins, and glacial grooves are closely related. All are produced by glacial ice moving over till or till and bedrock, molding and sculpturing this material into linear features that characterize almost all of central British Columbia. No other features give as comprehensive a picture depicting the overall glacial flow pattern and yet indicate clearly many minor variations dependent on local conditions and the influence of topography on a thinning ice sheet. The shape and dimensions of the features vary greatly depending on type of bedrock, depth of till, topography, thickness of ice, and many other local conditions. A description by Armstrong and Tipper (1948, pp. 288-291) of the drumlins, rock drumlins, and glacial grooves west and northwest of Prince George, mainly in the McLeod Lake map-area, applies equally well to the features throughout the area under discussion.

> "They vary considerably in outline and size, some are nearly circular; others are oval; and still others are 5 to 10 times as long as they are wide. They are generally from 1/2 to 1 1/2 miles long, although a few were observed more than 2 miles long. Most of them are 1/4 mile or less wide, however, a few reach widths of 1/2 mile or more. They vary considerably in height, probably averaging between 50 and 75 feet, although many are lower and a few range up to 150 feet high. Their heights in any one place are uniform but vary from place to place. In most cases the stoss or upstream end of a drumlin is much steeper, higher, and wider than the lee or downstream end. The narrower the ridge the steeper its sides, and the narrowest ridges have steeper

sides than ends. The surfaces of the individual ridges commonly show shallow, well-defined longitudinal grooves which are rarely observed except in air photographs. In some photographs two sets of intersecting longitudinal grooves were observed.

"The drumlins seldom occur singly and are for the most part alined in groups 5 to 6 miles long separated laterally by parallel trough-like valleys. In such a group the stoss end of a ridge either rises abruptly from the lee end of the ridge in front of it, or the two ridges are separated by an intervening flat area that may have been modified by later drainage. As a rule the lowest elevation between the ends of two alined ridges is still higher than the floor of the trough-like valleys separating the ridges laterally. Less commonly the ridges are closely spaced occasionally en echelon and are fused to one another laterally rather than separated by trough-like valleys. The ridges forming a group do not present a constant size.

"The intervening trough-like valleys are 50 to 150 feet deep and in places are up to one-half mile wide. In many places valleys extend uninterrupted for as much as 6 miles but not necessarily in a straight line. The valley may bend around the end of a drumlin, may split around a ridge and continue as two valleys, and may widen out into a flat area and then narrow again to a trough. The narrower more trough-like valleys generally separate narrow steep-sided ridges and the wider valleys separate broader, rounded ridges.

"In some parts of the area under discussion although the general arrangement of drumlins and intervening valleys is maintained the individual features are less sharply defined than in those just described. The ridges are lower, wider, and have more gentle slopes and the valleys are wider and not so deep. However, the longitudinal grooving of the ridges is still well developed...

"Widely interspersed among the drumlins of unconsolidated materials are ridges composed in part of bedrock. The stoss or front end of these ridges is composed of bedrock that has been scoured, gouged and rounded. The bedrock front which may have a gentle to abrupt slope forms the highest and widest part of the ridge. Behind the rock front here is a narrow ridge of till with steep sides. These ridges are from 25 to 200 yards wide, 200 to 700 yards long, and 100 feet or less high and are separated by narrow trough-like valleys. They have a more marked parallelism in the direction of ice movement than the ordinary ridges..." (see Figs. 10, 11, this report).

The glacial grooves are apparently closely related to the drumlins and rock drumlins (Fig. 11). In the description by Armstrong and Tipper the features were referred to as groovings but in the present report they are called glacial grooves, a more appropriate term. Most are shallow, linear troughs that stand out in air photographs, mainly because of differences in vegetation, and are indeed accentuated in many places by the vegetation (Fig. 12). They are not prominent on the ground and in a forested area are difficult to discern. They are the trough-like depression lying between the drumlins and rock drumlins as referred to by Armstrong and Tipper.

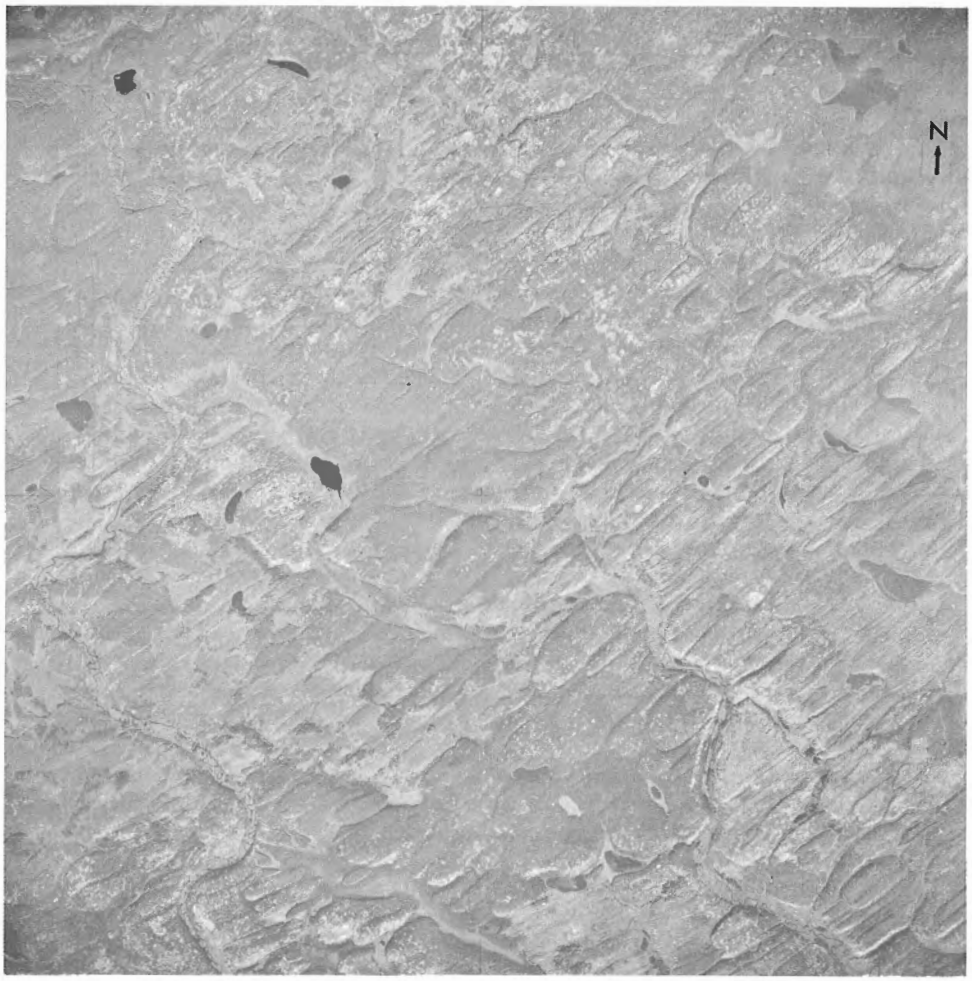

Figure 10. Drumlins, glacial grooves, and lateral overflow channels, McLeod Lake map-area. Ice moved northeasterly across map-area, up slope. Drumlins are characteristic of a heavily drift-covered area. Meltwater channels trending irregularly south-easterly mark the ice margin during retreat of the front. EMR Photo A13542-136

However in many places the area lying between glacial grooves cannot be described as a drumlin but is instead, a low, featureless till plain without any obvious drumlinoid form.

The glacial grooves may be very short, a matter of a few hundred yards long or may extend for two or three miles as a fairly well-defined striation on the till surface. However, they are for the most part, relatively short, shallow, and when not associated with drumlins, distributed at random over the area. Their orientation is identical with that of the drumlins and rock drumlins and certainly they are related in origin to these features.

In this paper the author does not propose to discuss the origin of drumlins, rock drumlins, and glacial grooves. They appear to be different

expressions of the process that formed them. They were molded and sculptured at the base of an actively moving glacier.

Several local conditions, such as the type of bedrock over which glacial ice was moving, had a determining influence on the shape and size of these features. If the underlying bedrock was a resistant granitic or metamorphic rock with an irregular surface and widely spaced joint systems the type of feature most commonly formed would be well-defined rock drumlins (Fig. 11). Where the underlying rock was soft sediments or easily disintegrated metamorphic rocks, the typical feature was usually a drumlin. Where the bedrock surface was flat, such as the upper surface of flat-lying basaltic lavas, the ice commonly moved across the surface forming only indistinct glacial grooves or striations (Fig. 13).

The thickness of till is obviously an important factor in determining the size and shape of these features. Where the overburden is deep, completely mantling the bedrock, rock drumlins are lacking. Instead, well-defined drumlins, commonly fairly narrow and higher than the average, predominate (Fig. 10). Where the till is very thin and the bedrock surface is very irregular, the finest forms of rock drumlins will occur, mainly bedrock with a very small tail of till behind the rock buttress. In some areas of thick till with very few irregularities a broad till plain showing only glacial grooves has been produced.

The slope of the surface over which the glacier ice moved appears to have exerted an important influence on the production of molded features. Where ice movement was up-slope (Fig. 11), well-defined drumlins and rock drumlins resulted but when the ice was on a steep gradient flowing downhill, a greater tendency to long, low drumlins and glacial grooves resulted (Figs. 14, 15).

The thickness of ice, and hence the downward pressure on the till, apparently influenced the local relief on the drumlin fields. The drumlins and rock drumlins, presumably formed by an extensive ice sheet through central British Columbia, are more distinct and more prominent glacial features than those formed by thinner, small lobes and valley glaciers that issued at a later stage from the mountains.

In central British Columbia drumlins, rock drumlins, and glacial grooves are not everywhere well developed. Rock drumlins and drumlins seldom formed on the tops of mountain ranges or on high plateau areas where usually only glacial grooves, if anything, are recognizable. The drumlins and rock drumlins were best formed in a broad valley not closely confined by valley walls. The best-formed glacial features are near the central axis of the Interior Plateau, namely in the McLeod Lake, Prince George, Nechako River, and Quesnel map-areas. The areas along the margin of the Coast Mountains and near the Cariboo Mountains are less distinctly drumlinized and the drumlin fields are patchy and less continuous.

Throughout this region, no attempt has been made to indicate the relative ages of the various drumlins and rock drumlins, obviously they were not all formed at one time. Generally those farthest from the source were formed earlier than those near the source. Drumlins believed to have been covered by late ice advances are of course thought to be younger than those in the rest of the area.

The rock drumlins, drumlins and glacial grooves, as well as bedrock striae, are all thought to have been formed by the active movement of the Cordilleran glacier. They are the best indicators of the direction of ice flow and clearly show variations in direction of flow that are imposed on the thinning ice by topography.

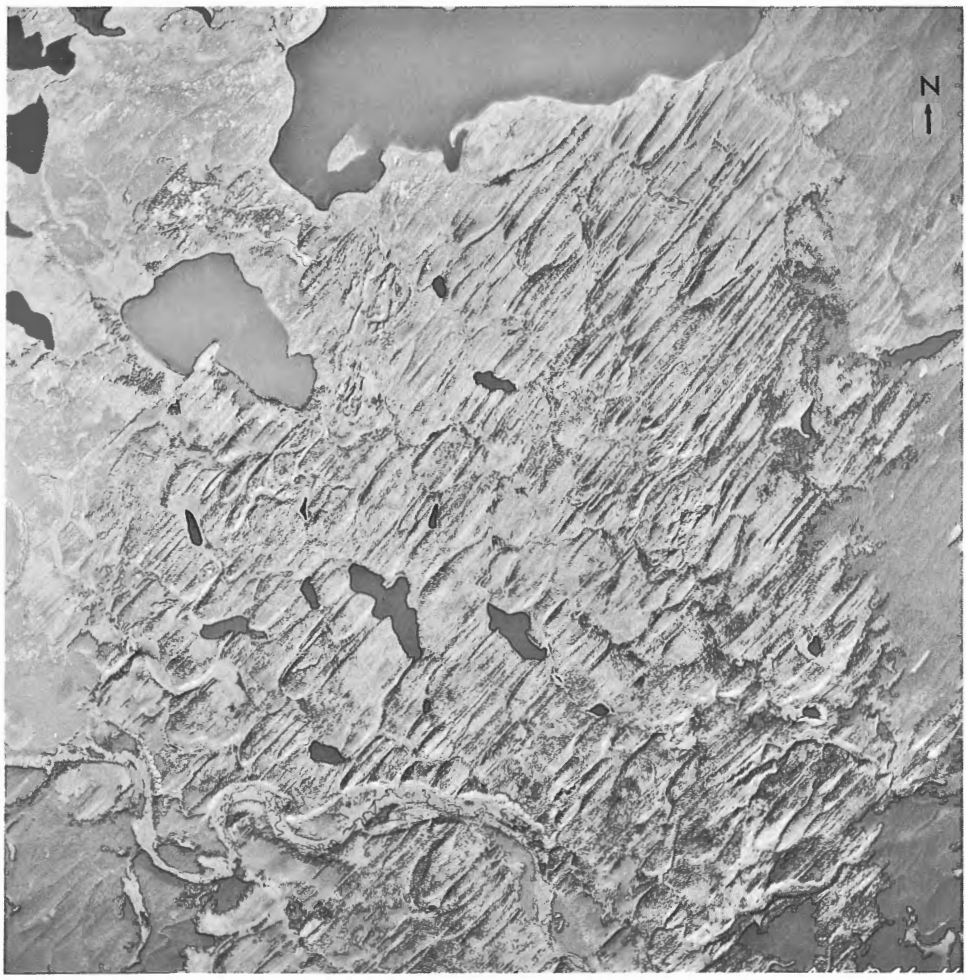

Figure 11. Rock drumlins, drumlins and glacial grooves south of Carp Lake, McLeod Lake map-area. The rock drumlins are the narrow crag-and-tail features in the right centre of the photograph that show up lighter than the broader drumlins. Glacial grooves are prominent on some drumlins and in the left centre of the photograph where well-formed drumlins are lacking.
EMR Photo A15046-16

ESKERS AND ESKER COMPLEXES

In all parts of central British Columbia, whether mountainous regions or areas of low relief, eskers and esker complexes are prominent and important glacial features of the region. These glaciofluvial deposits have been divided into two categories for purposes of description, true eskers and esker complexes.

Figure 13. Fraser Plateau north of Riske Creek, Quesnel map-area. Drumlinoid features of centre foreground are mainly glacial grooves and ill-defined drumlins, characteristic of an area of flat bedrock surface with a thin till cover. EMR Photo T23R-25

Figure 12. (opposite) View northeasterly across Fraser Plateau toward Itcha Mountains in centre background, Anahim Lake map-area. Gentle slopes of the range offer few obstacles to the glacier flow. In foreground glacial grooves striate the till surface; ice movement was from left to right. EMR Photo T24R-26

Figure 14. Drumlinoid features on Fraser Plateau near front of Coast Mountains, Taseko Lakes map-area. Poorly developed drumlins and glacial grooves produced on a flat bedrock surface covered by a thick till deposit nearer to the ice source than to the terminus of the ice sheet. Ice movement is to the northeast and down slope. The small abandoned channels in the lower central part of photograph are short-lived, direct overflow channels from the retreating margin of the Fraser ice sheet. EMR Photo A13318-9

Figure 15. (opposite) Fraser Plateau northeast of Redstone, Quesnel map-area. Widely spaced drumlins and glacial grooves in centre of photograph are typical for a heavily drift-covered area situated nearer to the ice source than to ice terminus. EMR Photo T23R-93

Eskers

The eskers, in general, are classical examples, i.e. typically long, narrow, ice-contact ridges, commonly sinuous, composed chiefly of stratified drift (Fig. 16). In most cases, the true eskers as here defined, are single ridges, but in places they divide into one or more branches and in plan resemble a dendritic drainage pattern. As a rule they do not form a network of ridges enclosing kettles as is common with esker complexes.

Eskers generally consist of single ridges varying in length from 30 miles to a few hundred yards but commonly 2 to 3 miles long. They may be only 5 to 10 feet high or up to 100 feet high, commonly varying along the length. In general they lie on the till surface or on other glacial deposits but sometimes lie directly on bedrock. Although many follow the centres of valleys, their location is not closely controlled by the topography. Their length is usually parallel to the local surface slope but they do not adhere to any present drainage pattern. Many trend subparallel to the direction of ice movement but others are in no way related to the direction of ice movement. Possibly the former were deposited while the ice was still active, the latter after the ice had ceased to move. Eskers are believed to have been deposited in subglacial or englacial channels confined by ice.

A relationship between eskers and abandoned stream channels seems apparent at several locations. At these sites one or two meltwater channels separate 2 or 3 aligned esker ridges. These are interpreted as the result of a single subglacial or englacial stream, confined by ice walls, flowing over an irregular surface and depositing debris in topographically low areas, but eroding a channel in topographically high areas. Eskers represent the part of the stream that was depositing material and the meltwater channels occur where the stream was eroding. A short area between esker and meltwater channel commonly shows little evidence of erosion or deposition but the surface material appears washed and is depleted of fine material. A longitudinal section along this stream course in several instances reveals that the upper surface of the esker and the bottom of the meltwater channel maintain a fairly constant or gradually changing gradient.

Esker Complexes

The esker complexes are a reticulation of short esker ridges that enclose kettles and may be several miles in width. Although they were referred to as compound eskers by Armstrong and Tipper (1948, pp. 292-299), esker complex seems to be a more suitable name in that it suggests the complexity of origin of the feature.

Esker complexes are up to 4 miles wide although widths of more than 1 mile wide are uncommon. One or two are as long as 30 to 35 miles although 3 or 4 miles are common lengths. Usually they occur in a large meltwater channel with the tops of the esker ridges not rising above the rim of the channel. The ridges form a network that in plan resembles a braided stream but it is not suggested that these features necessarily are deposits of braided streams (Figs. 17, 18). The ridges and enclosed depressions are elongated subparallel to the length of the meltwater channel in which the complex lies.

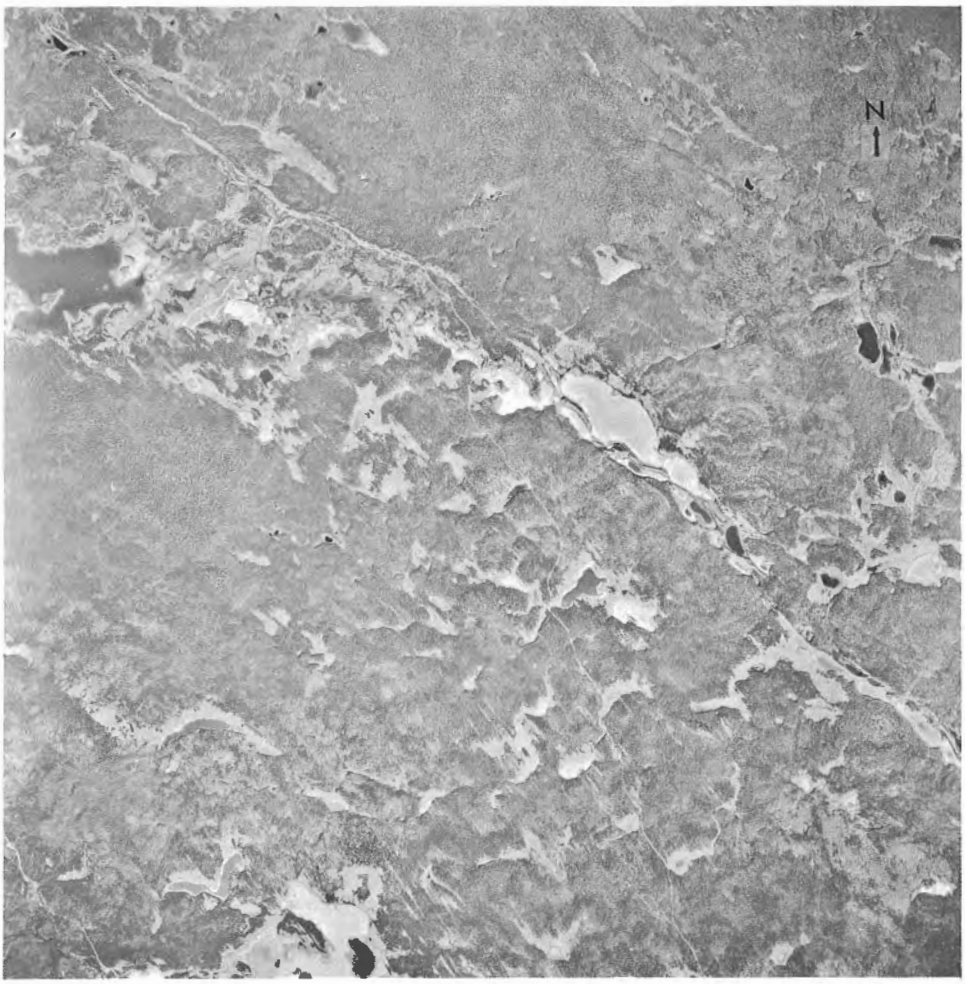

Figure 16. Single esker system near Meadow Lake, Bonaparte Lake map-area. The feature is essentially a single ridge although in a few places it breaks into two or more subparallel ridges for short sections. Glacial grooves trending southeasterly were produced by limited movement by the wasting, essentially stagnant remnant of the late Cariboo Mountain ice. EMR Photo A13233-94

The esker complexes, in general, have been laid down in meltwater channels that were excavated prior to the deposition of the esker complex. The assumed upstream ends of some esker complexes lie on the uneroded till surface but most enter channels at some point below their head end. Most present major drainage systems were originally major meltwater drainage channels and along most of these systems are remnants of esker complexes. The meltwater channels may have been either open channels between ice walls, enormous tunnels beneath the ice, large channels in the till beyond the ice margin, or all three. It is believed the ridges result from the burial along the channel of blocks of ice that resulted from the

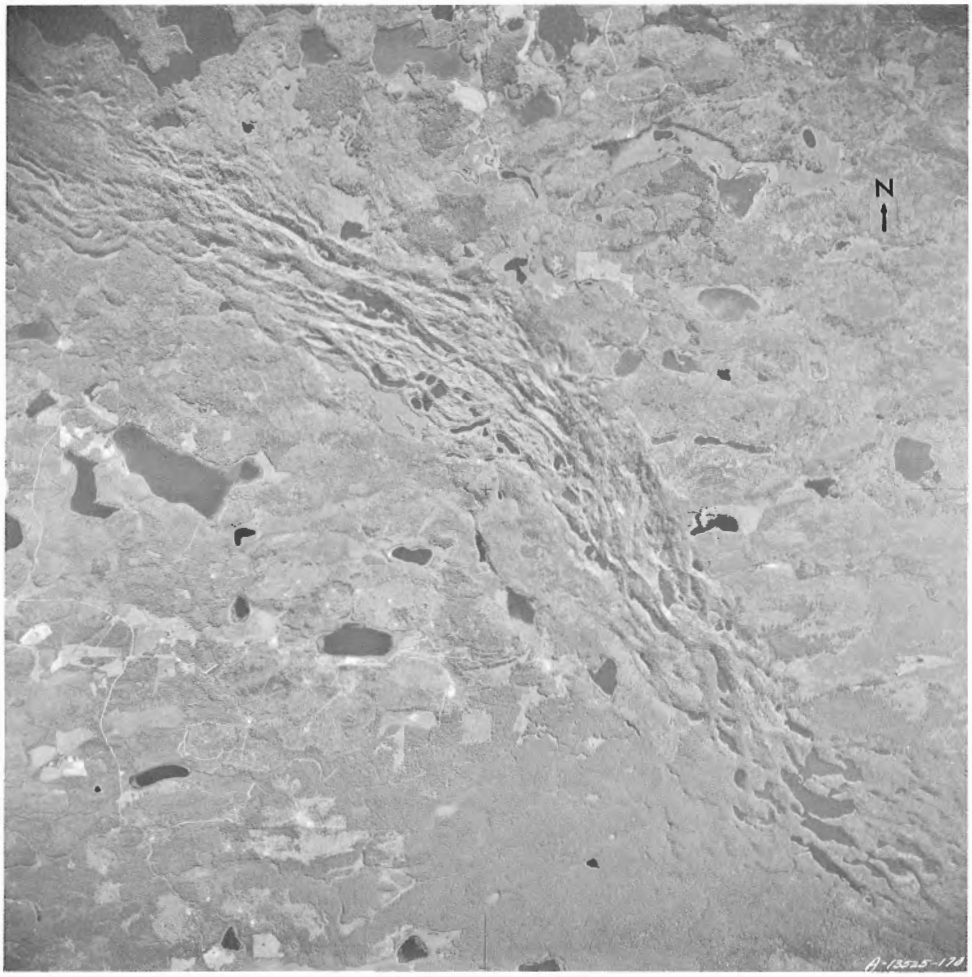

Figure 17. Stuart River esker complex, McLeod Lake map-area. The complex here has later lacustrine deposits (Prince George Lake basin) overlapping the lower part of eskers and covering them in the lower right hand part of the photograph. In lower left, the lacustrine deposits failed to completely mask the easterly trend of the older drumlinoid features. EMR Photo A13525-170

collapse of ice tunnels or possibly 'ice jams' along the channel. Sand and gravel deposited in the channel bottoms buried the blocks of ice. Melting of the ice left a network of esker ridges enclosing kettles and oriented subparallel to the course of the meltwater channel.

In general the eskers are more common on the steeper slopes whereas esker complexes commonly occupy broad low gradient valleys. Both eskers and esker complexes are more prevalent in areas of low to moderate relief than in high relief areas and in mountainous regions esker complexes are practically nonexistent. Although eskers and esker complexes may suggest areas of dead or stagnant ice, no generalization can as yet be drawn

from the evidence. In areas where ice probably stagnated, eskers and esker complexes are relatively common and in areas where ice appears to have retreated along a front of active ice, these features are rare. The rather close relation of eskers and esker complexes with meltwater channels confirms the usually accepted theory that they are built by glacial streams within ice-confined channels. Throughout the region eskers and, in particular, esker complexes are rather poor indicators of direction of ice movement.

MELTWATER CHANNELS

In all parts of central British Columbia meltwater channels are prominent and rival the drumlinoid and esker ridges in significance in an interpretation of the glacial history. It is neither the intent of the writer to offer a classification of meltwater channels nor to attempt to classify them according to existing systems (Derbyshire, 1962, p. 1122). However, in studying the channels on air photographs and in the field, four main categories seemed obvious and are referred to as, (a) esker channels, (b) lateral overflow channels, (c) direct overflow channels, and (d) major drainage channels. Some of the names have been borrowed from other writers (Kendall, 1902, Watson and Mathews, 1944) as there is no desire to introduce a new nomenclature.

The definitions of these four types of channels make no reference to size or shape but rather to interpreted position relative to the ice, their origin, and time of formation. Each can be of any size or shape but as a rule some are larger than others, for example the major drainage channels are usually larger than any other channel.

Esker Channels

Esker channels are those channels that are related directly to eskers and the meltwater streams that deposited them. They are usually short, occupying a position between two aligned eskers or at the beginning or end of an esker. Like the esker the channel was formed by meltwater flowing on, in, or beneath the ice and the channel represents an eroding part of the stream at the till-ice contact.

Lateral Overflow Channels

"Lateral overflow channels occur singly or in series and trend diagonally across the slope of the hillside... The interpretation is that the channels were cut by meltwater flowing between the ice-margin and the valley wall while the lower reaches of the valley were filled with ice. In some places the flow may have been submarginal...

" ... As the ice-margin retreated to lower levels early channels were abandoned and later ones cut at lower elevations. In this way the history of the valley-ward retreat of the ice-margin is indicated by a parallel series of channels that trace the change in form of the ice-tongue.

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"Lateral overflow channels are excellent indicators of the shape of the glacier but are commonly short and discontinuous. Several of them must therefore be joined on the map to delineate the shape of an ice-mass." (Fulton, 1967, pp. 9-10)

This account aptly describes a multitude of features throughout central British Columbia that are here interpreted as lateral overflow channels. Some may be subglacial in origin or be genetically related to esker channels, lacking only the esker. However, most are thought to have formed marginally or submarginally and would be classed as lateral overflow channels.

Most of these channels are oriented subparallel to the direction of ice flow and except in unusual circumstances the direction of downward slope of the channels would indicate the direction of ice flow. Such situations exist where ice flowed against the slope of the underlying till surfaces. At the front of the ice sheet or ice lobe meltwater could not flow directly away from the ice front but would flow subparallel to it, i.e. roughly at right angles to the direction of flow. The channels thus carved in the till roughly mark the position of the ice front. Successive parallel channels in places mark the ice front position at different times in the ice retreat (Figs. 19, 20, 21, 22).

These slightly different lateral overflow channels merge with one another and have in common an origin near the margin of the ice whether it be at the ice front or at the side of an ice lobe or sheet. These channels may merge also with major drainage channels or with direct overflow channels.

Direct Overflow Channels

Commonly the slope of the land was away from the ice front; meltwater discharging from the glacier took the easiest, most direct route away from the ice front (Fig. 23) and carved direct overflow channels in the glacial deposits or in bedrock. These channels contribute little information to our knowledge of ice retreatal history as they are not indicative of ice margin shape but may have been used continuously for the discharge of meltwater during the retreat of the ice for great distances. In any one channel however, upstream segments are younger than downstream.

Major Drainage Channels

On a broad scale most major drainage channels acted as direct overflow channels. Major streams such as Fraser, Chilcotin, North Thompson and the Nechako all flow in deep valleys eroded mainly in glacially deposited materials, till, outwash, and lacustrine deposits, which partly fill

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Figure 18. (opposite) Esker complex near Tatla Lake, Mount Waddington map-area. Complex is built on top of till plain and a later meltwater channel from Klina Klini valley has cut through it. Klina Klini River (left centre) flows northeasterly then turns sharply northwestward. This point marks the site of stream capture of the Klina Klini River that formerly flowed easterly beyond the photograph. EMR Photo A13795-147

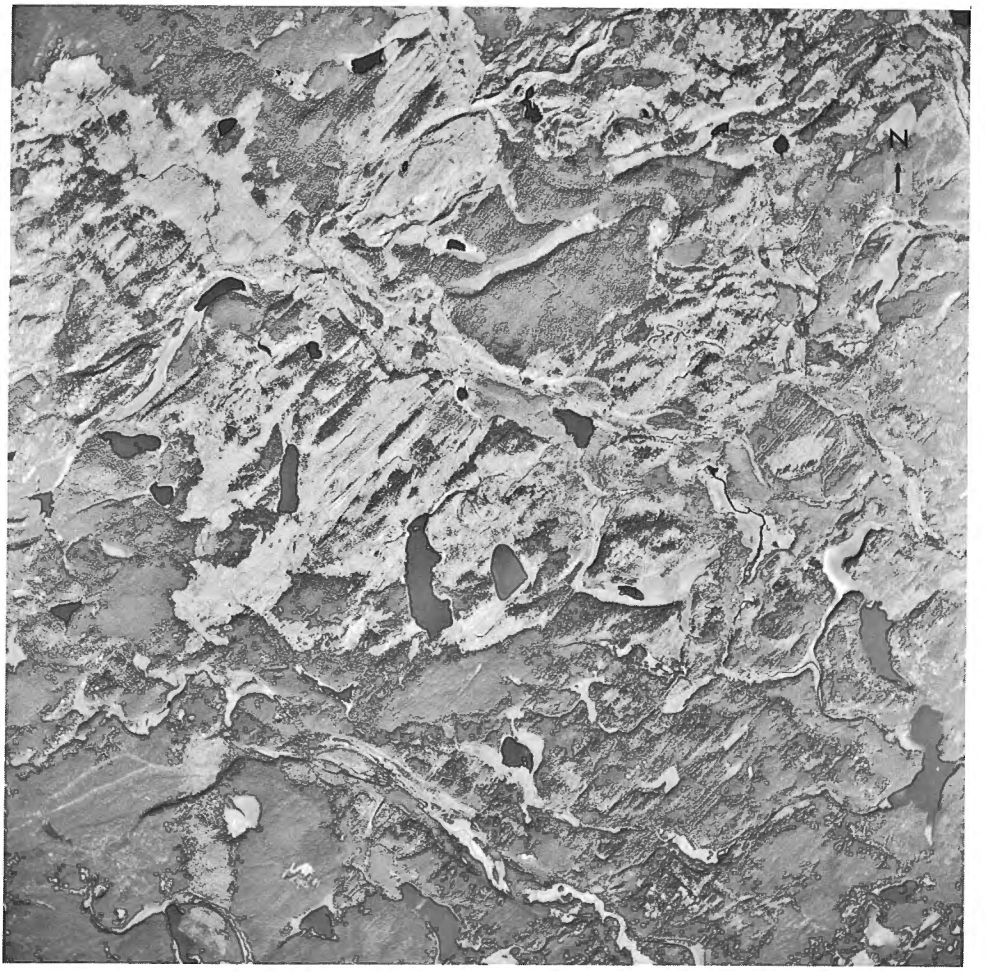

Figure 19. Lateral overflow channels west of Carp Lake map-area. The glacial ice moved up slope in a northeasterly direction over heavily drift-covered terrain. The irregular southeasterly trending channels represent ice front channels that mark the ice front at successive stages in the retreat of the ice. The esker at the top centre of the photograph and the northeasterly trending channels aligned with it represent a subglacial meltwater system in which the water flowed uphill, presumably under hydrostatic pressure. EMR Photo A15046-129

the pre-glaciation valleys. Kettles, eskers, and other ice contact features scattered along these valleys indicate occupation by meltwater. In some valleys erosion has continued from deglaciation to the present time; in others the streams could be described as underfit and so appear to carry less water today than during deglaciation.

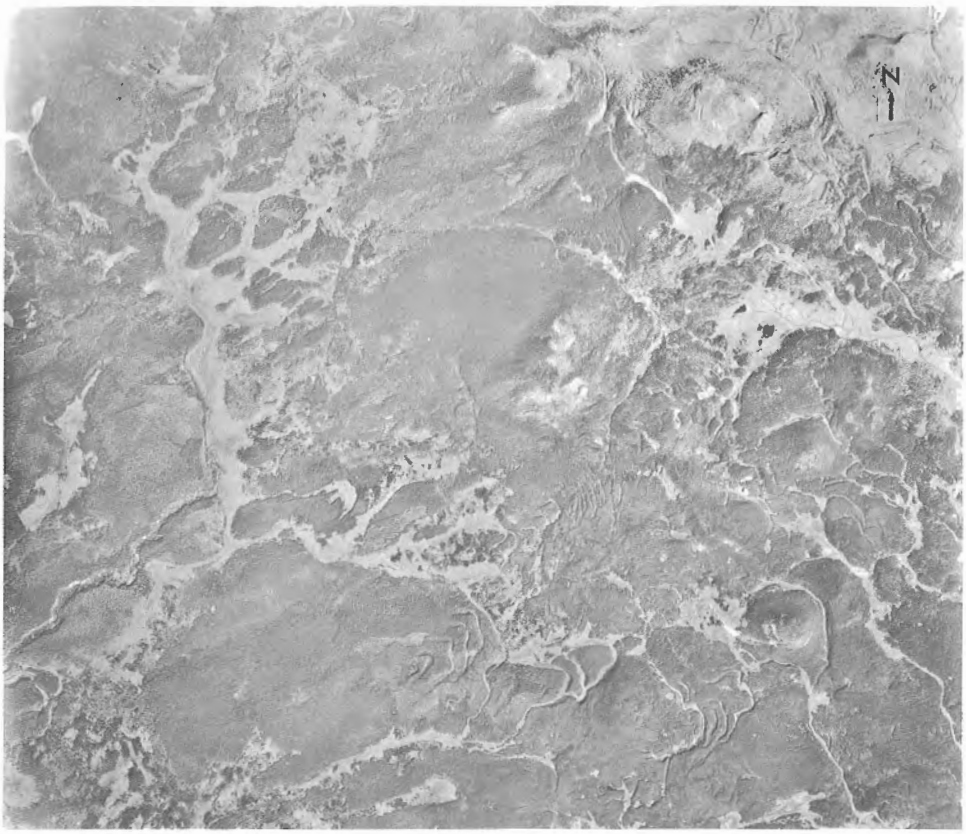

Figure 20. Lateral overflow channels southwest of Itcha Mountains, Anahim Lake map-area. The ice moved up slope northeasterly across photograph. Irregularly crescent-shaped channels in right centre of photograph are channels formed by meltwater flowing along ice front cutting into low till ridges. The crudely parallel channels mark successive stages in retreat of the ice margin. EMR Photo A18594-41

No attempt has been made to indicate on the maps the relative ages of the various meltwater channels. Obviously those formed in the first areas deglaciated are older than those nearer the source of the ice or those associated with later readvances. On the maps all have been represented by the same symbols.

KETTLES

In addition to those associated with esker complexes, kettles are widely distributed in all areas studied. This is not to say that kettles are equally prominent in all regions; they may be relatively few and scattered,

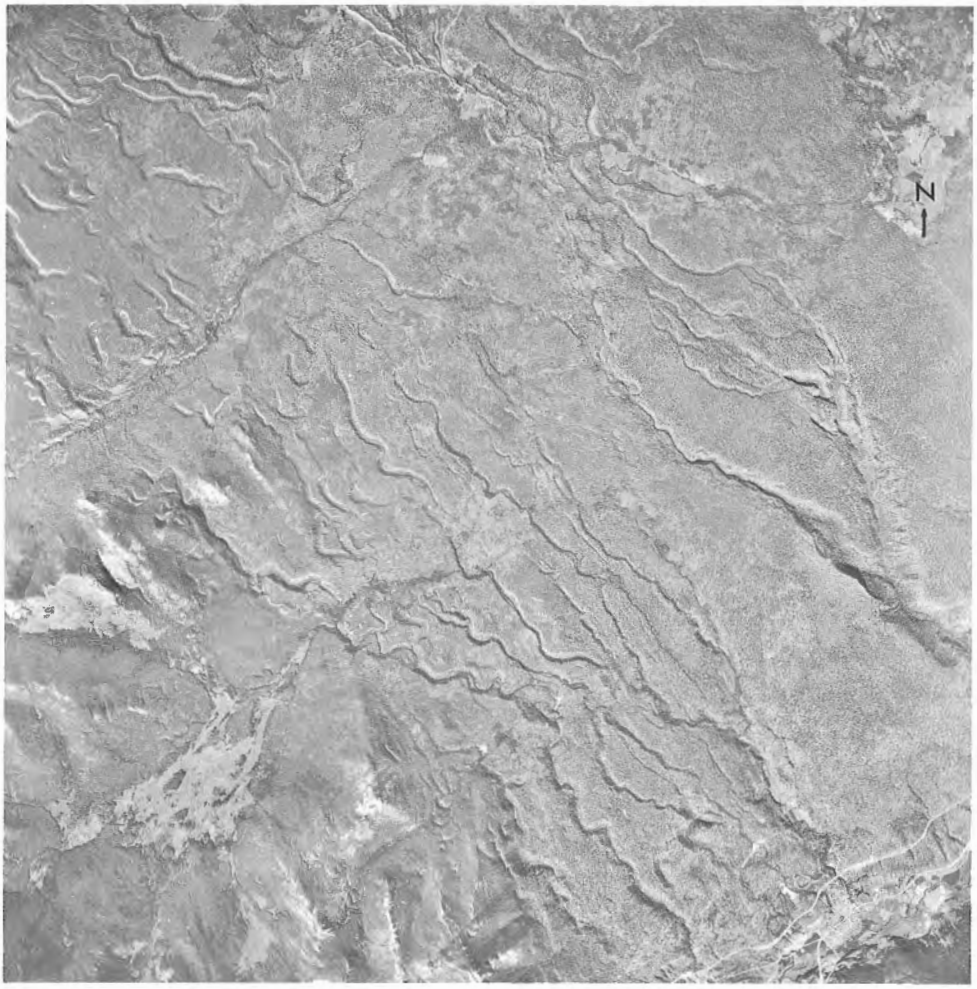

Figure 21. Lateral overflow channels on northeast side of Marble Range, Bonaparte Lake map-area. Each channel represents the position of the ice margin at different stages as the ice sheet thinned and drew back from the mountain flank. Top centre of photograph, eskers are part of the meltwater system indicating subglacial flow in part. EMR Photo A13320-19

or common and closely spaced. Although local conditions may have contributed to their formation and origin, basically kettled deposits have formed in the usual manner, the burial and subsequent melting of blocks of ice.

The size of the kettles varies greatly. Many are as much as 3 or 4 miles long, possibly longer, many are only a few tens of feet across. In general kettles of a few hundred feet in diameter are the rule. The shape is, of course, largely dependent on the shape of the block of ice that was buried, and is commonly circular in plan or roughly equidimensional.

The significance of kettled deposits as indicators of deglaciation history is not entirely understood. Kettles are not common in areas which from the presence of well-defined drumlins and lateral overflow channels are thought to have been deglaciated by normal retreat of the ice front. In areas of ablation moraine and stagnant ice kettled deposits are abundant. They also abound, as would be expected, in end moraines and outwash areas related to late glacial advances and valley glaciers, younger than the main ice sheet (Fig. 24).

MORAINES AND DRIFT RIDGES

The occurrence of well-defined ridges thought to mark significant ice frontal position has not been noted in central British Columbia. It is possible these features are present but are not sufficiently large to show on air photographs or to have been noticeable in the course of field work without detailed studies. As yet no end moraines have been recognized associated with the advance and retreat of the Fraser ice sheet. In some places end moraines may have been destroyed by ice front meltwater channels but if so some parts of the moraine, if it were prominent, would still be recognizable. Some of the late glacial advances and the valley glaciers are marked by distinct moraines recognizable from air photographs and on the ground. These will be mentioned further in describing the map-areas.

Drift ridges have been delineated on air photographs in a few places, and their origin is somewhat in question. They are low, fairly straight and have a relief of 5 to 15 feet and a length of two to three miles. They lie parallel to each other, separated by a shallow depression a few hundred yards wide. On the ground they are not obvious but from air photograph are recognizable as corrugations on the till surface oriented mainly at right angles to the direction of ice movement. Other low drift ridges lie along valley walls parallel or subparallel to the ice flow but these may be kame terraces or lateral moraines. The transverse drift ridges may be any of several types described by Prest (1968, pp. 3-8). Of these the De Geer moraines, including washboard or annual moraines at least superficially resemble these drift ridges. However no attempt will be made to classify them; only their existence is pointed out.

LACUSTRINE DEPOSITS

Near Prince George and west and south thereof, glacial lake deposits have been recognized both in air photographs and on the ground. They were deposited during deglaciation in basins formed by ice blocking the natural drainage of the area. Deposits of other small proglacial lakes have been recognized throughout the area and will be briefly mentioned in describing the individual map-areas. In general the glacial lakes were not extensive, being confined mainly to the fairly deep and narrow valleys

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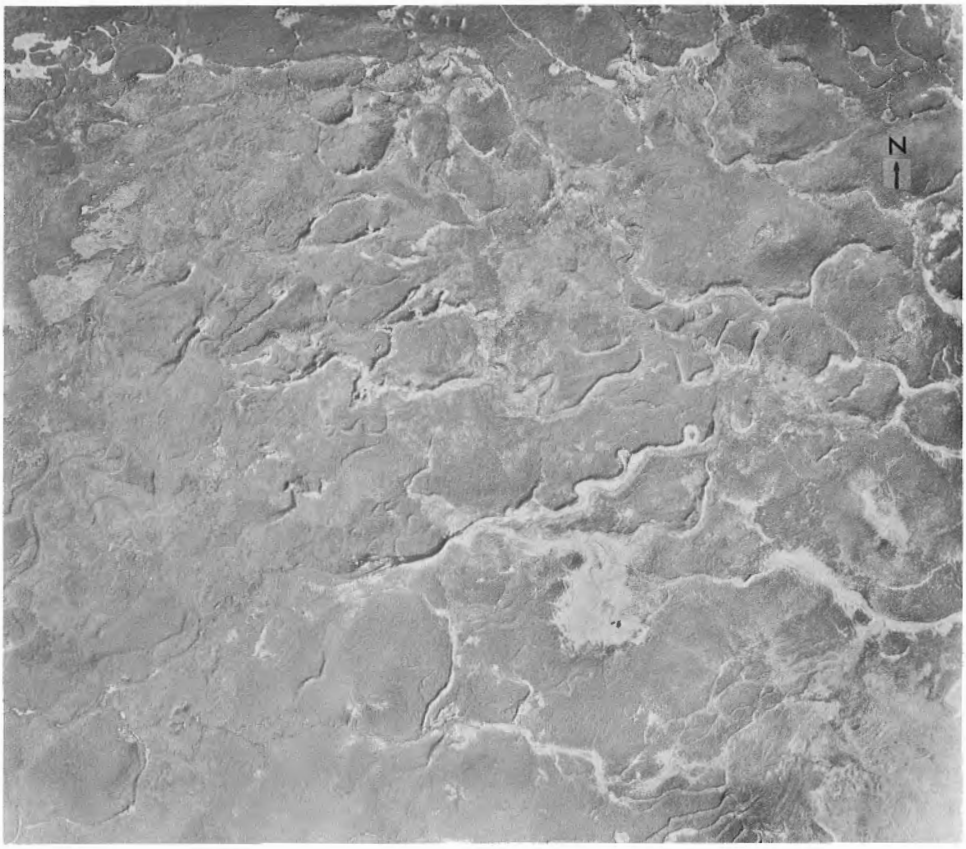
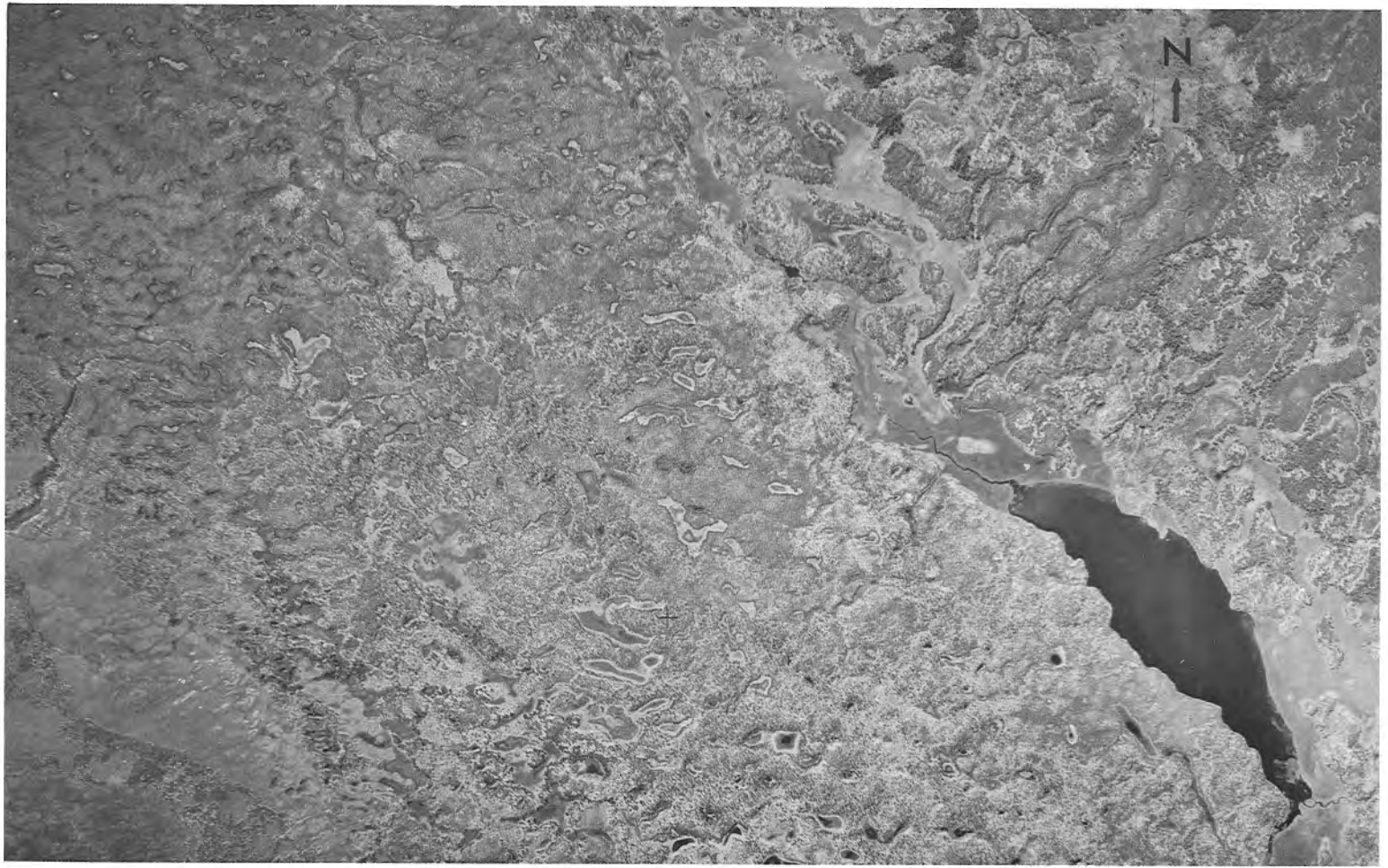


Figure 23. (Above) Direct overflow channels south of Itcha Mountains, Anahim Lake map-area. The several channels trending easterly were carved by meltwater issuing from an ice front that was along a north-south line left of centre in the photograph.
EMR Photo A18594-44

Figure 22. (opposite) Lateral overflow channels marking the margin of late ice advance on Ilgachuz Mountains, Anahim Lake map-area.
EMR Photo A11538-316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characteristic of the region. The deposits of these lakes comprise mainly silt, sand, and clay. Well-developed typical varves are present, particularly near Prince George. In a few places varve-like deposits have individual layers one foot thick. Shorelines of the lake basins are not well-developed except near Prince George (Fig. 25).

CIRQUES

Cirques are only prominent in the Coast Mountain area of the map-areas studied. In the Interior Plateau a few cirques are known on some of the isolated ranges; some of these are apparently older than the last ice advance. Only in the Coast Mountains, and there mainly in the central part of the belt, are there any cirques with active ice or ice fields of consequence. All cirques in the Interior Plateau, and even in the marginal ranges of the Coast Mountains are free of ice.

ERRATICS

Erratics have been used to a very limited extent in determining the direction of ice movement and limits of advance. The great diversity of bedrock geology through central British Columbia permits reasonable accuracy in determining the provenance of some erratics. For example, the distinctive Paleozoic quartzites of the Cariboo Mountains stand out in the drift of the Interior Plateau where no such rock types are present and their limit of distribution is interpreted as the limit of advance of Cariboo Mountain ice. Much more use of this tool can be made in future.

SYNOPSIS OF THE GLACIAL HISTORY

Before describing the individual map-areas, an outline of the writer's concept of the glacial history will be given to permit a clear understanding of the position and importance of each area in the evolving picture (Fig. 26). The evidence for this concept will not be given here but will unfold subsequently in the description of the areas. Although this synopsis refers specifically to the last glaciation it is thought that the glacial history of the area was roughly similar in each preceding glaciation. Much of the basic information is already known from other publications (Armstrong and Tipper, 1948; Prest, Grant, and Rampton, 1968; Fulton, 1963).

Figure 24. (opposite) Pitted terrain near Aktaklin Lake, Anahim Lake map-area. The area shown is part of the broad terminal moraine of the late glacial readvance. EMR Photo A11561-146

Figure 25. Shoreline of Prince George glacial lake marked by beaches (dashed line), Prince George map-area. Drumlinoid forms produced by northeast-moving ice sheet terminate at the beaches. Northeast of the beaches lacustrine deposits mask the older drumlinoid features and have a featureless surface. Fraser River has carved a new channel through the lake deposits. EMR Photo A13959-200

Glacial ice accumulated on the mountains ringing the Interior Plateau, formed valley glaciers, coalesced to form piedmont glaciers, and eventually covered all central British Columbia, with what has been referred to as the Cordilleran Ice Sheet. Ice flowed off the Coast Mountains easterly, northeasterly, and northerly and extended at least to Fraser River. In this general area it met or coalesced with ice flowing southerly, westerly, northwesterly and northerly from the Cariboo Mountains and the single mass

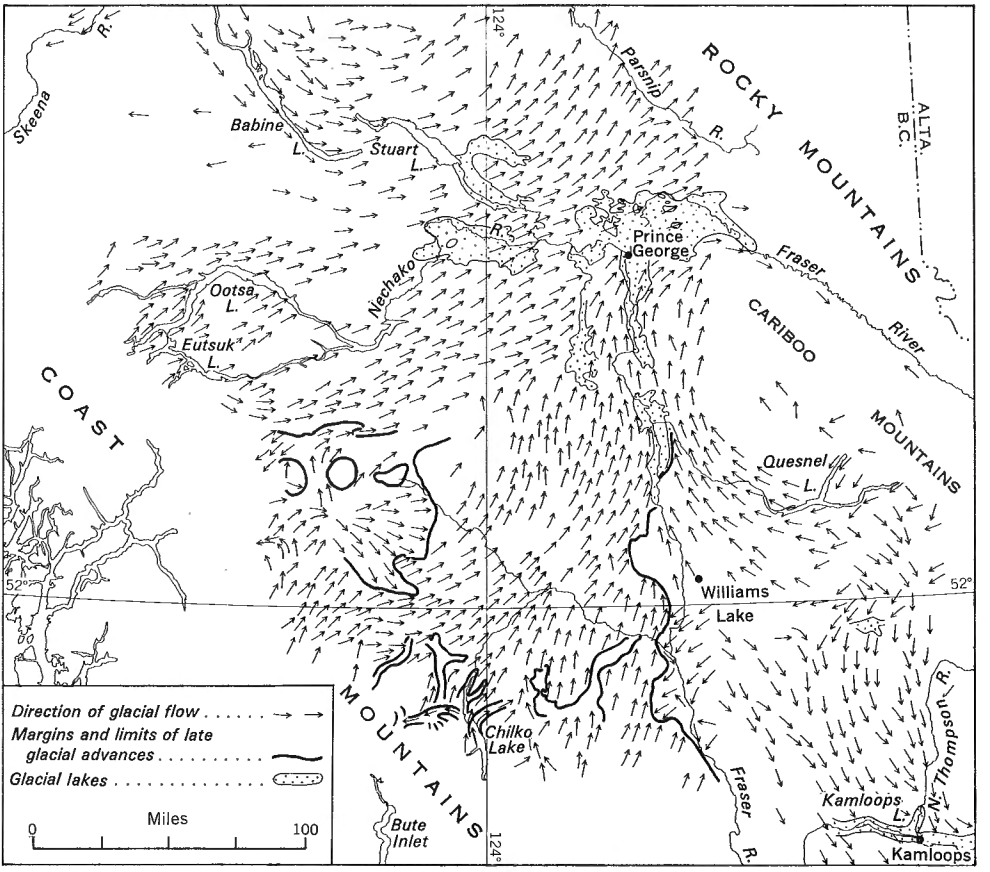

Figure 26. Direction of ice movement in central British Columbia of Fraser ice sheet and late ice readvances.

pushed northeasterly into Parsnip River valley. Northeast of Parsnip River, the ice sheet encountered the Rocky Mountains and was diverted northerly toward the Peace River and southeasterly along the upper Fraser River.

During deglaciation, the ice sheet thinned and retreated along a front in the low-relief northern part of the area around Prince George. In the hillier part of the central region ice flow was controlled by topography as the ice thinned and eventually broke up into isolated masses of stagnant or dead ice that wasted in situ. Near the mountains normal ice front retreat with final reduction to valley glaciers apparently occurred.

Late in the glacial history there was a temporary readvance of glacial ice. A lobe advanced over much of the Anahim Lake map-area, in Taseko Lakes map-area valley glaciers advanced into the Interior Plateau, and along the west side of the Cariboo Mountains ice readvanced westerly to and across Fraser River and flowed northerly toward Quesnel and southerly

toward Kamloops. These late advances are marked in several places by well-defined terminal features. Final deglaciation in the Interior Plateau was by normal retreat of the ice lobes and tongues and by isolation of large masses and stagnation.

No attempt has been made to correlate ice advances of central British Columbia with Wisconsin or earlier glaciations. The last advance around Prince George has been called Fraser Glaciation (Armstrong and Leaming, 1968, p. 152) and is the glaciation that has produced the bulk of glacial features seen in British Columbia. It covered most of the province and all of Interior Plateau and in this report will be referred to as the Fraser Glaciation or ice sheet. The limited advance of ice later than Fraser Glaciation will be referred to as late glacial readvances or late ice advance fully realizing that these are probably late phases of Fraser Glaciation. All glaciations prior to Fraser Glaciation are mentioned only as earlier glaciations. Detailed stratigraphic studies, radiocarbon age dating, and dating of volcanic ash falls will in future permit precise correlations with glaciations in other areas.

Practically all the glacial features visible in air photographs were produced during deglaciation. A basic assumption in this report is that the direction of ice movement during deglaciation of the Fraser ice sheet and of the late readvances closely parallels the direction of ice movement during the advances. The direction of ice movement during initial stages of accumulation and during final deglaciation were strictly controlled by topography and even at its maximum the ice sheet was confined to the Interior Plateau by the encircling mountain ranges. At no time during these glaciations was it thick enough to be completely free from topographic influence. As the ice thickened this influence declined but as the ice thinned topography reasserted its influence and to a degree deglaciation recapitulated, in reverse order, the events of the advancing stages. This basic assumption is applicable only to Fraser Glaciation and late glacial readvances; as will be explained later, earlier glaciations may not conform to this assumption.

DESCRIPTION OF MAP-AREAS

The accompanying maps (in pocket) depict symbolically the glacial features of central British Columbia. Many of the symbols do not refer specifically to one feature. For example the drumlin symbols do not necessarily reflect the trend of a single drumlin but may indicate the trend of one or of several drumlins. The relative abundance of symbols for drumlins, rock drumlins, and glacial grooves is, in a general way, a representation of the local abundance and proportion of these features. On the other hand, the symbols for cirques and meltwater channels outline individual features as do eskers and lake basins. Kettled deposits, esker complexes, and drift ridges are symbolically represented. The map-scale precludes any attempt to represent every glacial feature in proportion and to scale.

McLEOD LAKE MAP-AREA

McLeod Lake map-area (see Fig. 1 and Map 1287A) is the most northerly map-area examined by the writer and within it is the terminus of the Fraser ice advance. Physiographically it lies mainly within the Nechako Plateau and Nechako Plain (Fig. 2). The Rocky Mountain Trench cuts southeasterly across the northeast quarter separating the Rocky Mountains to the northeast from the hilly McGregor Plateau. In general therefore it is an area of low relief that becomes hillier to the northeast and rises abruptly to mountainous terrain on the northeast side of the Rocky Mountain Trench.

The map-area was overridden by the Fraser ice sheet moving across the area in a northeasterly direction varying from N15°E in the northwest corner to N75°E in the southeast part. It extended to the Parsnip River and was diverted northerly and southeasterly by the Rocky Mountains. The ice retreated by fairly uniform retreat of the ice front and the successive positions of the ice margin are more or less defined by lateral overflow channels. In the southeastern and western parts glacial lakes were impounded by ice and glacial drift blocking the normal southerly drainage forcing northerly drainage to Peace River. Final melting of ice blockages, far beyond the area, permitted re-establishment of the Fraser River drainage pattern.

Another ice sheet, earlier than that described apparently overrode the Rocky Mountains, presumably in a northeasterly direction. This earlier ice must therefore, have been thicker and of greater extent.

Drumlins, Rock Drumlins, Glacial Grooves, and Glacial Striae

All of these features combine to give a well-defined picture of the direction of ice movement, the best illustration to be found in central British Columbia. These features are prominent and well-formed except northeast of the Rocky Mountain Trench and in areas of younger lake deposits. A northwest-trending belt of metamorphic and volcanic rocks in the north-central part of the map-area has provided ideal conditions for the production of closely spaced, typical rock drumlins (Fig. 11). In the south-central and southwesterly parts of the area well-formed drumlins abound in an area of flat-lying volcanic rocks, soft sedimentary rocks, and heavy drift (Fig. 10). South of Tacheeda Mountain near the Rocky Mountain Trench, glacial grooves suggest a local movement of ice. In the northwest, west of Mount MacKinnon, topography apparently influenced the direction of ice movement.

The area northeast of Parsnip River contrasts markedly with the area to the southwest. In the former the Rocky Mountains do not exhibit the outstanding drumlinoid forms of the Nechako Plateau and although there are a few areas of glacial grooves indicating direction of movement there is little to suggest sense of movement. These glacial grooves occur on rounded shoulders and summits, commonly above treeline, at elevations between 5,000 and 5,500 feet, and in one place above 5,800 feet. They are less distinctly defined than any other grooves in the map-area, suggesting that they are older. The ice that produced them must have been an ice sheet rather than valley glaciers as the direction indicated by the grooves is consistently northeast. The coincidence in direction of these glacial grooves and the drumlinoid forms of the Nechako Plateau does not argue for production by the same ice sheet; any successive ice advances in the same area would be expected to take roughly similar courses.

The drumlinoid forms of the Nechako Plateau, when viewed over a wide area suggest that the Rocky Mountains formed a barrier to ice advance and were instrumental in diverting ice down Parsnip River and up Fraser River. This diversion is suggested in this area near the Rocky Mountain Trench; in the adjoining areas to the north (Pine Pass) and east (Monkman Pass), studied briefly in air photographs, this diversion is more pronounced and obvious.

Eskers and Esker Complexes

Many esker complexes and a few single eskers are widely distributed in the map-area. Two of them have been named by Armstrong and Tipper (1948, pp. 292-299) as the MacKinnon compound esker, about 10 miles west of Carp Lake, and the Stuart River compound esker that crosses the south margin of the map-area at 123 degrees W (Fig. 17). Several other complexes, almost equally as prominent, are related to the several large meltwater channels, commonly direct overflow channels, such as occur between Merton Lake and Tacheeda Lakes, northeast from Weedon Lake and northeast from Carp Lake.

In general most eskers and esker complexes are parallel or subparallel to the direction of ice movement and have been formed by streams flowing in the same sense of direction. The main exception is the Stuart River esker complex which takes a course that in places is almost at right angles to the ice flow.

Meltwater Channels

McLeod Lake map-area is laced with a complex of interconnected meltwater channels of several types that vary in width from two or three miles to a few feet. They are conspicuous on air photographs and readily apparent on the ground. They offer much information regarding the glacial history of this area.

A topographic high trends southeasterly through Carp Lake and illustrates the effect of topography on the development of lateral overflow channels and direct overflow channels. Southwest from Carp Lake the general slope of the land is southwesterly or southerly for about 50 miles as far as Stuart River. Ice flowing over this area in a northeasterly direction was flowing uphill. Many meltwater channels, both large and small trend across this slope in a southeasterly direction. These channels are cut into drift and are not bedrock controlled. The normal direction for water to flow off this surface prior to the erosion of the channels would have been generally southwesterly or southerly and hence a means must be envisaged to control the direction of flow in an unnatural course. This control, in the writer's opinion, was the ice front which lay at right angles to the direction of ice movement and forced meltwater to take a course along the ice front and across the opposing slope of the land. The many channels southwest of Carp Lake that trend parallel or subparallel to each other in a southeasterly direction represent successive positions of the ice front in the normal retreat of the ice (Fig. 19). The larger channels possibly represent a static ice front for a longer period of time. A careful examination of the area will reveal a

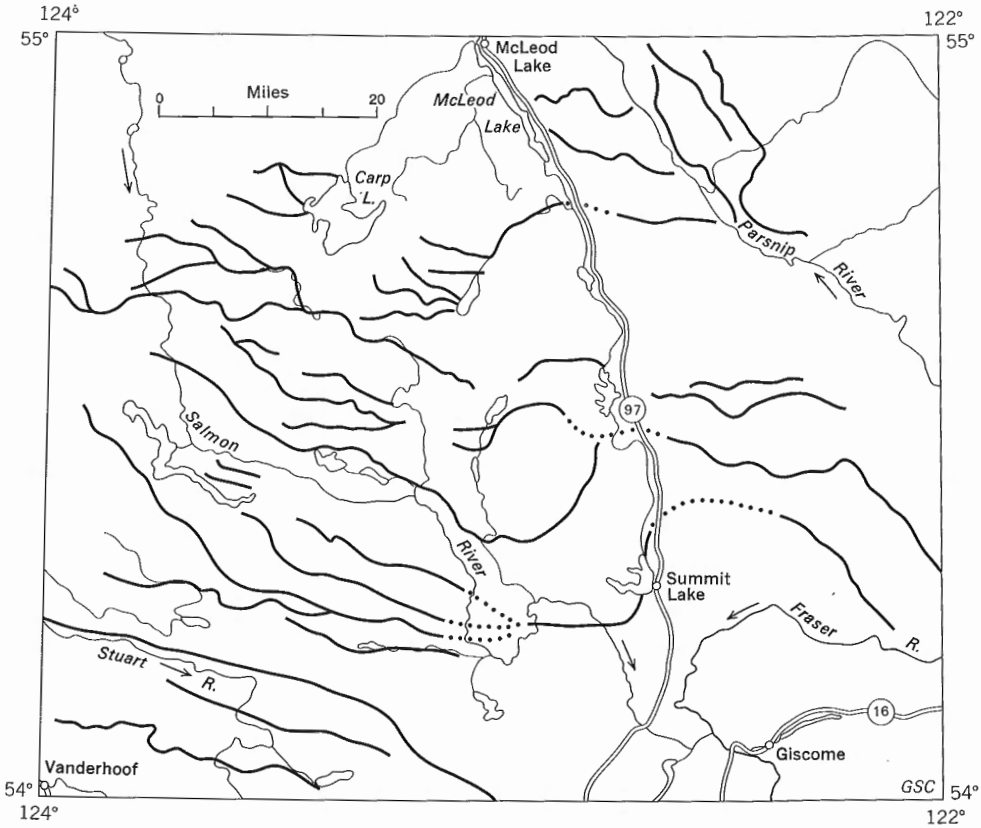

Figure 27. Various positions of ice front during recession in McLeod Lake map-area as suggested by lateral overflow channels. Ice front retreated southwesterly.

multitude of such lateral overflow channels lying at right angles to the direction of ice flow and having an abnormal course. For this reason it is the writer's contention that the ice front retreated from Parsnip River southwesterly beyond the southwest corner of the map-area in a manner compatible with a hypothesis of normal retreat of the ice margin. The successive positions of the ice front during retreat can be determined by reference to the lateral overflow channels (Fig. 27).

Northeast of Carp Lake and the topographic high mentioned previously, the land slopes northeast in the direction the ice flowed. Here large meltwater channels parallel or subparallel the direction of ice movement and are believed to be direct overflow channels. They appear to follow the natural slope of the land and have been formed by meltwater discharging directly from a retreating ice front. A few small meltwater channels at right angles to the direction of ice movement are considered to have been lateral overflow channels that reflect minor reversals in the slope of the land. The direct overflow channels are the predominant type where the slope was away

from the ice. Many of these occur in the area wherever the slope of the surface permitted free flow directly away from the ice front.

Along Parsnip River several large meltwater channels oriented at right angles to the ice flow parallel the river in a northwesterly direction. They lie along the northeast limit of the area displaying the outstanding drumlinoid features and are interpreted as lateral overflow channels defining the maximum advance of the Fraser ice sheet. Here the meltwater apparently escaped northwestward to the Peace River valley. Although the channel in which Parsnip River is flowing probably had its origin as a lateral overflow channel, continued use of the channel for discharge of meltwater from a retreating glacier as well as normal runoff, has deepened and accentuated it and now could be classed as primarily a major drainage channel. The three channels extending out of the Rocky Mountains are related to valley glaciers and to a large extent are floored by outwash.

The channels that lie along Salmon River in the central west half and along Crooked River north of Summit Lake are direct overflow channels from glacial lakes. The Crooked River channel probably acted as a spillway long after the ice retreated from the area as the glacial lake basin it drained, as will be pointed out later, maintained its levels for a long time. This extended use has removed fine sediment from the channel leaving coarse sand and gravel. In this valley the Crooked River is a misfit stream.

The channel through which Fraser River flows is a major drainage channel cut into the glacial lake deposits of the southeast quarter. Thus it is a relatively late feature formed after the draining of the glacial lake but presumably while glacial ice remained in parts of central British Columbia resulting in the discharge of abundant meltwater into the Fraser River system thus eroding the channel. The branch channel through Eaglet Lake presumably was an early course of this channel that was abandoned in favour of the present course of the river.

Lake Basins and Lacustrine Deposits

Four main areas of lake deposits are shown on the map, one in the southeast quarter and three along the western margin of the map-area. These deposits were laid down in basins formed by the blockage of normal drainage channels by glacier ice or by glacial deposits. Melting of the ice and erosion through the drift obstructions permitted draining of the lakes and exposure of the deposited material - silt, sand and clay. The characteristic sediment is varved with a coarse facies, probably representing beach deposits, occurring in places around the basin margin.

The basin with lacustrine sediment along Stuart River and around Great Beaver Lake has been referred to as the Fort St. James Basin, that in the southwest corner as part of the Vanderhoof Basin, and that in the southeast quarter as the Prince George Basin. The Fort St. James and Vanderhoof Basins drained easterly into the Prince George Basin which in turn drained northerly by way of Summit Lake and Crooked River to the Peace River, or possibly for a time by a connection east of the map-area to Parsnip River and thence to Peace River. The level of the Prince George Basin was maintained by a bedrock lip at Summit Lake. This northern drainage persisted until the ice blocking the Fraser River permitted re-establishment of normal southerly flow and emptying of the basin. The western glacial lakes

apparently formed behind drift dams and the basins were drained when these dams were removed; no bedrock lip is known at the outlets of those glacial lakes.

The thickness of these glacial lake deposits is unknown but more than 400 feet has been suggested by Armstrong and Tipper (1948, p. 300). Many parts of the basins have shallow deposits, islands of till rise above the lacustrine deposits, and in places older features such as drumlins and eskers were covered by a thin veneer of silt and clay, insufficient to obliterate their form. The Prince George Basin in particular had many islands, the margins of which may be marked by beach deposits.

Kettled Deposits

Except in esker complexes, kettled deposits are not characteristic of the area. Such deposits are common along the Rocky Mountain Trench, possibly associated with terminal moraine deposits. In the eastern part of the Prince George Basin and in parts of Vanderhoof Basin the kettled lacustrine deposits are noted but their significance is not apparent. Elsewhere in the area, kettled deposits are uncommon. The writer uses their paucity as further evidence against a theory of ice stagnation.

Cirques

The only cirques in the map-area are on the northeast slopes of the Rocky Mountains between 4,500 and 5,500 feet elevation. These are ice-free and sharply defined. They appear to be younger than any ice sheet that may have crossed the range but whether they were associated with the Fraser ice sheet or with a more recent climatic deterioration is open to question.

PRINCE GEORGE MAP-AREA

The Prince George map-area (see Fig. 1 and Map 1288A) lies directly south of McLeod Lake map-area. Physiographically it is within the Interior Plateau and includes parts of Nechako Plateau and Nechako Plain in the northern two thirds and part of Fraser Plateau in the southern one third. In general it is hilly in the south, east, and west merging with a rolling plateau and plain in the north. The Fraser, Nechako and Blackwater Rivers have incised deep channels well below the plateau surface.

The map-area was overridden by the Fraser ice sheet that in its final stages entered the area from the west and south (Coast Mountain ice) and from south and southeast (Cariboo Mountain ice). This sheet flowed northerly and northeasterly across the area and veered sharply eastward near the latitude of Prince George. Hills including Mount George and south thereof were not covered. Glacial features – particularly drumlins, glacial grooves, eskers and esker complexes, and meltwater channels – are abundant throughout the area delineating the direction of flow, N10°E in the southwest part, N55°E in the west-central part, N75°E in the north-central part, and N80°E to due east in the northeast part.

Topography had a distinct effect on the ice movement. In the southwest quarter it is apparent that ice entering the area was flowing around higher areas to the southwest. Southeast of Prince George ice apparently split on the range of hills of which Mount George is the northern summit. Although all the area was glaciated at some time there is a suggestion that the summits of this latter area were above the Fraser ice sheet; a few glacial grooves suggest direction of ice movement contrary to the overall pattern.

Manner of deglaciation varied in different parts of the area. The central and eastern parts of the area give little evidence to suggest anything but a normal retreat of ice along a front. The western third of the area has many eskers, kettled deposits, and meltwater channels that suggest a complex history of normal retreat in part with well-defined ice front channels but also stagnation and melting in situ of large masses of ice. In the northwest, limited readvance and retreat is suggested.

Ice retreating southward along Fraser River ponded at its margin a large proglacial lake around Prince George and southward; another lake was ponded by drift in the northwest quarter. The lake in the Fraser River valley became larger as the ice retreated but maintained a constant level and flowed northerly into the Peace River drainage. Melting of the ice dam permitted rapid drainage of the lake and dissection of the lake deposits by the re-established major drainage systems.

Recent work by Armstrong and Leaming (1968, pp. 151-152, 1969) has provided more detailed information on the surficial geology of Prince George map-area. Several conclusions were reached regarding the Quaternary stratigraphy and chronology. Four till sheets were recognized along Fraser River north of Quesnel and in places intertill deposits were recognized. This was interpreted as suggesting more than three major glaciations. They further concluded that "at least 95 per cent of the glacial deposits exposed at the surface were laid down by the last major Cordilleran glacier during Fraser Glaciation" (Armstrong and Leaming, 1968, p. 151).

Drumlins, Rock Drumlins, and Glacial Grooves

The Prince George map-area is heavily drift-covered and drumlins and glacial grooves in drift are more common than rock drumlins. Only in an area east of Prince George and in the west-central part of the map-area are rock drumlins abundant, developed particularly on resistant volcanic rocks. The area as a whole does exhibit drumlins, rock drumlins and glacial grooves almost everywhere that clearly show the direction of last ice flow across the area. The best developed drumlins are in the central part of the map-area where a combination of heavy drift, topography of moderate to low relief, and fairly readily eroded bedrock has produced a broad area of drumlins with low or moderate relief but with well-defined intervening depressions.

Glacial grooves and drumlins are recognizable in two areas of lacustrine deposits. South of Prince George drumlins older than the lacustrine deposits are reflected through a shallow mantle of lake silts. In the northwest quarter, lake deposits were overridden and grooved by a later ice advance. This will be discussed further under lacustrine deposits.

Eskers and Esker Complexes

Esker complexes are fairly common in the area but individually are not as large as in McLeod Lake area. The southeast end of the Stuart River esker complex extends from the northern margin of the map-area to Prince George. Between Cluculz Lake and Bednesti is a maze of esker ridges, kettled deposits, and meltwater channels that has been called the Bednesti compound esker (Armstrong and Tipper, 1948, p. 299). Along the upper Blackwater River and its tributaries and in the northeast quarter, east of Willow River, there are esker complexes that are confined to large meltwater channels.

Single eskers are fairly common in the west half of the map-area but elsewhere are uncommon. Several good examples of merging eskers and esker channels illustrate their common origin. The few eskers present are well developed, several are more than four miles long, and may suggest local stagnation of ice.

Meltwater Channels

The map-area is dissected by major drainage channels. The valleys of Fraser, Nechako, Blackwater, Nazko and several tributary streams are fairly late features in the glacial history but, for the most part, are deeply incised and have been major direct overflow channels as well as the drainage system for normal run-off. Some of these channels, particularly Blackwater River, clearly show their glacial beginnings by the presence of eskers and kettles along their course.

Direct overflow channels oriented down-slope and subparallel to ice movement are readily recognized; good examples are south of Pantage Lake and southeast of Sinkut Mountain. Lateral overflow channels oriented at right angles to the direction of ice flow are found north of Chilako River west of Punchaw and in the valley of Euchiniko River.

Glacial Lake Basins and Lacustrine Deposits

Two main lake basins present in the map-area; (1) the Prince George Basin along Fraser River and its tributaries and (2) the Vanderhoof Basin (Armstrong and Tipper, 1948, p. 299) along Nechako River in the northwest quarter.

The Vanderhoof Basin extends beyond this map-area to McLeod Lake (93J) Nechako River (93F), and Fort Fraser (93K) map-areas. Its water level was slightly above 2,500 feet elevation and its basin was a depression of irregular shape in the till surface. Although ice may have been partly instrumental in blocking the drainage of the lake, it is thought to have been mainly a till dam, which, when breached, permitted the draining of the lake along the present course of Nechako River to the Prince George Basin. The length of time the lake lasted after the removal of ice is unknown. The Bednesti esker complex may have been involved in the drainage from the basin in the initial stages of the proglacial lake. The deposits of the basin are mainly typical varved silt, clay and sand.

In places the surface of the Vanderhoof Basin deposits are distinctly drumlinized and grooved with linear features parallel to the regional direction of ice movement. Pebbles and cobbles have been noted in these lacustrine deposits and previously were interpreted as ice-rafted material (Armstrong and Tipper, 1948, pp. 300-302). Although ice-rafting of pebbles may have occurred in places, the writer no longer subscribes to this theory to explain the presence of most of the pebbles. In several road-cuts along Highway 16 that crosses this lake basin, varved clays are well exposed in short sections. The lower part of the section is commonly evenly bedded, flat-lying, and lacking pebbles. The upper few inches, up to 18 inches, displays a section of contorted and disturbed varves that include pebbles at the surface. The transition from undisturbed varves to deformed varves is gradual. The writer now attributes the presence of pebbles, the grooving of the deposits, and the deformation of the varved deposits to a temporary readvance of the ice; the upper few inches of the deposits with the pebbles represents a thin till deposit. The extent of the readvance is not known definitely but the northern part of the basin does not appear to have been overridden.

The glacial lake level in the Prince George Basin generally lay below the 2,500-foot level and was largely formed by ice blockage to the south of Fraser River and its tributaries. South of Prince George the margin of the basin is well-defined by beach deposits, particularly west of Tabor and north of Buckhorn Lake. The drumlin and glacial groove symbols shown within the area of lake deposits southwest of Buckhorn Lake and elsewhere are thought to be the reflection of a drumlinized surface through a thin lake deposit.

The material of this basin is varied. Near Prince George, silt and clay deposits that are over 400 feet thick and which in section display typical varve structure predominate. In places north of Prince George varves one foot thick were noted. The basin-fill along Blackwater River is more than 600 feet thick and consists of surface sand overlying thick silt. Elsewhere in the basin the sediments are varied but silt predominates, sand is locally abundant, and clay is commonly of minor importance.

The lake that formed in the Prince George Basin was a proglacial lake prevented from draining southward by the ice sheet and forced to escape northward by way of Summit Lake, Crooked River and Parsnip River in McLeod Lake map-area to the north. The level of this lake was controlled by the bedrock lip at its outlet at Summit Lake. The present elevation of this lip is 2,316 feet and presumably during the life of the glacial lake was slightly less than 2,500 feet to correspond with the elevation of lacustrine and beach deposits around Prince George (Fig. 25). As the ice retreated southward the lake would enlarge but would maintain a constant level until the ice in the Fraser River valley melted and the lake was drained. The lake extended far south of the Prince George map-area at its maximum.

NECHAKO RIVER MAP-AREA

The Nechako River map-area (see Fig. 1) lies west of Prince George map-area and is entirely within Nechako Plateau. It is an area of moderate relief, varying from rounded mountains in the central and western parts, low hills in the northern part, and a low plain in the northeast. No map of this area is included in this report as it has already been published (Tipper, 1963) and discussed. Only a brief summary will be given here.

The entire map-area was overridden by glacial ice whose movement at its maximum was in a direction varying from N40°E to east. Drumlins, glacial grooves, rock drumlins, eskers and esker complexes, meltwater channels and other glacial features are well developed and widespread. Ice was apparently thick enough to flow over all topographic features without appreciable deflection.

The mode of deglaciation is thought to have been a combination of stagnation and normal retreat. In the north and northeast parts, the well-defined drumlinoid features suggest normal retreat whereas the southern and southeastern parts display many eskers, kettles and disoriented terrain that suggests ablation moraine and stagnation. In this latter area the topography is thought to have been instrumental in the breakup of a thinning ice sheet, loss of mobility, stagnation of large isolated blocks in valleys, and melting in situ with deposition of a large amount of ablation moraine that masks the drumlins in these low areas. In the final stages of deglaciation a multitude of meltwater channels, commonly bounded by stagnant ice, were eroded in the till and bedrock surface to provide outlets for torrential streams from a rapidly melting ice sheet.

QUESNEL MAP-AREA

The Quesnel map-area (see Fig. 1 and Map 1290A) lies south of the Prince George map-area. It is entirely within the Fraser Plateau and is an area of moderate relief with rounded summits and broad, flat valleys. Fraser River and its tributaries, Quesnel, Chilcotin and Nazko Rivers, flow in valleys incised well below the plateau surface.

The whole area has been glaciated but the relatively simple history of areas to the north has become complex here. Whereas most of the features of the Prince George, McLeod Lake, and Nechako River map-areas were attributable to one major ice advance, in this area there appears to be one major advance from the Coast and Cariboo Mountains and a later readvance from the Cariboo Mountains. The length of time between these two events may be relatively short.

The Fraser advance moved across the area in a northerly direction. The effect of topography on a thinning glacier is clearly indicated by the variations in direction of ice movement. In the hilly, relatively high region northwest and west of Nazko River, a trend of N15°E prevails and represents movement when ice was thick enough to move relatively undeflected by local relief to the east and south, in the somewhat lower central and southern sections of the map-area, the glacial features indicate that the ice was deflected eastwardly from the hilly northwest region in a direction N37°E. The interpretation is that the ice was thinner and could no longer maintain a path over the higher ground veering towards lower country. East of Nazko River this ice was forced to split on the hills on the height of land and produced a tongue of ice flowing northerly along Nazko River. As the thinner ice sheet approached Fraser River valley it was forced to turn northward, presumably by the pressure of ice moving in from the south and from the Cariboo Mountains to the east.

Along the eastern margin of the area it is difficult to determine the direction of movement of the main ice advance as the drumlinoid features

cannot be related with confidence to this ice advance or the later Cariboo Mountain readvance; both are assumed to have taken roughly the same course, N25°W.

During deglaciation the ice sheet thinned until it was incapable of flowing indiscriminately over the irregular topography. The ice was deflected by the higher hills and followed the lower terrain; thin ice covering the higher hills probably stagnated and melted in situ. Ice in the low areas continued to thin and probably retreated along a front but there is no evidence in this area to suggest a general retreat of the ice front, on the contrary the glacial features strongly suggest that over much of the area the ice thinned, broke up into stagnant blocks and melted in situ. This break-up may have been a progressive deterioration from the front so that a general stagnation of the whole area at one time is not envisaged. Large segments of ice became detached from the main mass and no longer responded to pressure from the ice sheet but acted independently or stagnated completely.

Presumably after the complete disappearance of glacial ice from the area, a limited readvance occurred. Ice from the Cariboo Mountains flowed into the area from the southeast, crossed Fraser River and extended at least 30 miles westward from the east margin of the map-area to The Dome. Northwestward it extended to near Dragon Mountain and possibly farther north. This ice advance blocked Fraser River forming a lake north of Castle Rock. South of the area it blocked Chilcotin River forming a lake that escaped by a channel northward through Alexis Creek to Nazko River. In this map-area this ice lobe apparently retreated along a front; different ice-front positions in its retreat are well marked by lateral overflow channels. Other tongues of ice may have entered the area from the Coast Mountains at the time of this advance of Cariboo Mountain ice but this has not been clearly established.

Drumlins, Rock Drumlins, and Glacial Grooves

These features are poorly to well developed throughout the map-area. As the area is heavily drift covered, rock drumlins are less conspicuous than in the areas to the north; only on the higher hills do they exhibit typical crag and tail features. Drumlins occur in all parts of the area except the southeast but are generally less sharply defined than in the Prince George and McLeod Lake areas (Fig. 15). This trend to less prominent drumlins continues southward resulting in glacial grooves on till becoming the more pronounced feature in the central and southern parts (Fig. 13). Possibly with careful examination these grooved areas might be recognized as having very subdued drumlins but in a cursory examination the drumlin form is not readily apparent.

The southeast part of the area – around Williams Lake, westward to The Dome and northward to Granite Mountain – has a noticeable lack of drumlinoid features. Only a few indistinct glacial grooves suggest a northerly to northwesterly direction of movement. This area reflects the late advance of Cariboo Mountain ice into the Interior Plateau across the trend of the Fraser ice advance. It is uncertain whether the few grooves mentioned earlier were formed by the Fraser ice advance or the late Cariboo Mountain advance. The sharp change from a grooved and drumlinized surface to an unoriented terrain around The Dome and northward defines the westernmost

advance of late Cariboo Mountain ice. Between Granite Mountain and Dragon Mountain to the north there is an acute intersection of two drumlin trends on the eastern margin of Fraser Valley. These trends are thought to be a product of the two ice advances but northward the trends merge and the distinction is lost.

Eskers and Esker Complexes

These glaciofluvial features, particularly simple eskers, are common throughout the area. Esker complexes are best developed along Chilanko River west of Redstone and for short distances along major drainage channels near Quesnel River and near Hawks Creek north of Williams Lake. The esker complex near Redstone is nearly 15 miles long in this area and extends west of the map-area discontinuously for another 10 to 15 miles (Anahim Lake map-area), an overall length of 25 to 30 miles. In places it is 1 to 2 miles wide and the individual ridges have a local relief in places of more than 100 feet. The material is coarse sand to coarse cobble gravel.

The single eskers are relatively simple features consisting of one ridge or several that branch dendritically; a reticulate pattern is absent. Many examples were noted in which the esker is a segment of a simple meltwater channel, presumably subglacial. The orientation of the eskers is consistently parallel or subparallel to the direction of ice movement. They tend to slope down the general slope and occur on the lee side of a glaciated hill. Lengths of one mile or more are common and the longest, along Mount Creek in the north-central part is over 6 miles long. Single eskers are uncommon in the southeast quarter where late Cariboo Mountain ice advanced into the area.

Meltwater Channels

Esker channels are common, oriented parallel to direction of ice movement. These are particularly noticeable in the northwest quarter. They are usually short and narrow but some are 6 or 7 miles long.

Lateral overflow channels are present along Nazko River near mouth of Clisbako River and east of Mount Creek, apparently related to waning stages where tongues of ice were confined to the valleys.

Direct overflow channels are present in the area but are difficult to distinguish from the major drainage channels of which some of them were the precursors. The Fraser River channel crossing the area in a north-south direction is clearly younger than any other glacial feature; erosion is still active along its course. Many of its tributary channels are clearly of glacial origin and hold eskers and kettles along their courses. Similarly the Chilcotin River channel and its tributaries, Chilko and Chilanko Rivers, are clearly major drainage channels carved by the meltwater and eskers occupy parts of the channel. Recent erosion is confined to small channels in which the river is now flowing. The part of the Chilcotin River channel below Redstone is floored in part by lacustrine deposits laid down in the channel as a result of the damming of the channel by late Cariboo Mountain ice in the Taseko Lakes map-area to the south; when the block melted, these lacustrine deposits were channelled and terraced and sections are now exposed along the north side of the valley.

The Nazko River likewise is a major drainage channel that originated as a glacial meltwater stream. It and its tributaries clearly were eroded by meltwater discharging directly from the front of an ice tongue that occupied the valleys. However the Nazko River valley itself has a more involved history. As is readily apparent, the channel extends southward beyond the height of land at its head and connects with the channel of Alexis Creek flowing into Chilcotin River. This through-going channel is thought to have formed and been deepened by the stream flowing northerly from the lake ponded by the blocking of the Chilcotin River as mentioned previously. For this lake to have been drained by a stream flowing into Nazko River, its level must have been at approximately 3,700 feet elevation.

Around the margin of the late Cariboo Mountain ice, many lateral overflow channels developed. As the ice advanced westward onto the plateau it was moving against the slope of the ground. As the ice shrunk back from its greatest extent, water ponded in front of the glacier moved along the margin eroding channels in the till. Successive stages in the retreat are marked by the subparallel channels developed and are best exposed in the area north and northeast of The Dome. They roughly parallel the margin of the Cariboo Mountain ice as defined by drumlinoid features. The slopes of the channels indicate that some drained northward and some southward. Significantly the channels are not developed east of Fraser River where the slope of the land is westward and meltwater could discharge directly into the Fraser River when the margin had withdrawn to that point. Some of these channels may also have been outlets for the lake ponded by the late Cariboo Mountain ice along Chilcotin River to the south.

Ablation Moraine

On the height of land at the head of Nazko River an area has been outlined that is believed to be underlain by ablation moraine. It is characterized by an irregular topography with many erratics and kettles and a lack of drumlinoid features and is interpreted as an area of ablation moraine deposited by a large mass of ice that became stagnant after being separated from the main ice sheet to the southwest. The shape of the area suggests that it may derive from a tongue of ice flowing down the Nazko Valley but it is unknown whether this ice tongue was part of the retreating Fraser ice sheet or represents the disconnected end of a later tongue of ice advancing from the Tatla Lake or Chilko Lake valleys to the southwest.

Drift Ridges of Uncertain Origin

A group of ridges about fifteen miles east of Nazko Indian Village have been interpreted as crevasse fillings. They are relatively short, less than one mile, straight, steep-sided, generally less than 100 feet high, sharply defined, and intersect each other at an angle rather than merging. The type of material is not known.

Near The Dome, there are low irregular, slightly sinuous ridges, but unlike esker ridges in plan or section. They are discontinuous but as a group form a distinct band trending northwest. Their origin is unknown but their position suggests that they may be the terminal moraine of the late Cariboo Mountain ice.

Within the area of Cariboo Mountain ice advance south of Williams Lake, west of Meldrum Creek, and southwest of Castle Rock, groups of low, parallel ridges are discernible on air photographs; on the ground they are not obvious and are easily missed. They have a low relief, about 10 to 15 feet, very gentle slopes, and give the impression of a rippled surface. The few seen on the ground are apparently till. In a general way they resemble the De Geer moraines or ribbed moraines discussed by Prest (1968, pp. 6-8).

TASEKO LAKES MAP-AREA

The Taseko Lakes map-area (see Fig. 1 and Map 1292A) is immediately south of Quesnel map-area. Physiographically it is diverse with the southwest one third within the Coast Mountains and the remainder within the Fraser Plateau. In general the part within the Coast Mountains becomes increasingly rugged from northeast to the southwest forming a maze of jagged, glacier-studded peaks. The northeast margin of these mountains although reaching high elevations, exhibits gentler slopes and more subdued crests.

The Fraser Plateau is moderately hilly in the central part of the area rising to rounded mountains in the Camelsfoot Range to the southwest. Northeast and northerly from this belt the area becomes more subdued and merges with the flatter plateau areas along Chilcotin River.

Taseko Lakes area differs from those already discussed in that it was not only overridden by ice but the southwest part was an area of ice accumulation. It is believed that ice built up on the mountains, formed valley glaciers that coalesced into a piedmont glacier and eventually formed a great sheet of ice that flowed directly from the mountains undeflected by local topography and spread beyond this area. During deglaciation the ice thinned and although the sheet disintegrated and stagnated in parts of Quesnel area, in Taseko Lakes it is thought to have retreated more or less along a front with only local stagnant blocks. Later, ice from Cariboo Mountains invaded the area from the east, and disrupted the Fraser drainage. Tongues of ice that may have been contemporaneous with this Cariboo advance appear to have moved out of the Coast Mountains along major valleys, i.e. Big Creek, Taseko River, and Konni Lake. Whether all these late events were contemporaneous and whether they mark a glacial episode significantly later than the Fraser ice advance is not known.

The direction of movement of the Fraser ice sheet in this area is readily apparent. In the northwest corner the direction is N40°E, in the centre of the area N15°E, in Camelsfoot Range N25°E and near Riske Creek nearly due north. The advance of late Cariboo Mountain ice nearly obliterated evidence of the Fraser ice sheet advance east of Fraser River but on Big Bar Mountain and possibly on the hills north of Canoe Creek there are drumlinoid features and striae, apparently related to the main ice sheet, indicating that the main ice sheet crossed Fraser River in the southeast part of the area. Scant evidence in the Marble Range east of Big Bar Mountain and in Clear Range to the southeast of the area (see Fig. 2) indicates that near the southeast corner the ice took an easterly and southeasterly course, but except for evidence preserved at high elevations the pattern was destroyed by the late ice.

The late Cariboo Mountain ice advanced into the area from the east and northeast, crossed Fraser River, and reached an irregular front as indicated on Map 1292A. North of Black Dome Mountain this front reaches its highest elevation. Apparently the ice did not cover all hills behind its front, such as Big Bar Mountain, and was deflected by hills to follow valleys and low areas. Erratics of fossiliferous Permian limestone were observed near the headwaters of Farwell Creek at elevations near 4,500 feet. As Permian limestone is known only east of Fraser River in this area, it is obvious that ice moved westerly across Fraser River up Chilcotin River, and reached elevations of at least 4,500 feet. This ice filled Fraser Valley and provided an effective block to normal Chilcotin River drainage. A lake was impounded behind this dam and extended up Chilcotin Valley beyond the map-area to near Redstone. Silts and sands deposited in this are exposed at many places along the valley. Drainage to the south from this lake was prevented by the ice front and must have escaped northward into the Prince George Lake basin by way of Nazko River or by channels along the ice front in the Quesnel area. Removal of the ice dam permitted rapid down-cutting and re-excavation of the Chilcotin Valley so that only remnants of the former lake deposits are noted along the valley walls.

Drumlins, Rock Drumlins, and Glacial Grooves

Drumlinoid features are only locally well-developed and are not ubiquitous. This trend towards less prominent and ill-defined features has been noted in crossing the areas from McLeod Lake and here the trend is accelerated. In the northern half of the area, drumlinoid features are reasonably abundant (Fig. 28) but near the Coast Mountains drumlins are rare, glacial grooves predominate but are confined mainly to broad valleys (Fig. 14), and in the main mass of the mountains linear features of any type, other than a few in valleys and rare exceptions on flat-topped mountains, are lacking. Rock drumlins are generally not abundant except on some of the sharper volcanic hills of the plateau.

The drumlinoid features related to the Fraser ice advance maintain a fairly consistent direction unaffected by local topography and are oriented roughly at right angles to the mountain front. The features related to late Cariboo Mountain ice, mostly glacial grooves, have no consistent orientation but are controlled by local topography. Where lineations of these two ice advances meet, there is such a sharp contrast in direction that the margin of the late advance is readily defined.

Eskers

No esker complexes have been recognized in this area and single eskers are rare. In a small area west of Hanceville several well-developed single eskers reach lengths up to seven miles and have heights to 100 feet or more. Some of these have small meltwater channels aligned with them. A few eskers, some with lengths up to four miles, occur here and there throughout the plateau area in an esker channel system.

Figure 28. Fraser Plateau along Chilcotin River south of Riske Creek, Taseko Lakes map-area. Coast Mountains on the horizon are the source of glacier ice that moved northerly toward the viewer. Drumlins and rock drumlins in foreground. EMR Photo T32L-25.

Meltwater Channels

Meltwater channels are only significant in the plateau area and are mainly major drainage channels. Subglacial meltwater channels, associated with eskers, are present but are nowhere abundant. Along the northwest side of the hills southeast of Mons Lake several prominent lateral overflow channels have been recognized parallelling the course of the late ice tongue in Big Creek valley.

The map-area has a general northeastward slope and except for local areas it is thought by the writer that the main ice sheet retreated upslope along a front. In the waning stages the sheet may have divided into several ice tongues but even these continued to shrink back into the mountains.

Meltwater was discharged directly from the ice front and was quickly channeled into the major depressions, Chilko River, Taseko River, and Big Creek valleys and eventually into the Chilcotin and Fraser Valleys. Most of the meltwater channels of the area can be classified as direct discharge channels that in following their course gradually lose the evidence of their glacial origin and merge with the major drainage systems of the area.

Drift Ridges of Uncertain Origin

Low, parallel ridges of drift were noted in several places near Gang Ranch, along Big Creek and between Chilko and Taseko Rivers. Most are oriented transverse to the direction of ice movement and apparently are composed of till. Like those of the Quesnel area they give a faint rippled appearance to the surface and are thought to be De Geer or ribbed moraines. They are particularly noticeable associated with deposits of the late advances.

Lacustrine Deposits

Along Fraser River from Alkali Creek northward, silts, sands, and minor clay are exposed on the side of Fraser Valley. They are overlain by a thin till. These sediments are thought to have been deposited in a pro-

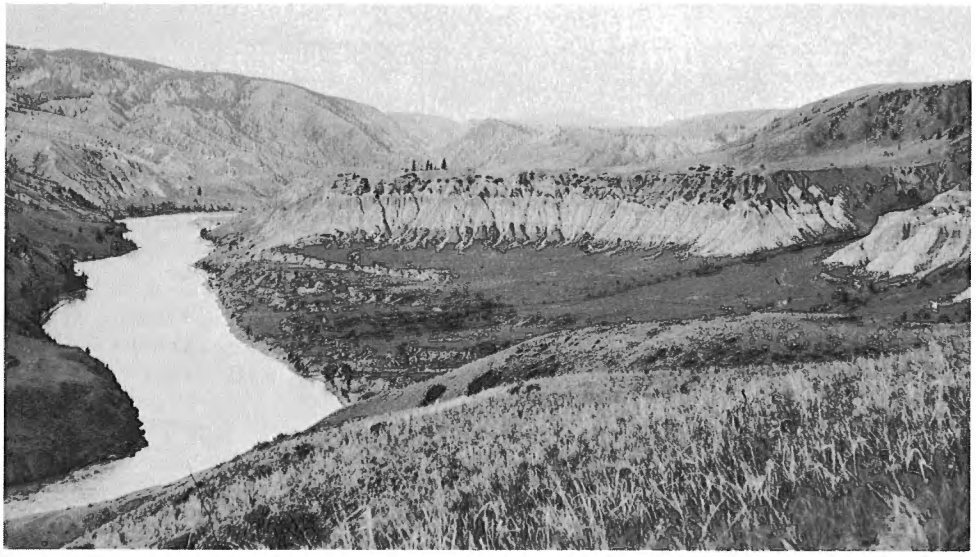

Figure 29. Fraser River incised below the Fraser Plateau surface, Taseko Lakes map-area. River has cut a channel about 1,800 feet below the plateau surface partly in pre-Pleistocene time. Exposed sediments are Pleistocene lacustrine deposits, apparently related to the Fraser ice advance. They are overlain by a late Cariboo Mountain till. GSC photo 119499.

glacial lake ponded in front of the southward retreating ice front of the Fraser ice sheet and confined to Fraser Valley (Fig. 29). Late Cariboo Mountain ice overrode the sediments and deposited the thin till.

BONAPARTE LAKE MAP-AREA

Bonaparte Lake map-area (see Fig. 1 and Map 1293A), directly east of Taseko Lakes and southeast of Quesnel map-areas, is entirely within the Interior Plateau but encompasses several subdivisions of that major division. Topographically the area varies, southwest to northeast, from the rounded mountains of the Marble Range to the flat to rolling terrain of Fraser and Thompson Plateaus of the central part to the broad, rounded summits of the Quesnel and Shuswap Highlands.

The Fraser ice sheet covered the entire area, moved into the area from the Coast Mountains to the west and presumably from the Cariboo Mountains to the east, and probably met in this area, veering northwestward and southeastward. The fragmentary evidence for this is obtained from the Marble Range and mountains west and south thereof and possibly from the mountains south of Mahood Lake.

Subsequent to Fraser Glaciation ice readvanced into the area from Cariboo Mountains in a southwesterly direction out of Canim-Mahood Lake valley, fanned out northwesterly and southerly, and flowed westerly beyond the area. No evidence suggests that the Marble Range was covered in this advance but large basaltic erratics from the central plateau area were carried onto the northeasterly sides of the range to elevations of 6,000 feet. Possibly the mountains south of Mahood Lake were also left uncovered by this advance.

The direction of movement of this late Cariboo Mountain ice as indicated by drumlinoid features and striae varied greatly. In the western half the direction was N25°W to N35°W. In the eastern half the ice flowed southerly and southwesterly out of the northeast corner, veered sharply southerly and southwesterly in the central part and in the southern part flowed beyond the area in a direction S25°E. It is questionable whether the movement suggested was all related to an advance and retreat of a single ice sheet.

During deglaciation the ice apparently broke into two separate masses. The one mass, in the northwest quarter of the area, appears to have separated from the main mass. This western segment stagnated and shrank to an area of dead ice centred west of Lac la Hache. The eastern segment retreated along a front into the Cariboo Mountains.

Drumlins, Rock Drumlins, and Glacial Grooves

If a line is drawn from Mount Timothy through Green Lake to Mount Grant and on to the southern margin of the map-area, two regions are delineated that differ in the type and abundance of certain glacial features. West of the line rock drumlins are nonexistent or rare and only a few ill-defined glacial grooves are discernible. East of the line the drumlinoid features are well-formed, particularly from Horse Lake southeastward, with

abundant drumlins and rock drumlins clearly defining the direction of movement. In the Mahood-Canim Lake valley the features are not as well formed, possibly because of steeper slopes. The area north of Lemieux Creek to Mahood Lake and from Clearwater River to Bowers Lake is relatively high with rounded mountains that exhibit only a few glacial grooves with no consistent direction of ice movement. This part may represent an area that was glaciated by an earlier advance (Fraser Glaciation) of Cariboo Mountain ice but was not inundated by the latest advance.

Eskers and Esker Complexes

Esker complexes are not prominent in this map-area. One west of Young Lake in a major meltwater channel possibly was longer but has been eroded by later drainage.

Single eskers are particularly abundant and well-formed west of the previously described medial line but eastward they are rare, short and insignificant. The outstanding single esker system extends from Chasm Provincial Park northwestward about 25 miles. In places it is two parallel ridges, short eskers join the main ridges at one or two places, and the main ridge is interrupted here and there. To the northwest several smaller eskers and meltwater channels suggest that the system may have extended at least 10 miles farther. The esker, which is on the till surface, ends abruptly at Chasm Provincial Park where the stream that formed the esker appears to have carved a deep gorge. All other single eskers are related to meltwater channels with which they are commonly aligned.

Meltwater Channels

Major drainage channels such as North Thompson-Clearwater Valley, Fraser Valley and Bonaparte River valley are deeply incised into the plateau surface.

East of the medial line, particularly north of Young Lake many lateral overflow channels are oriented at right angles to the direction of ice movement and suggest a frontal retreat to Mahood Lake valley. Some of these channels drained southward to Thompson River and others may have drained northwestward through Lac la Hache to Fraser River.

West of the medial line, a large mass of ice stagnated and shrunk to a central area. Movement within this mass was slight. As it pulled back from the Marble Range lateral overflow channels developed parallel to the range, flowed southeast and cut deep channels where they flowed into Bonaparte River valley (Fig. 21). These are probably the best examples of lateral overflow channels in central British Columbia. Several channels north of 70 Mile House and some west of 100 Mile House are direct overflow channels suggesting the position of the margin of the shrinking ice mass at several stages.

Drift Ridges of Unknown Origin

West of the medial line, in the area where ice stagnated, there are many examples of low, parallel drift ridges oriented at right angles or nearly so to the direction of ice movement. They present an irregular, rippled topography with low rounded hills and shallow depressions. It is difficult to trace individual ridges but bands of ridges occur up to 10 miles long and several miles wide. Their origin is not known but the similarity in appearance to De Geer or ribbed moraines is noted (Prest, 1968). It is further noted that in central British Columbia they are more commonly associated with late ice advances.

Lacustrine Deposits

Silt and sand accumulated in many small basins throughout the area. Most of these basins were proglacial lakes formed by ice blocking normal drainage. Such a lake occurred around Canim Lake when ice in Mahood Valley prevented normal eastward drainage. Lacustrine deposits are common in the channels around 100 Mile House, Horse Lake, and along North Thompson River. Much additional study would be required to define the basins.

Kettled Deposits

In the northwest quarter in particular and west of the medial line in general, kettled deposits are common; east of the medial line, they are insignificant. Their abundance in the northwest quarter indicates to the writer that this is the area into which the mass of stagnant, in situ melting ice shrank.

MOUNT WADDINGTON MAP-AREA

The Mount Waddington map-area (see Fig. 1 and Map 1291A) lies west of Taseko Lakes and southwest of Quesnel map-area. The Coast Mountain physiographic division encompasses the entire area except for the northeast quarter which extends into Fraser Plateau. The area is generally a rugged mass of jagged peaks and ridges and narrow valleys with local relief to 12,000 feet, commonly 6,000 feet. To the northeast the mountains are less rugged and the Fraser Plateau section is characterized by rounded hills (Fig. 4). Only the northeast half of the map-area was examined in the field by the writer.

The Mount Waddington map-area was an area of ice accumulation and its history probably followed the four stages of mountain glaciation as envisaged by Kerr (1934, p. 22). This involved the initial local alpine glaciation, followed by a period of intense alpine glaciation in which all valleys were filled with ice. A mountain ice sheet developed in which the mountains were capped by ice that flowed out from the mountains into the lower Interior Plateau. By the time these mountain ice sheets coalesced into the all-encompassing Fraser ice sheet, this map-area was blanketed by ice with a thickness great enough to permit unrestricted movement onto the Interior

Plateau. There are no glacial features in this area that can confidently be attributed to these stages of glaciation but the high-level striae and drumlinoid features are thought to be a probable result of the Cordilleran ice sheet stage.

The direction of ice movement in the area is not easily determined. Late movement along valleys is obvious but direction of earlier, high-level movement can be determined only in the northeast third of the map-area, along the mountain front. Here the direction varied from N15°E in the north-central part to N25°E near Chilko Lake; in the northeast corner the direction was N70°E. The centre of accumulation is thought to have been along the crest of the Coast Mountains or slightly northeast thereof but its position probably shifted at different stages of glaciation and deglaciation. Thus the direction of movement when ice was near a maximum was to the northeast at right angles to the crest (Fig. 33). Presumably in the southwest half ice moved southwesterly from the crest but no high-level lineations are noted. The crest would be defined roughly as a line running southwesterly from Monarch Mountain through Mount Waddington to Homathko icefield (Fig. 30). Late valley movement followed the course of the valleys and in the latest stages was in the direction of slope of the valleys. Only in Klina Klini River, Moseley Creek, and Tatlayoko Lake valleys did the valley ice flow in a direction opposite to the slope. The valley glaciation is probably related to a late readvance of ice as recognized in areas to the east.

In other areas of central British Columbia there is evidence of a late readvance of ice into the Interior Plateau and for these reasons a similar advance is thought to have occurred here as well. However, the features seen in this area could as well be related either to the Fraser Glaciation or to subsequent readvances that, although of limited extent in other areas, covered all or most of this map-area. The map suggests tongues of ice extending onto the plateau but these may have been the remnants of a shrinking mountain ice sheet retreating to a valley glacier stage (Figs. 31, 32).

Whatever the history of deglaciation may have been, at some time a stage was reached in which the Coast Mountains were capped by a mountain ice sheet and valley glaciers extended from the main valleys of the area northeastward onto the Interior Plateau. Three of these valleys, Klina Klini River, Moseley Creek and Tatlayoko Lake, had valley glaciers that flowed northeast against the slope of the valley. Apparently their termini were nearly stationary for an extended period as large moraines were built of granitic material derived from the interior of the Coast Mountains. How far this northeastward flowing ice extended into the mountains is not known but may have been as far as the present crest, Mount Queen Bess or Mount Waddington.

This northeastward flowing ice would maintain its course so long as the valleys to the Pacific Ocean were incapable of accommodating all the flow of ice from the Coast Mountains. When the ice sheet melted sufficiently so that ice flowing into the Klina Klini and Homathko River valleys could follow the slope of the valleys, the northeastern segments of these glaciers were left without nourishment from the centre of the Coast Mountains. These segments stagnated and melted in situ, shrinking slowly back from their margins. Thus when the Homathko River was capable of accommodating the ice flowing into the south end of Tatlayoko Lake valley from Chilko Lake valley, the direction of flow of ice in Homathko River valley was reversed. Valley

glaciers retreated farther, gradually freeing the mountains of their ice cover. Whether the present valley glaciers and snowfields are remnants of the Pleistocene ice sheet or remnants of still later brief ice advances is unknown.

Drumlins, Rock Drumlins, and Glacial Grooves

Drumlinoid features are nowhere well-developed or abundant in this map-area. In the drift-covered area of the northeast quarter drumlins occur here and there but most of the linear features are indistinct glacial grooves. On the rounded summits along the mountain front and in the intervening valleys, drift-cover is not great and rock drumlins and glacial grooves clearly show the direction of ice movement. In the southwest half of the area, in the Klina Klini and Homathko River valleys where a southward flow is indicated, few drumlinoid features are evident.

The features appear to present a conflicting pattern of glacial flow. However when it is realized that these represent several stages in a single deglaciation or stages of two or more deglaciations, a complex history can and must be envisioned. For example the tongue of ice that flowed northward in Tatlayoko Lake valley is thought to represent a late advance of ice, later than the main ice sheet that covered the summits. The features in the valley clearly indicate northward flowing ice. South of Tatlayoko Lake valley the rock drumlins in Homathko Valley were formed by a later stage of the readvance in which ice flowed from Chilko Lake valley southwestward down Homathko Valley, a direction of movement previously recognized by Munday (1943, p. 161). Considerably more detailed study of the area would be required to satisfactorily explain the development of the drumlinoid features. It should be noted that of all areas of central British Columbia mapped by or familiar to the writer, this has the poorest development of drumlinoid features.

Eskers and Esker Complexes

These features are only noteworthy in the northeast third of the area, along the mountain front and on the plateau. The only esker complex of note lies west of Tatla Lake (Fig. 18). It is a maze of reticulate ridges that, unlike most esker complexes of the Interior Plateau, is not within a meltwater channel. A later meltwater channel has destroyed it in part and a few later eskers have been formed in that channel.

Single eskers are short, up to 2 or 3 miles long, are commonly associated with meltwater channels and appear to have a random orientation. Their abundance in some valleys of the northeast quarter suggest stagnation of ice in these valleys.

Meltwater Channels

A major meltwater channel extends from Klina Klini post office to near Tatla Lake where it is joined by another channel from the upper Klina Klini River and the combined channel extends northeastward through Tatla Lake and beyond the area into Chilcotin River system (Fig. 18). This

channel recreates the probable former course of Klina Klini River in pre-Pleistocene time before stream piracy cut off the eastward flow. This channel, as well as those from Chilko Lake and Tsuniah Lake valleys are direct overflow channels.

Many lateral overflow channels along valley walls and associated with valley glaciation are noted in the northeast quarter wherever valley walls are gentle enough to preserve them. In the very mountainous southwest half, few valley walls have slopes gentle enough to preserve lateral channels or any other glacial features.

Cirques

The mountainous part of the area has been sculptured by cirque glaciers. No study of cirques has been undertaken by the writer but a few observations can be recorded. The main ice fields of this area are along the crest of the mountains but whether this signifies that this was an ice divide in Pleistocene time is not known. Possibly this is a late development, a shift of the major area of accumulation from a line somewhat farther to the northeast. Toward the northeast, cirque glaciers are noticeably smaller, cirques are smaller and many are free of ice. North of Choelquoit Lake several cirque-like basins in the low hills appear to have been overridden by ice. They are possibly cirques developed during an earlier glaciation or initially during the last main ice advance.

Valley Moraines

Most valleys in the Coast Mountains exhibit many moraines marking the terminus of the present valley glacier at several periods during retreat. They are too numerous to attempt to show on this scale of mapping nor are all easily recognized on the air photographs available. Typical examples of moraines of a shrinking valley glacier are shown along Ottarasko Creek, west of Tatlayoko Lake, where they are fresh and well-defined. The positions of the margins of valley glaciers that issued onto the plateau from Klina Klini River, Moseley Creek, Tatlayoko Lake, Chilko Lake, and Tsuniah Lake valleys are sharply defined by a slight change in topography visible on air photographs but whether these are all marked by distinct lateral and end moraines is not clear; some are morainal ridges. The tongue of ice that flowed from Tatlayoko Lake valley produced fairly well-defined moraines that mark successive stages in the shrinking and retreating of the ice.

Figure 30. (opposite) Southerly along Talchako River toward Monarch Mountain, Anahim Lake and Mount Waddington map-areas. The rounded mountains in the centre of the photograph were overridden by ice and subsequently sculptured by cirque action. The mountains around Monarch Mountain and Mount Waddington (centre horizon) lie along the main ice gathering ground in the Coast Mountains. EMR Photo T24L-68

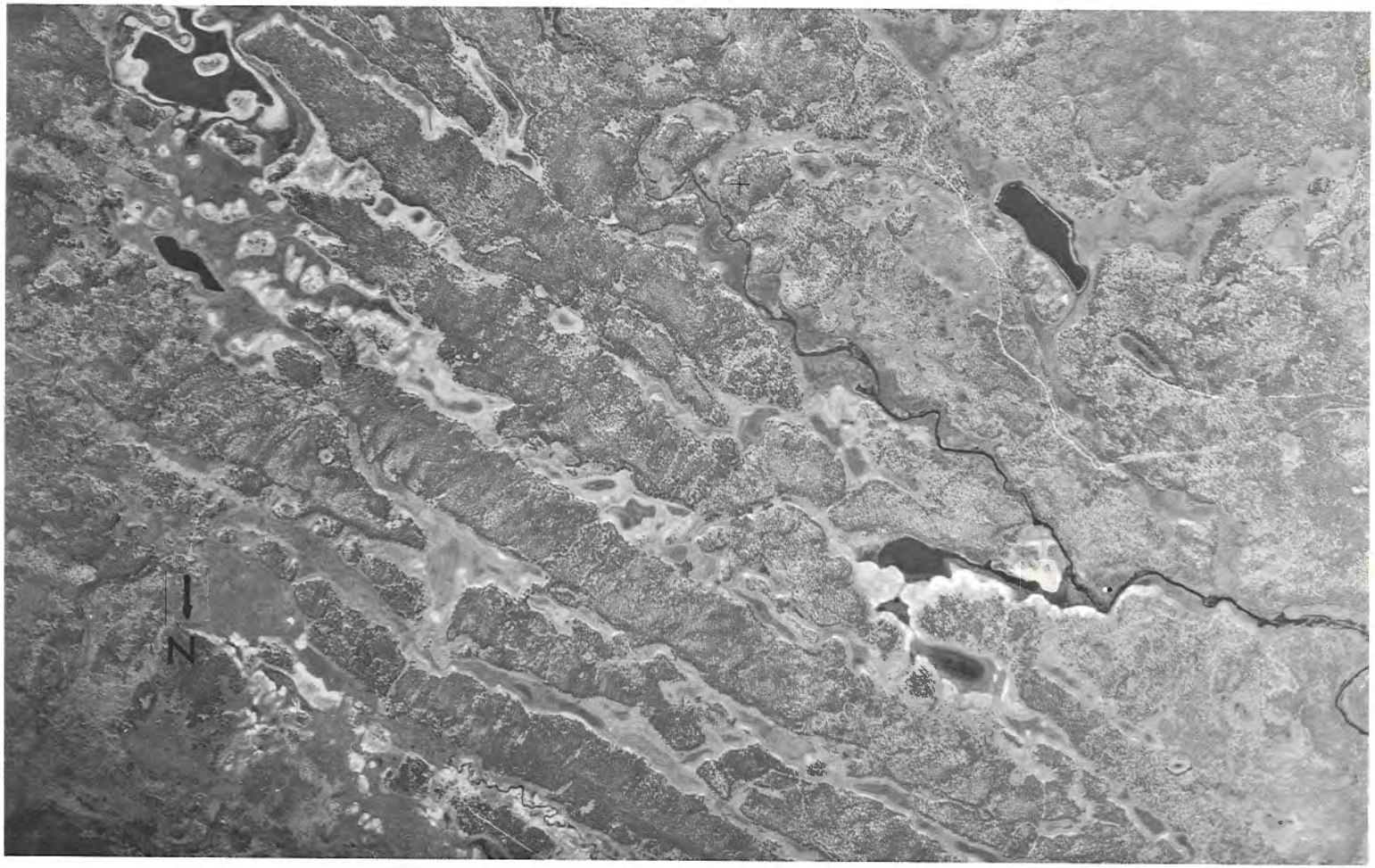
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Figure 32. (Above) Intersecting drumlinoid features near Nimpo Lake, Anahim Lake map-area. The broad, low, wooded ridges trending southeasterly from Nimpo Lake were produced by late ice readvance from the northwest. Smaller ridges on these broad ridges are oriented northwesterly and are remnants of older drumlins produced by the northeast moving Fraser ice sheet. The esker in the southwest quarter of the photograph was produced by a northeasterly and northerly flowing meltwater stream, presumably during a late stagnant phase of the ice sheet. EMR Photo A19672-51

Figure 31. (opposite) Intersecting sets of drumlinoid features, Anahim Lake map-area. The broad bands of forested area separated by shallow swampy gullies represent a glacially grooved till plain produced by the late ice readvance moving southeasterly. An indistinct, northeast trending lineation is visible on these broad bands, a remnant of the drumlinoid pattern produced by the northeast moving Fraser glacial ice. EMR Photo A11561-208

Alluvial Fans

The numerous alluvial fans are a characteristic late Pleistocene and recent development in the mountain valleys of this map-area. They are abundant in most major valleys (e.g. see the valley of Moseley Creek, Map 1291A). The valleys were over-deepened by valley ice, tributary streams brought in more debris than could be transported along the main valley and a fan was built on the valley sides. Several of the fans can be related to the presence of ice at one stage and another set of fans at lower elevations suggest a later stage of deglaciation. Fans are particularly abundant along major through valleys and are responsible for blocking the valleys in places forming lakes, such as Middle and Bluff Lakes.

ANAHIM LAKE MAP-AREA

The Anahim Lake map-area (Fig. 1 and Map 1289A) lies north of Mount Waddington and west of Quesnel map-areas. The southwest quarter is in the Coast Mountains and the remainder is in Fraser Plateau. The young volcanic ranges of the central part are a further subdivision of Fraser Plateau. The Coast Mountains have rounded summits on the northeast but to the southwest the mountains become rough, jagged peaks and ridges dotted with numerous cirque glaciers. The volcanic ranges of Fraser Plateau are high but have gentle slopes; Rainbow and Ilgachuz Ranges retain their conical volcanic shape. The remainder of the plateau varies from the rounded hills of the east half to the broad, flat valleys of Anahim Lake and Blackwater River.

Two major advances of ice are recognized, one the Fraser ice sheet that covered practically all the area and the other a later ice lobe that advanced eastward from the Coast Mountains; the approximate limits of the advance are shown on Map 1289A. The direction of movement of the two advances must be considered separately.

The Cordilleran ice sheet moved off the Coast Mountains approximately at right angles to the northwest trend of the range. The direction of movement varies from N45°E in the northwest quarter and around Charlotte Lake, to N65°E in the southeast quarter, and N30°E in the northeast quarter. In this map-area the Fraser ice sheet reached the highest recorded elevations beyond the source areas as erratics are found on Tsitsutl Peak at 8,130 feet elevation. It is noted that glacial trends at high elevation are fairly consistent in their northeast orientation suggesting that in this area the ice was, at its maximum, thick enough to flow essentially undeterred by topographic features. Divergent trends at lower elevations suggest that thinning during deglaciation forced the ice sheet to react to the influence of topography. Drumlins extend south of the area to near the snowfields around Monarch Mountain (Fig. 30). Some accumulation of ice probably occurred within the area and at different stages the centre may well have been within the area. At its maximum the ice flowed across the area in a northeasterly direction and was thick enough to move with little influence of topography; ice was at least 5,000 feet thick over Anahim Lake valley and probably thicker. During deglaciation the Cordilleran sheet thinned and gradually topography controlled the direction of flow. Ice was diverted easterly from the higher northeast quarter so that in this quarter the thinned ice stagnated while the ice was still

active northward and southward. The final deglaciation of the Fraser ice sheet is not apparent as the late stages are completely masked by the later readvances. However it is believed that the ice completely withdrew into the mountains before readvance occurred.

Assuming that the Fraser sheet completely withdrew, the readvance of ice would take the following pattern of development. Ice build-up on the Coast Mountains produced valley glaciers that followed the Talchako and Atnarko River valleys into Bella Coola Valley and westward to the Pacific Ocean. As build-up of ice continued, the narrow Bella Coola Valley was incapable of handling the flow of ice, the upper valleys became filled, the mountains became covered to a high elevation and ice flowed easterly onto the plateau areas through the broad valley west of Anahim Lake. Ice flowed northerly from the Monarch Mountain area, turned eastward toward Anahim Lake and rode up the lower slopes of Rainbow Mountains. The ice fanned out in the broad Anahim Lake valley, flowed southward to near Cariboo Flats, eastward over Itcha Range to near the eastern base of the range, and northward down Dean River where it turned westward and southwestward back into the Coast Mountains and eastward to the Blackwater Valley.

The glacial map of British Columbia contained in the British Columbia Atlas of Resources (B.C. Natural Resources conference, 1956, Map No. 4, p. 10) depicts the terminus of this ice lobe as an ice divide from which ice flowed westerly and funneled westward through the Bella Coola Valley to the Pacific Ocean, in the opposite direction indicated by the evidence. Terminal moraine deposits at the southern margin, direct overflow channels away from the margin, a few well-formed drumlins, and numerous lateral overflow channels along the ice front clearly indicate movement in an easterly direction from the Coast Mountains.

This ice lobe at its maximum did not cover the volcanic ranges of the north-central part of the map-area but apparently reached elevations between 6,000 and 6,500 feet. The position of the northeast margin is uncertain as there is a wide area of nondescript kettled topography stretching northward into Nechako River area that could be related to either ice advance.

The pattern of withdrawal of this lobe is complex. The thin extremities of the glacier may have quickly lost their mobility, become stranded in the retreat, and stagnated. However, west of the Itcha Range the ice thinned and retreated for several miles along a front. The speed of this retreat was dependent on nourishment from the source area where the ice sheet was also thinning. This source area had two means of egress, into the Anahim Lake valley to the east or through the lower Bella Coola Valley to the west. As ice accumulation decreased a stage was reached when this valley could accommodate the flow of all the ice accumulating in the source area. When this point was reached the head of the lobe of ice flowing eastward was decapitated and whatever remained stagnated in the Anahim Lake valley and in Dean River valley and melted in situ. The eskers and kettled topography of this region support this contention. Ice in the source area continued to thin, be confined to valleys, and retreat as valley glaciers.

Drumlins, Rock Drumlins, and Glacial Grooves

Drumlinoid features are relatively common but vary in abundance and development from place to place. Rock drumlins and drumlins developed by the late ice lobe are few. Shallow, widely spaced grooves characterize

the till surface of the Anahim Lake valley but elsewhere only a few scattered grooves indicate the trend of late ice movement. The grooved till of the Anahim Lake valley may have low drumlin forms but the relief is so low, 10 to 25 feet, that in most places the lee and stoss ends are indistinguishable and the ridges appear as low, elongate mounds.

The Fraser ice sheet failed in this area to produce in abundance the outstanding drumlinoid features typical of areas to the east. Only in the southeast quarter are there well-defined drumlins and rock drumlins as well as many glacial grooves. The moderately high northeast quarter, the Coast Mountains, and the Rainbow and Ilgachuz Ranges exhibit only a few drumlins and scattered glacial grooves.

In a unique situation around Towdystan in Anahim Lake valley the trends of two sets of drumlinoid features intersect at right angles (Figs. 31, 32). One set, oriented northeasterly consists of low mounds and parallel shallow intervening depressions with an indistinct outline or definition; a few mounds can be recognized as somewhat distorted drumlins. These are oriented parallel with other drumlinoid features of the Fraser ice sheet. The other set of features are southeast-trending shallow glacial grooves related to the late ice advance. These intersecting drumlinoid features are interpreted as the product of two ice advances, the former by the Fraser ice sheet and the latter by the late advance. Presumably the late ice was thin, generally inactive, and near its margin where it overrode the drumlinoid features of the Fraser ice sheet, so thin that it was incapable of destroying these earlier features and only modified them.

Similarly northwest of Rainbow Range near Squiness Lake there are rock drumlins and drumlins that indicate ice movement in opposing directions. Presumably there is a coincidence of trend between the two ice advances, the earlier moving northeast, the later moving southwest. The later movement apparently did not destroy completely the earlier features.

Eskers and Esker Complexes

Several esker complexes are noted in the area, the most prominent is along Tatla Lake Creek and Chilanko River. This is an extension of one described in Quesnel area west of Redstone. Other short complexes were noted northeast of Ilgachuz Range, east of Itcha Mountain, and northwest of Puntzi Lake but these are unusual in that they were not formed in a channel cut in the till surface.

Many single eskers or groups of single eskers are scattered through the area and although some are aligned to the ice movement many have a random orientation. Commonly they are associated with meltwater channels. Several long single eskers five to ten miles long are well-developed in the Anahim Lake valley and suggest an area of stagnant ice. Two or three of these that trend into Hotnarko River slope in a westerly direction, opposite to the direction of ice movement.

Meltwater Channels

Related to the last ice lobe are a myriad of direct overflow channels particularly on the east and northeast side of Itcha Range (Fig. 23) and from Charlotte Lake to Chilanko River. Many of these have been deepened by later drainage but all had their courses determined by the slope of the

land beyond the margin of the ice lobe. In the northeast corner, the channels are probably of a similar origin but related to the wasting of the Fraser ice sheet.

West of Itcha Range many examples of lateral overflow channels delineate the various positions of the ice margin during retreat (Fig. 20). The ice lobe east of Anahim Lake flowed easterly against the slope of the land. During retreat of the margin numerous small channels were eroded parallel to the front. Excellent examples lie between Lehman and Bryant Creeks and south of Punkutlaenkut Lake where meltwater was forced southerly along the ice front, into a shallow proglacial lake and through another channel to the direct overflow channel along Chilanko River. The normal course for run off in this section would be westerly, parallel to the present drainage. The channels indicate that the lobe retreated along a front initially.

The ice lobe did not cover Rainbow, Ilgachuz and Itcha Ranges completely and the ice contact is marked, particularly on Ilgachuz Range, by lateral overflow channels (Fig. 22). The many parallel channels show the ice contact at several stages during thinning of the ice. A few are also evident 10 miles east of Mount Kappan, north of Clearwater Lake and north of Hotmarko Lake.

Moraines

The southern edge of the late ice lobe is marked by a broad area of terminal moraine around Cariboo Flats. Here is exhibited typical knob and kettle topography with irregular hills and hummocks composed of sand and gravel (Figs. 24, 32). The belt of moraine is five to ten miles wide and extends from Chilanko River to Cariboo Flats and northwestward along the mountain front to near Kappan Lake.

The kettled topography northwest of Anahim Lake is thought to be ablation moraine deposited during the melting in situ of a mass of stagnant ice. Similar areas are so interpreted northeast of Itcha Range.

The mountainous region contains many valley end moraines; a few have been shown on the map but many more can be seen on photographs and on the ground.

Drift Ridges of Unknown Origin

Low drift ridges oriented transverse to direction of ice movement were noted at several localities northwest of Chilanko Forks and northwest of Abuntlet Lake. These resemble others in central British Columbia that have been compared to De Geer or ribbed moraines.

Near the margins of the late ice lobe on Rainbow and Ilgachuz Ranges, low, elongate mounds parallel the approximate ice limit. These may well be lateral moraines or kame terraces. They were not examined on the ground.

ADJOINING AREAS

Information from several areas adjoining those already described has contributed to the glacial picture in central British Columbia. This will be briefly outlined beginning in the north and proceeding counter-clockwise around the study region of central British Columbia (Fig. 1).

Fort St. James Map-area

Armstrong (1949, pp. 11-17) observed many glacial features in this area and determined that the ice sheet moved into the area from the northwest, crossed the area in an easterly direction and moved out of the area in a northeasterly direction. The source of much of this ice was the Omineca and Skeena Mountains to the north and northwest. The ultimate direction of movement was always easterly. Erratics indicate that ice reached elevations of at least 7,600 feet in Omineca Mountains. Drumlinoid features clearly depict the direction of flow.

West of the Fort St. James map-area the writer has recently (1969) found evidence (striae, drumlins, erratics) to indicate that high level ice moved westerly across the Babine Mountains and across the Hazelton Mountains west of Smithers. Only at a late stage did ice move easterly into Fort St. James area and then only from the Babine Lake valley. Evidence suggests that an ice centre may have existed on the mountains around Trembleur or Takla Lakes in Fort St. James map-area and flowed radially.

Whitesail Lake Map-area

According to Duffell (1959, pp. 22-26) the Whitesail Lake map-area was completely glaciated and covered by glacial ice to depths of 4,500 feet. Glacial features are common and clearly depict the direction of ice movement. Ice accumulated in the Coast Mountains and flowed northeasterly into the Interior Plateau. In the eastern part of the area the ice swung somewhat more easterly.

Bella Coola Map-area

In the Bella Coola map-area Baer (in preparation) believed the ice sheet covered the entire area except the higher peaks. He reasoned that the maximum ice elevation was to the east of his area as there are erratics at higher elevations in the Anahim Lake area. The direction of ice movement, determined by striae, was westerly or southwesterly. In the northeast quarter an exception was noted; striae suggest northeasterly movement. This he suggests as a late phase after a westward migration of the ice divide.

Ashcroft Map-area

Duffell and McTaggart (1952, pp. 69-72) found erratics and glacial striae up to 8,300 feet elevation and suggest that the whole area was covered by ice during Pleistocene time. Direction of ice movement across the area was southeasterly and southerly although initially this ice moved easterly out of Coast Mountains.

Kamloops Lake Map-area

Fulton mapped the glacial features of this area in detail, indicating that the ice moved across the area in a southeasterly direction (Fulton, 1963). He concluded that deglaciation was by downwasting. In this area of moderate relief the ice thinned and became segregated into tongues of ice lying in the valleys while the upland surface was bare.

Quesnel Lake Map-area

A study of air photographs by Smith (1965) of the Quesnel Lake map-area indicates that ice moved out of Cariboo Mountains into the Interior Plateau in a southerly and southwesterly direction. There it swung westerly and northwesterly toward Fraser River valley. Ice reached thicknesses of at least 2,000 to 3,000 feet over the plateau.

DEVELOPMENT OF THE GLACIAL CONCEPT IN BRITISH COLUMBIA

Many scientists have contributed to the understanding of Cordilleran glacial history. Practically all reports on regional geology by members of the Geological Survey of Canada and the British Columbia Department of Mines and Petroleum Resources contain a few sentences, several pages, or complete accounts of the glacial history and geology of local map-areas. In this way a great wealth of information, much of it generalized, has accumulated. In the following paragraphs some of the more pertinent contributions to the glacial geology of central British Columbia are outlined.

G.M. Dawson

In 1878 G.M. Dawson made the first comprehensive contribution to glacial studies by establishing that British Columbia was glaciated (Dawson, 1878). He presented his evidence for a province-wide glaciation insisting that it moved from north to south between the Rocky Mountains and the Coast Mountains but noted that later glaciation radiated from the mountains. He discounted the possibility of a northern ice cap, considered the accumulation of ice within the area itself, but favoured a land submergence of over 5,000 feet, southward flowing "ice-laden water", and the simultaneous deposition in water of the "boulder-clay". Dawson appealed to the rounding of pebbles in the till, the terraces on valley walls, and high-level gravel deposits or "beaches" as evidence supporting the submergence of the province and glaciation according to the iceberg theory. His concept of a later glaciation from the mountain valleys appears to involve the iceberg theory of glaciation as well as the glacier ice theory and to this stage of glaciation he attributed the formation of most moraines.

By 1881 Dawson's views had changed slightly and were summed up as follows: "It therefore appears to remain as the most probable hypothesis that a great glacier mass resembling the inland ice of Greenland has filled the region which may be called the Interior Plateau, between the Coast Mountains and the Gold and Rocky Mountain ranges, moving (though perhaps very slowly) southward and southeastward from the region of great precipitation and high mountains of the northern part of the province, and discharging by the Okanagan depression and through the transverse valleys of the coast range. It still appears to be most probable, however, that this stage of the glacial period was closed by a general submergence, during which the deposit referred to as Boulder-Clay was laid down in the interior plateau, and that as the land again rose it assumed its present terraced character..." (Dawson, 1881, p. 283).

By 1888 Dawson had accepted the glacial theory. He decided that ice had accumulated within the interior of British Columbia and "the main gathering-ground or névé of the great Cordilleran glacier of the west coast, was included between the 55th and 59th parallels of latitude in a region which, so far as explored, has proved to be of an exceptionally mountainous character. It would further appear that this great glacier extended, between the Coast Range and the Rocky Mountains, south-eastward nearly to latitude 48 degrees, and north-westward to latitude 63 degrees, or beyond, while sending also swollen streams to the Pacific Coast" (Dawson, 1888, p. 349). In this reference Dawson named the ice sheet, the Cordilleran glacier and considered it an ice mass separated from the Laurentian ice sheet.

In 1889, Dawson restated his position but did not conceive of the ice reaching elevations above 7,200 feet in central British Columbia. He spoke of the "recession of the main front of the great confluent glacier beneath which the interior or plateau region of British Columbia was buried". He envisaged its decline by breaking up "into numerous local glaciers confined to the valleys of the several mountain ranges which limit the plateau" (Dawson, 1889, p. 350). He talked less of the submergence of the province and now postulated ice sheets up to 6,000 feet thick, a situation compared to that of Greenland.

In 1890 (Dawson, 1891) he advanced his most comprehensive report on glacial geology of the Cordillera. His concept involved the accumulation of snow and ice in the mountains, particularly along the Coast Mountains, forming valley glaciers and eventually an ice sheet completely burying the Cordillera. This mass he believed moved slowly southeasterly through the Interior Plateau from a main ice centre in northern British Columbia. North of this centre the ice moved northwesterly into the Yukon. Some of the ice escaped westerly to the Pacific Ocean by way of through-valleys.

Dawson completely abandoned his concept of inundation by the sea to account for deposition, as he thought, of boulder-clay in water. Instead he now appealed to a deglaciation and virtual stagnation of the ice sheet and the formation of englacial lakes around the melting margins of the mass. As these margins retreated the boulder-clay was supposedly deposited in the lakes which, occurring at several elevations, produced the terraces and supposed beaches.

The Cordilleran glacier was supposed to have broken up into valley glaciers and retreated to the mountains. This permitted re-elevation of the province and initiated a second advance of ice of lesser extent that formed valley glaciers which pushed out into the Interior Plateau. A second depression of the province forced a withdrawal of the ice and this was followed by renewed elevation of the Cordilleran region.

Many of Dawson's conclusions were based on misinterpretation of features and were influenced by the conflicting arguments of a then current evolving glacial hypothesis. However, he contributed more to the overall concept of a Cordilleran ice sheet in British Columbia than any other geologist. His arguments and conclusions, although in many instances erroneously founded, were the antecedents of later ideas based on factual evidence and accepted principles.

G.S. Malloch

Working in the upper Fraser River valley, Malloch (1910, p. 128) recognized two tills, an older one derived from the Rocky Mountains and a younger one derived from the west.

J.B. Tyrrell

Based on a brief observation around Prince George and Quesnel, Tyrrell (1919) questioned the existence of a great Cordilleran ice sheet as envisaged by Dawson. His argument was that the area was not geomorphologically compatible with the concept of an ice sheet.

W.A. Johnston

In 1926 Johnston discounted Tyrrell's objection to a Cordilleran glacier and accepted Dawson's belief in a southeast moving glacier (1926, p. 138) with a maximum thickness not much greater than 3,000 feet. He recognized in the Cariboo Mountains at least two till sheets and postulated an interglacial period. He proposed that the term "Cordilleran system of intermontaine, piedmont and valley glaciers" was more suitable than Cordilleran glacier (Johnston, 1926, p. 147).

F.A. Kerr

Kerr worked in northern British Columbia in the area described by Dawson as the gathering ground of the Cordilleran glacier and evolved a theory of four stages of glaciation applicable to a mountainous terrain. He summarizes his conclusions as follows (Kerr, 1934, p. 17): "Glaciation in northern British Columbia is divided into four types: alpine, intense alpine, mountain ice sheet and continental ice sheet. During alpine glaciation glaciers were limited in extent as at the present time and followed the normal water gradients. In intense alpine stages the glaciers were more extensive and accumulation of ice in axial areas of such mountain systems as the Coast Range became so great that all major valleys including trans-range valleys were blocked with ice and in these as well as elsewhere ice moved outward from the axial areas. During mountain ice sheet stages ice was so extensive that systems such as the Coast and Cassiar were capped by ice sheets which moved outward from the axial areas. In continental ice sheet stages the whole of northern British Columbia was covered with ice which moved outward from a centre at the headwaters of the Cottonwood, Jennings and Inklin rivers and moved in places across mountain systems such as the Coast and Mackenzie ranges."

W.H. Mathews

The most prolific writer in recent years on geomorphology, glaciology, glacial geology and other Pleistocene phenomena related to the Canadian Cordillera is W.H. Mathews. His work in several areas has

provided specific information bearing directly on the Cordilleran glaciation as a whole. He was directly responsible for the compilation of a glacial map of British Columbia (British Columbia Atlas of Resources, 1956) and contributed the Cordilleran part of the glacial map of Canada for the Geological Association of Canada (Wilson et al., 1958).

In 1944 Mathews collaborated in presenting a hypothesis of four phases of glaciations in southwestern British Columbia (Davis and Mathews, 1944). The four phases proposed, closely resembled Kerr's four phases of ice-sheet development but related erosional forms were clearly defined.

Mathews described (1944, pp. 39-57) several lake basins in southern British Columbia around Kamloops and Merritt that were a result of ice dams. He postulated that ice retreated northwestward and northeastward along an arcuate front and arms and lobes of this ice front dammed the normal drainage systems forming lake basins in which glacial silt was deposited.

In northern British Columbia, with Watson, he described the glacial features of the Tuya-Teslin area where southwesterly movement into the Coast Mountains was postulated (Watson and Mathews, 1944). From this area he also described Pleistocene volcanic rocks with the typical exposure in this area of tuyas originating by subaqueous-subaerial eruption of basic lava through intraglacial lakes (Mathews, 1947, p. 568).

In the Carbon Creek-Mount Bickford map-area, in the Rocky Mountains south of Peace River, he found evidence of glaciation to 6,000 feet and suggested "that the ice-sheet covered the highest peaks of the area" (Mathews, 1946, p. 17). An easterly movement of the ice was interpreted and no evidence of more than one glaciation was found.

In a brief abstract (Mathews, 1950, p. 1529), he indicated in the Lightning Lakes area of southwestern British Columbia that ice had left the Cascade Mountains while it still blocked valleys in the Interior Plateau.

In another abstract (Mathews, 1955, p. 1657), he defined an ice divide (see British Columbia Resources Conference, 1956, Map 4, p. 10) extending southeasterly from Cariboo Mountains across Bonaparte Lake map-area to Coast Mountains and thence northwesterly following an irregular line east of the Coast Mountains. Movement out from this divide was postulated and this concept would envisage ice moving through the valleys of the Coast Mountains to the Pacific Ocean. In its recessional stages the ice surface slope was also outward from this divide.

In Mount Garibaldi map-area in southwestern British Columbia, he reported southwesterly ice movement during the last regional glaciation. Evidence of glaciation to 7,000 feet elevation was noted (Mathews, 1958, pp. 183-185). In this area he also studied and described in detail Pleistocene volcanic phenomena.

In 1963 Mathews described the glacial history of the Fort St. John region of northeastern British Columbia (Mathews, 1963) where he found "a twice repeated succession of gravel overlain by sand, silt, and clay, and each of these in turn by till of eastern origin". He records that Cordilleran ice reached to within 15 miles of Fort St. John, overriding areas from which earlier Laurentide ice had withdrawn. He reports this Cordilleran ice as having moved across the Rocky Mountains, fanned out on the plains, and formed a drumlinized area whose pattern truncates that of the Laurentide ice. He found no evidence that the two sheets coalesced.

J.E. Armstrong

In 1948 Armstrong and Tipper (1948) described the glacial features of north-central British Columbia from airphotographs and ground observations. They showed that the last ice moved across the area in a northeasterly direction as a confluent mass from the northwest, west and southwest. They postulated two ice advances to account for the drumlinized plain developed and advanced the hypothesis that the final deglaciation was by stagnation and melting in situ. The main area of accumulation was believed to be in the Coast Mountains at about the latitude of Queen Charlotte Sound but there were several other distinct but smaller ice centres.

Armstrong discussed the glaciation of the Fort St. James area where ice moved across the area in an easterly and southeasterly direction from the Omineca Mountains (Armstrong, 1949). He contributed to the knowledge of the glacial stratigraphy and history of the lower Fraser Valley (Armstrong and Brown, 1954; Armstrong et al., 1965). In 1966-67 he studied the Prince George map-area and found evidence for at least three ice advances with, in places, interglacial deposits (Armstrong and Leaming, 1968, pp. 151-152, 1969).

A. Sutherland Brown

In several publications Sutherland Brown has contributed to the glacial geology and history of British Columbia. He presented evidence for considering Cariboo Mountains as a centre of accumulation from which ice moved outwards (Sutherland Brown, 1957, pp. 14-15; 1963, pp. 9-11). He believed that the mountains were capped with ice above which only a few peaks projected; erratics were found to near 7,000 feet elevation. Evidence for erosion by the ice sheet is scant and the ice cap was considered to be nearly static; in the lower slopes of the range and on the plateau there is good evidence of the outward movement of the ice.

H. Nasmith

Recently Nasmith described the glacial deposits and history of the Okanagan Valley in southern British Columbia (Nasmith, 1962). The ice is postulated to have flowed from the Monashee and Coast Mountains and to have coalesced into one mass moving southward across the 49th Parallel. The ice sheet at its maximum covered most of southern British Columbia to an elevation of 7,000 feet or more. A climatic change is postulated, either less precipitation or increase in rate of melting, to account for the wasting of the glacier. As the ice surface lowered, the ice stagnated and retreated from the margin.

R.J. Fulton

In recent years Fulton has mapped the glacial geology of the Kamloops area (Fulton, 1963) where deposits indicate a southeasterly moving ice sheet covered the area. Fulton believed that "the last ice sheet retreated

largely by downwasting, tongues of ice remaining in the main valleys after the surrounding uplands were bare". In a later report, Fulton (1967) discussed deglaciation in an area of moderate relief defining four phases of deglaciation, an active phase, transitional upland phase, stagnant phase, and dead ice phase. Each tongue of ice retreated in response to local conditions. He inferred that "valley glaciers from the Coast, Cariboo, and Monashee Mountains fed piedmont glaciers in the Interior Plateau. Piedmont glaciers from the rimming mountains joined in a single sheet that ultimately overrode the Interior Plateau. The interior ice sheet, hemmed in by the mountain chains to the east and west, flowed north and south from a central dome formed in the vicinity of the 52nd parallel" (Fulton, 1967, p. 1).

GLACIAL HISTORY OF CENTRAL BRITISH COLUMBIA

The entire history of the glacial episode in central British Columbia is impossible to outline with the limited available information. Only that part for which there is a surficial and geomorphic record can be described with any confidence; the earlier glaciations, known mainly from till layers seen in section, are largely a subject of speculation. The Fraser ice sheet and the late readvances will be described first and some ideas on earlier glaciations will be subsequently outlined.

The four stages of mountain glaciation outlined by Kerr (1934) or the four phases of Davis and Mathews (1944) show a logical development of an ice sheet in a mountainous terrain. The history of central British Columbia will be described using Kerr's sequence of events and terminology; the terms alpine, intense alpine, mountain ice sheet, and continental ice sheet have the advantage of visualizing the stage of glaciation. These terms will be used essentially as envisaged by Kerr.

FRASER GLACIATION

Alpine Stage

With the onset of glacial conditions, snow and ice accumulated in the mountains in heavy precipitation areas, namely Coast and Cariboo Mountains in central British Columbia. Other ranges in central British Columbia, such as Nechako, Fawnie, Rainbow, Ilgachuz, and Itcha may have had an accumulation of ice as evidenced by the few small cirques that indicate a limited glaciation. Whether all such alpine glaciers developed synchronously is debatable; most likely glaciers formed in the higher, wetter mountains first. In any event alpine glaciers formed initially, were confined to individual ranges and were single features. Sculpturing of the ranges produced fairly rugged peaks and ridges. Glaciers were following a natural gradient and valley glaciers were developing. The present glacial conditions resemble the alpine stage of glaciation.

Intense Alpine Stage

The intense alpine stage was characterized by more extensive glaciers. The axial valleys of the mountains were filled and tongues of ice were moving outward from the axis toward the lower country. The direction of ice movement was along the valleys but not necessarily in the direction of slope.

In the Coast Mountains the axis of the range was a mass of coalescent valley glaciers commonly overflowing the valleys and crossing divides. Present snowfields probably mark the axis of the ice mass during this stage but evidence for this is lacking. All valleys became clogged with ice. The "through valleys" or "transrange" valleys such as Homathko and Dean River valleys had so much ice pouring into them that it was not possible for all of it to flow down the slope. As a result, where ice build-up was great enough, it flowed up-slope at the eastern end out onto the plateau. As the build-up progressed, the topography exerted less and less control over the direction of flow, particularly the slope of the valleys. The valley walls continued to exert a guiding influence on the direction of flow of the tongues of ice reaching out into lower country from the axis of the range.

In the Cariboo and Columbia Mountains the glaciers grew to valley glaciers, filled the valleys with ice, and flowed radially into lower country. The Premier Mountains in particular were a main gathering ground from which tongues of ice reached the Rocky Mountain Trench (R. B. Campbell, pers. comm.) and flowed along it. As most of the valleys in general slope radially from this range, the glaciers were moving down-slope in most cases.

It is doubtful if the ranges of the Interior Plateau ever reached the intense alpine stage of glaciation. Some ranges such as Rainbow and Ilgachuz Mountains have long valleys that obviously had valley glaciers but the topography of the ranges suggests that glaciers were confined to and completely controlled by the valleys in which they lay. It should be borne in mind that this limited glaciation of the interior ranges could be related to late readvances rather than Fraser Glaciation or to both advances.

Mountain Ice Sheet Stage

In the mountain ice sheet stage the main gathering grounds, Coast Mountains and Cariboo-Columbia Mountains, were capped by ice sheets that flowed outward from the axis or centre of the range. The direction of movement would be influenced by topography only in the outer limits of the mountain ranges and on the plateaus near the ice margins. The tongues of ice extending out from the mountains would coalesce and form an apron-like piedmont glacier which would have an irregular margin and be influenced in direction of flow only by major topographic features.

During this stage the Coast Mountains were completely engulfed by the ice and only the higher peaks projected above the ice surface. The through valleys, or any valleys, had little if any influence on the direction of flow. The ice divide may have lain, as suggested by Baer (in preparation) east of the crest of the mountain chain but there is no evidence to suggest a divide east of the mountains, that is, over the Interior Plateau, during this or any later stage.

The Cariboo Mountains were completely dominated by an ice cap, that, in the opinion of some workers (Sutherland Brown, 1957, p. 14, Campbell, R.B. pers. comm.) was nearly static at its centre but increasingly active towards its margin. Presumably only the higher peaks projected above the ice surface. The ice moved radially from this range, from a centre or possibly from an axis, but in any event out onto the plateau to the west and south and into the Rocky Mountain Trench to the northeast. Presumably the direction of flow was controlled by topography only in the outer ranges of the mountains.

Continental Ice Sheet Stage

This stage of glaciation was reached in northern British Columbia when the ice accumulated to such a thickness that a sheet of ice spread across the whole Cordillera and flowed northeast and southeast through the Coast Mountains, from a central ice dome. Recognition of such a stage in northern British Columbia is reasonable and is a fair interpretation of the available evidence.

However, in central British Columbia, there is no evidence to indicate the development of an ice sheet domed over the Interior Plateau from which the ice flowed east or west or radially. The evidence from the several areas of central British Columbia suggests only a great expansion of the piedmont glaciers into one coalescent mass that, had it continued to thicken might have reached an ultimate continental ice sheet stage (Fig. 33). The stage of development reached might be described as an initial continental ice sheet stage that was terminated by the beginning of deglaciation.

The history of this final stage in the advance of the Fraser ice sheet is well documented in the features preserved throughout central British Columbia. The piedmont glaciers developed along the margins of the ice centres, thickened, expanded, and flowed onto the Interior Plateau. The Coast Mountain ice flowed in a general northeasterly direction across Nechako Plateau, northeasterly and easterly across Fraser Plateau, and southeasterly across Thompson Plateau.

The Cariboo Mountain ice flowed radially and presumably in the Bonaparte Lake map-area southwesterly moving Cariboo Mountain ice met northeasterly moving Coast Mountain ice along a probable northwesterly-trending front. This coalescing of the two ice sheets would force a diversion in the direction of flow forcing the sheets to split into northwesterly-trending ice and southeasterly-trending ice. Presumably this southeasterly segment, with additions from Monashee Mountains, southern Coast Mountains, and other local centres became the ice sheet that eventually reached southeasterly beyond the 49th Parallel.

Ice also moved into central British Columbia from the northwest from the Skeena and Omineca Mountains. This ice moving southeasterly from the ice centre in northern British Columbia, met the northeasterly moving ice of the Nechako Plateau and swung easterly and northeasterly in a confluent flow.

As these piedmont glaciers thickened and expanded, they formed a great coalescent mass which, north of Bonaparte Lake map-area converged on Parsnip River, north of Prince George. Up to this point in time the ice had thickened sufficiently that it was capable of overriding practically all the

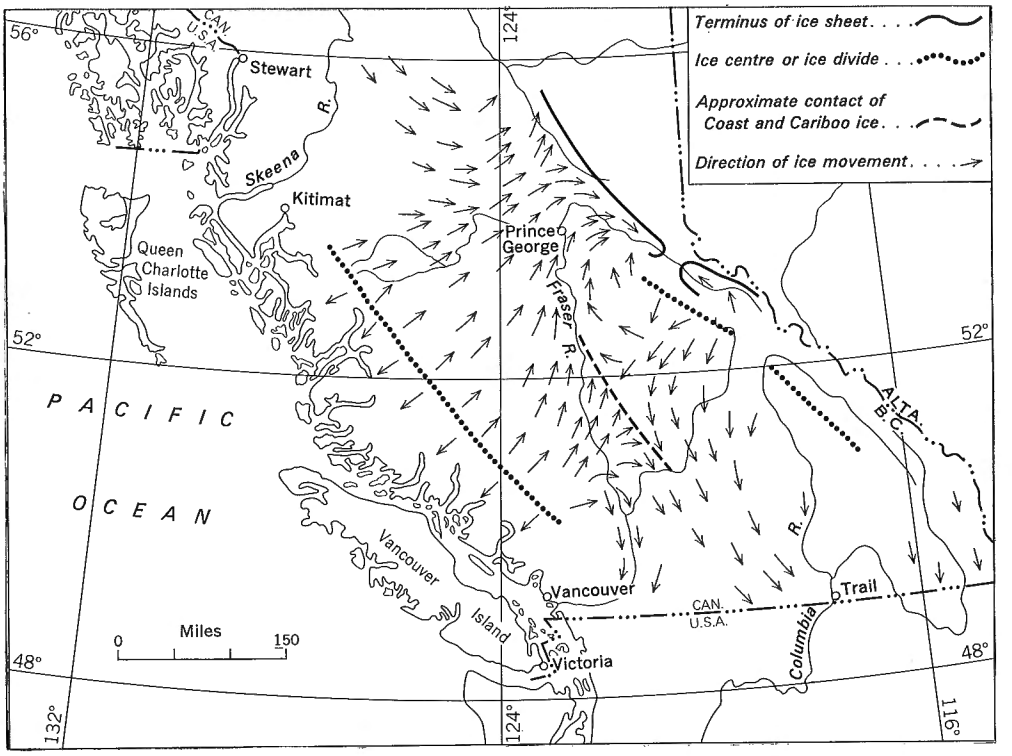

Figure 33. Maximum extent of Fraser ice sheet in central British Columbia.

main ranges of the Interior Plateau. The trends of ice movement as determined by high level features in central British Columbia suggest that the ice was sufficiently thick to move over practically all the topographic features without being diverted from a direct line of flow from the source area to Parsnip River; only the pressure of coalescing ice sheets caused a streamlined diversion. After crossing Parsnip River the ice sheet met an insurmountable barrier, the Rocky Mountains. The evidence from McLeod Lake map-area indicates that the ice rode up the sides of the Rocky Mountains to an elevation of only 3,500 feet and the ice sheet was diverted southeasterly up the upper Fraser River valley and northerly down Parsnip River valley toward Peace River. How far the ice went along these valleys is unknown but the margin of the ice along the southwesterly slope of the Rocky Mountains is marked by large meltwater channels, pitted terrain, and an abrupt change from a thoroughly drumlinized surface southwest of the margin to one with only a few indistinct grooves. This evidence, together with the diversion along Fraser and Parsnip Valleys, convinced the writer that the ice did not override the Rocky Mountains during the Fraser ice advance and that its terminus lay just east of Parsnip River.

The thickness of this ice sheet varied inversely as the distance from the source. Thus in Anahim Lake area it overrode Tsitsutl Peak and must have been more than 5,000 feet thick; to have accomplished this without being diverted by the range suggests considerably thicker ice. A comparable

thickness of ice would also be required in Whitesail Lake and Mount Waddington map-areas. In the Prince George map-area the ice appears to have split around Mount George and the hills to the south suggesting a thickness of no more than 1,500 to 2,000 feet. To the northeast the thickness would be expected to decrease so that near Parsnip River 1,000 feet or less might be all that is required to explain the evidence.

Argument against an Ice Dome over Interior Plateau

A concept of a radially flowing ice dome over the Interior Plateau has been held by several workers since Dawson's investigations. He likened the maximum ice condition to that of Greenland with ice flowing through the valleys of Coast Mountains, from an interior ice mass to the Pacific Ocean (Dawson, 1881). Kerr certainly envisaged an ice dome in northern British Columbia (Kerr, 1934), and the correctness of his conclusion would encourage a similar hypothesis farther south. Mathews defined an ice divide that lay over the Interior Plateau but near the Coast Mountains (Wilson et al., 1958; Mathews, 1957). From this divide the ice surface sloped outward and the flow was outward. In a recent publication Fulton accepted Mathews' view as follows: "The interior ice-sheet, hemmed in by the mountain chains to the east and west, flowed north and south from a central dome formed in the vicinity of the 52nd parallel" (Fulton, 1967, p. 1). The development of an ice dome over central British Columbia would be a maximum condition or stage of a Cordilleran glaciation but, as mentioned previously, the writer does not believe this stage was ever reached during Fraser Glaciation.

It is conceivable that ice flowing into the mountain-fringed basin of the Interior Plateau would thicken and fill the low interior. This elevation of the region's surface could change the pattern of precipitation so that the Interior Plateau would become a major centre of snowfall and hence an area of accumulation of ice. With a build-up in the interior, an ice dome would form at an accelerating rate and when the domed surface became higher than the ice in the through valleys of the encircling mountains, the ice would flow radially. If the dome became thick enough it could flow over the Coast, Cariboo, and Rocky Mountains.

The difficulty in accepting this hypothesis is that in deglaciation the process is not reversible. If a simple valley glacier is considered, it is apparent that its retreat will recapitulate roughly in size and shape the stages of advance but in reverse order. This could not happen with an ice dome. During deglaciation the lower and marginal areas for a dome would melt first, that is, in the fringing mountains. Even with considerable downwasting, the lower parts should melt first or even if there were a uniform lowering of the ice surface, such an ice sheet would retreat to a centre on the Interior Plateau, not in the mountains. Such a centre would, during the retreat and wasting, exhibit radial flow and it should be expected that drumlinoid forms would be in evidence related to this flow. There are no such forms in central British Columbia, only those indicating unequivocal ice flow from the Coast and Cariboo Mountains. The great flood of glacial erratics carried into central British Columbia from the Coast Mountains clearly demonstrate the dominant direction of transport but are not in themselves conclusive proof. An explanation of a few areas of erratics that contradict this general flow pattern is given in a later section.

Deglaciation

The manner of deglaciation of an area is to a large degree a function of its topography. The recession of an ice front in an area of low relief is well known and typical of the Laurentide ice sheet withdrawal. In a mountainous region, Kerr (1934) believed the ice sheet waned following his four stages of alpine glaciation but in reverse order. Fulton (1967) studied deglaciation in an area of moderate relief and contended that it was accomplished by downwasting, stagnation along valleys and eventual decay in separated blocks of dead ice. Central British Columbia offers a topography varying from the flat Nechako Plain to the high relief of the Coast Mountains; between these extremes are many variations. With such a complex topography, a complex deglaciation history should be expected, a composite of deglaciation in areas of high, moderate, and low relief.

Very little attention has been paid to the manner of deglaciation by geologists writing on glacial history in British Columbia. Influenced by the concept of frontal retreat of the glacier in eastern and central North America and by the obvious ice margin retreat of most existing alpine glaciers, they apparently assumed that the Cordilleran ice receded from its terminus to its centre of accumulation. Dawson briefly suggested the possibility of stagnation in the central areas but believed that the ice retreated normally in the mountains (Dawson, 1891). Armstrong and Tipper (1948, p. 307) advanced the theory that the last ice sheet stagnated and melted in situ over broad areas of the Nechako Plain and Plateau. In mountainous areas they believed the ice retreated in the normal manner.

Deglaciation of central British Columbia began shortly after the advancing ice crossed Parsnip River and was diverted by the Rocky Mountains. The ice apparently thinned and receded from its terminus along a front across the Nechako Plain and Plateau. As the front retreated to the hillier country of the northern part of Fraser Plateau (south of Blackwater River) the thinning ice was gradually diverted by the higher hills and channelled into major valleys. As the ice continued to thin it lost its mobility over wide areas, broke up into blocks lying in small valleys, stagnated and decayed. Along some major valleys such as Fraser River the ice probably retreated along a front but over a wide area of moderate relief in Quesnel, Anahim Lake, and Nechako River map-areas the ice had ceased to act as a single sheet of ice. While this stagnation and decay was in process in the central areas the main ice sheet had degenerated to apron-like piedmont glaciers skirting the margins of the Coast and Cariboo Mountains. These glaciers retreated steadily, more or less along an irregular front, separated into valley glaciers, and continued receding in a manner envisaged by Kerr.

The writer does not believe that ice stagnated over all of central British Columbia but prefers to attribute the evidence for stagnation to several broad ice masses successively stranded as the active ice front retreated. These separated blocks wasted away independently. The downwasting stressed by Fulton (1967) permitted large areas to lose their mobility and destroyed any possibility of an orderly retreat of an ice front unaffected by topography.

The lack of end moraines has been cited as evidence that ice stagnated over large areas. This situation is more apparent than real and the writer believes that moraines will be recognized in detailed studies. In areas where lateral overflow channels are abundant, end moraines could be

repeatedly destroyed. A steady and rapid retreat would not produce end moraines visible on air photographs. Possibly many of the drift ridges of unknown origin are end moraines. Whatever the explanation for their obscurity, end moraines may be more common than formerly believed.

The retreat of the ice down Fraser River ponded large lakes at the ice front. The Prince George Lake basin extended from south of Williams Lake to Prince George, up Nechako and Chilako Rivers to the west and up the Fraser River to near McBride (R.B. Campbell, pers. comm.). The level of this lake was maintained at about 2,500 feet elevation by a bedrock lip at its outlet, either at Summit Lake or at Arctic Lake on the divide between Parsnip and McGregor River (east of McLeod Lake map-area). These northern outlets would persist so long as ice blocked Fraser River to south or some other low outlet.

The retreat of the ice sheet does not appear to have been uninterrupted. For example, near Vanderhoof, there is evidence that ice briefly readvanced over lake deposits formed at its margin. How widespread or recurring such events were, is unknown.

LATE GLACIAL READVANCES

The final alpine deglaciation stages of the Fraser Glaciation are obscured by late advances of ice from Coast Mountains and from Cariboo Mountains. Whether this late stage is a separate advance completely divorced from the Fraser Glaciation or a readvance of that glaciation after a partial retreat, is unknown. Rather than considering it a separate, limited glaciation, it is tentatively thought to be a readvance of the Fraser ice sheet after recession to an alpine or intense alpine stage. Whether a readvance or a new advance is of little importance in the interpretation of the evidence except for the possibility of an interstade having occurred.

Ice Advance

The ice of the Fraser ice sheet had probably withdrawn into the mountains leaving the Interior Plateau free of ice except for a few cirque glaciers on the interior ranges and possible scattered stagnant or dead ice masses in some areas. The low interior was probably completely free of ice and through valleys of the Coast Mountains may have been open or may have been filled with ice flowing westward.

Ice began to accumulate again and the build-up followed the same pattern as with the Fraser Glaciation. The mountain valleys became choked with ice, the through valleys could not carry all the ice to the west and ice began pushing eastward from the Coast Mountains and radially from the Cariboo Mountains. From Monarch Mountain region ice moved northward into the southwest quarter of Anahim Lake map-area and swung eastward to the Anahim Lake valley. Here it fanned out to the southeast, to the east between the Ilgachuz and Itcha Mountains, to the north down Dean River, thence eastward along Blackwater Valley and westward down Dean River. The eastern terminus is not known but is thought to have been just east of Itcha Mountains. Thickness of the ice was about 3,000 feet as the ice reached an elevation of 6,500 feet on Rainbow, Ilgachuz, and Itcha Mountains; near

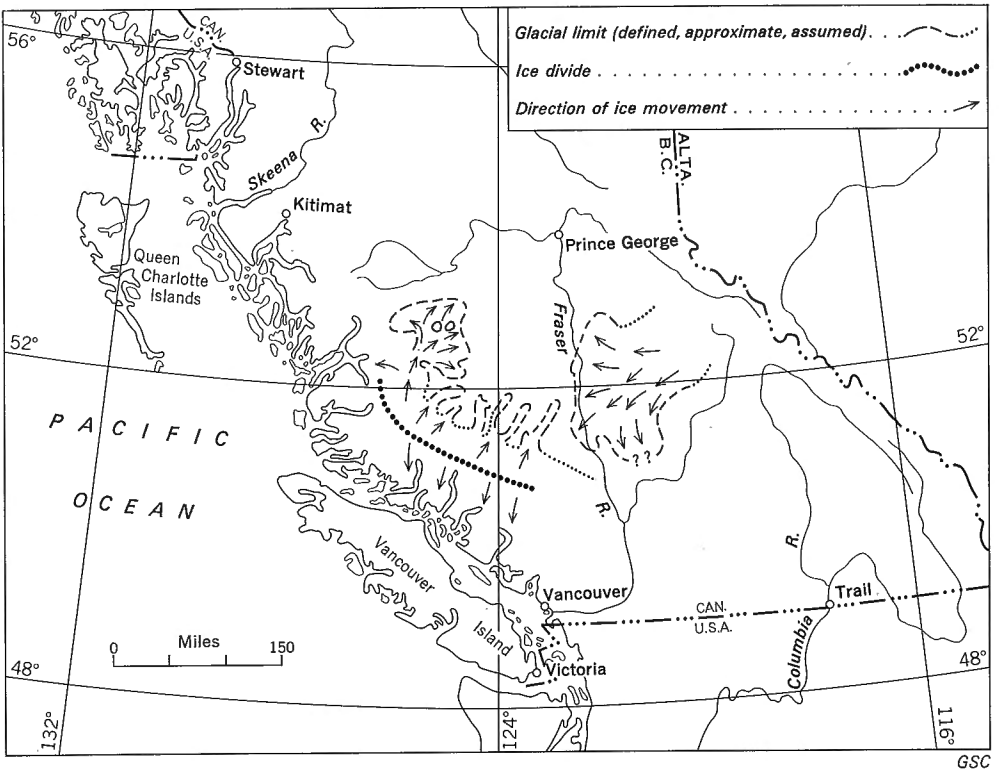

Figure 34. Maximum extent of late ice readvance in central British Columbia.

the margins it was undoubtedly thinner. In Mount Waddington map-area tongues of ice extended easterly from Klina Klini, Tatlayoko and Chilko Valleys for an unknown distance, possibly to the vicinity of the northeast corner of that map-area. In Taseko Lakes the valley glaciers extended down Konni Lake valley to Taseko River, out of Taseko Lakes valley, and down Big Creek to Chilcotin River. All these tongues and lobes were separate entities and did not coalesce into a piedmont sheet (Fig. 34).

Ice from the Cariboo Mountains presumably radiated from the range but only the southwesterly flow from the range is known to the writer. This ice moved out of Quesnel Lake valley, along Canim-Mahood Valley, and down Clearwater Valley. When it reached the lowlands it fanned out, crossed Fraser River westerly, blocking that river as well as Chilcotin River, and moved south and southeasterly across Bonaparte Lake map-area and northwesterly into Quesnel map-area. The western terminus of the ice is clearly delineated by lateral overflow channels and a sharp intersection of drumlinoid forms of this advance and the Fraser ice sheet. The termini of the northwesterly and southeasterly movement are not easy to distinguish on air photographs as the trend of their drumlinoid forms coincides with those of earlier advances and prominent terminal moraines are lacking.

The southeasterly limit of this advance is probably somewhere north of Kamloops if movement southeasterly approximates in distance that of the westerly movement.

Ice Retreat

Deglaciation of these late readvances involves normal ice front retreat and stagnation. The western part of the Cariboo Mountain ice lobe separated from the main mass and melted as a stagnant mass. The main part of Cariboo Mountain ice retreated, largely as separate valley glaciers (see Bonaparte Lake map-area).

The Coast Mountain ice tongues and lobes initially retreated along a front but when the ice had been reduced sufficiently to permit the through valleys to carry the ice, the frontal parts of these masses were stranded, stagnated, and wasted away (see Anahim Lake map-area, Mount Waddington map-area). Once the ice flow had been adjusted to valley flow down slope retreat continued to an alpine stage and possibly complete dissipation of the ice sheet. Whether the present glaciers are remnants of the late readvances or a still later brief return of glacial condition is not known.

EARLIER GLACIATIONS

Repeated glacial episodes are known in the Yukon and southwestern British Columbia as well as with the Laurentide ice mass. Evidence for multiple glaciation, although scant, is present in central British Columbia. Johnston (1926) postulated more than one ice sheet in Cariboo Mountains. Armstrong and Leaming recognized at least three distinct till sheets, possibly four, and related each to a separate ice advance (Armstrong and Leaming, 1968, p. 151). The writer has accumulated some evidence of glacial episodes earlier than the Fraser Glaciation.

In Figure 35 location of several erratics and their probable source are illustrated. These stand out because of the impossibility of reaching their present position through the agency of the Fraser ice sheet or the late readvances. These erratics are small, well-rounded, and generally spherical to elliptical in cross-section; their shape and size suggest intense abrasion. Erratic No. 1 is a chert-pebble conglomerate boulder about 6 inches in diameter, fresh and unmetamorphosed, similar to Mesozoic conglomerates of the interior. All remotely similar conglomerates in the Coast Mountains are sheared and altered. Erratics No. 2 are cobbles and pebbles of Tertiary vesicular basalt for which there is no known source to the southwest. They vary in size from 1 inch to 8 inches and the average size noticeably decreases from northeast to southwest over a distance of 5 to 10 miles suggesting a decreasing distance from the source. Erratics No. 3 are fossiliferous greywacke boulders up to 10 inches diameter. For stratigraphic reasons it is highly improbable that the source could be to the south or southwest within the Coast Mountains. Furthermore they lack the metamorphic effects common to sedimentary rocks within the Coast metamorphic complex. Erratics No. 4 are abundant chert-pebble conglomerate boulders derived from outcrops to the north. Similarity of rock type and abundance suggests this local relationship.

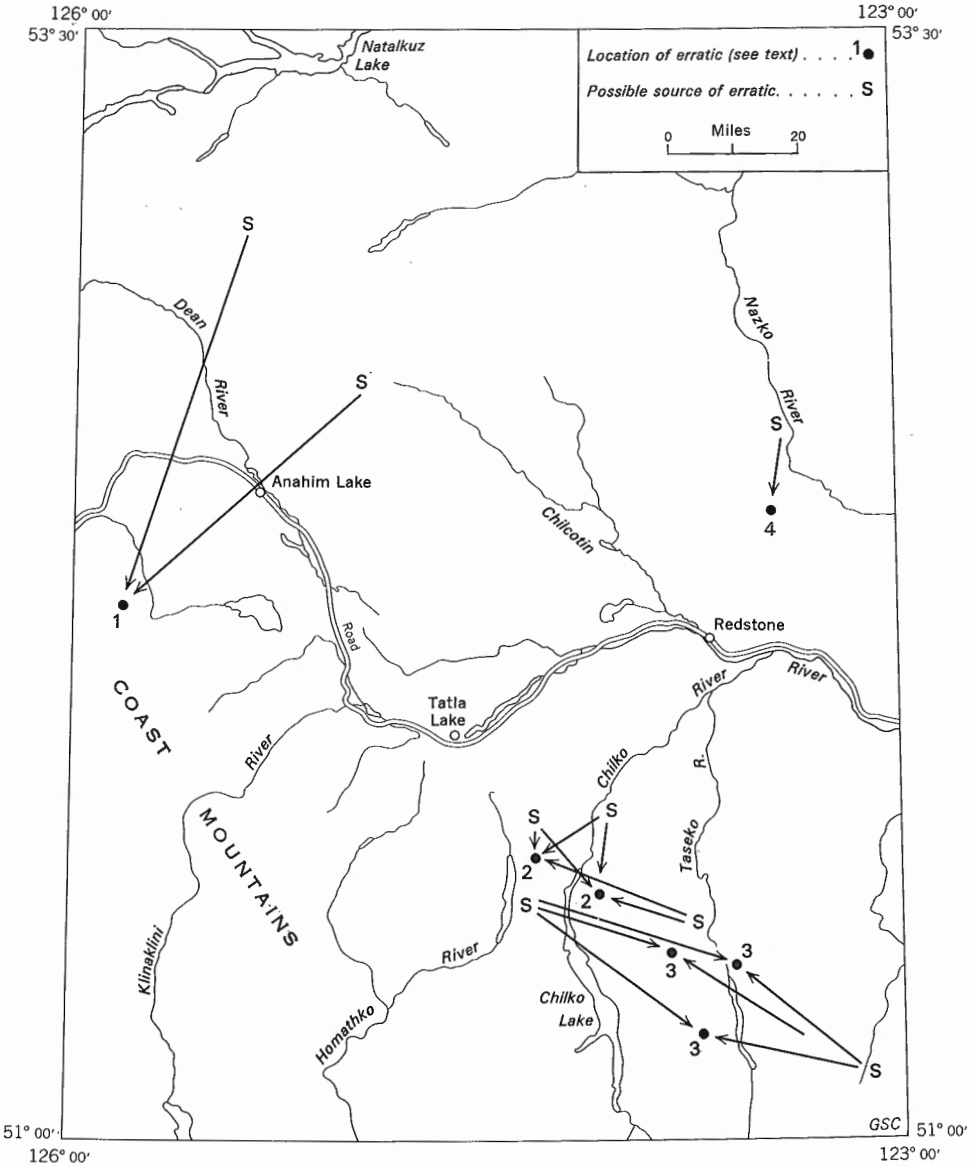

Figure 35. Location of erratics and the possible sources. Movement is attributed to glaciations earlier than the last Cordilleran ice sheet.

These erratics suggest movement from the Interior Plateau toward the Coast Mountains, evidence contradictory to movement by the Fraser ice sheet. This evidence coupled with the argument against an ice dome as the ultimate stage of the Fraser ice sheet suggests strongly that these erratics obtained their position through the action of an earlier glaciation and that the climax of this earlier glaciation was an ice dome flowing radially from central British Columbia.

Further corroborating evidence for such an ice dome exists in the Rocky Mountains. In McLeod Lake map-area glacial grooves were noted on the Rocky Mountains at elevations up to 5,800 feet and suggested that ice had completely overridden the range. Mathews (1946) reported that ice was active over the range south of Peace River at 6,000 feet and subsequently he reported (1963) that Cordilleran ice crossed the Rocky Mountains and reach nearly to Fort St. John. Roed, Mountjoy and Rutter (1967) found that in the area of the Rocky Mountains around Jasper, Alberta, Cordilleran ice had moved easterly through passes in Selwyn Range to elevations of 7,100 feet and transported westerly-derived erratics to the Edson area, in the Athabasca Valley, east of Rocky Mountains. Which glaciation this is related to is not suggested.

This evidence suggests (a) that ice flowed radially from an ice dome in central British Columbia, (b) that ice flowed over and through the encircling Coast and Rocky Mountains, and (c) that this earlier ice was thicker and spread farther than the Fraser ice sheet; ice must have been considerably thicker to have overridden the Rocky Mountains. Such a situation is compatible with present knowledge in the Yukon where an earlier glaciation was more extensive than the last ice advance.

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