

# GLACIATION IN NORTH CENTRAL BRITISH COLUMBIA<sup>1</sup>

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**ABSTRACT.** Described in detail are many of the glacial features of north-central British Columbia, the more important of these being the widespread development of remarkable, nearly parallel drumlins and intervening depressions or groovings, three large compound eskers; and three large glacial-lake basins, characterized by white silt deposits. The present paper also reviews the glacial history of the region and the writers outline their reasons for believing that the ice forming a Cordilleran ice sheet accumulated in the mountains, particularly the Coast Mountains, and that the ice moved eastward across north-central British Columbia.

## INTRODUCTION

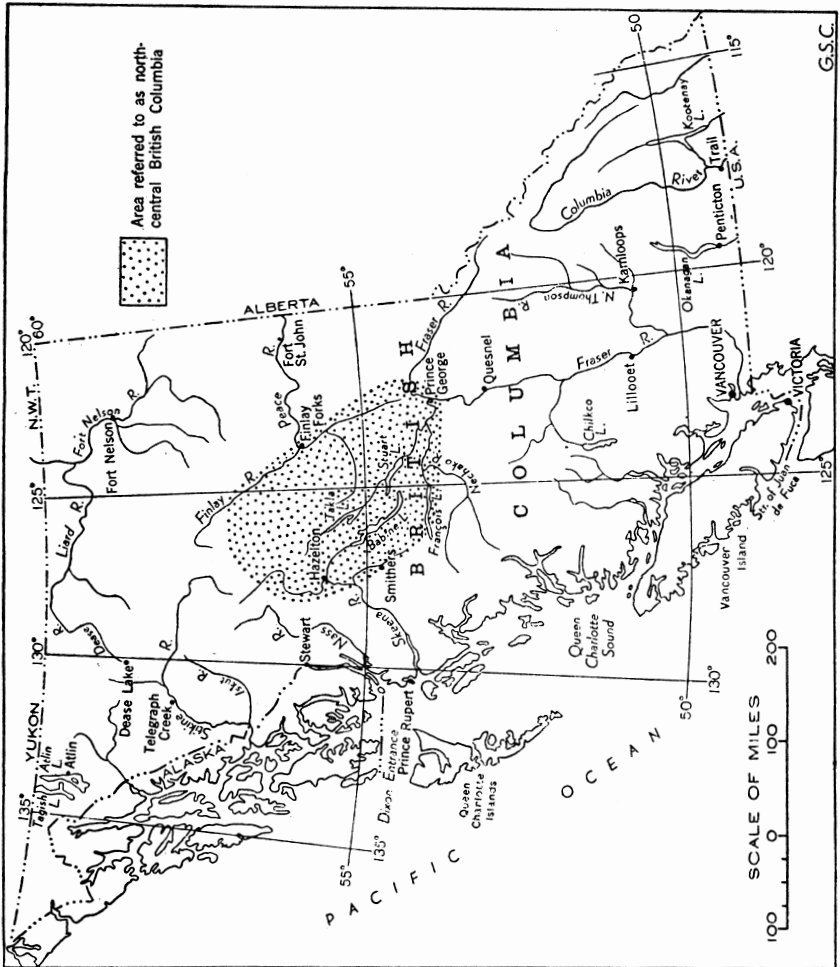
**T**HAT part of British Columbia under consideration lies between the Rocky Mountains on the east, the Skeena and Bulkley River Valleys on the west, and latitudes  $53^{\circ} 30'$  and  $57^{\circ} 00'$  north (Text-Fig. 1). It comprises an area of 45,000 square miles. During the past 10 years the senior author, while in the employ of the Geological Survey of Canada, has mapped geologically at least 20,000 square miles of this area. In the course of this work a great deal of information pertaining to Pleistocene glaciation was obtained. In 1941 and 1942 the United States Army Air Forces photographed from the air by means of the trimetrogon camera much of northern British Columbia. As a result of the study of several thousand of these photographs in conjunction with the observations made on the ground the authors have endeavoured to reconstruct the glacial history of part of the Omineca and Cariboo districts of north-central British Columbia.

Dawson, one of Canada's most famous geologists, was the first to come to the conclusion that during Pleistocene time all of British Columbia west of the Rocky Mountains, except possibly a few of the higher peaks, was covered by a Cordilleran ice sheet. In the course of his field work between 1875 and 1890 he observed, described, and attempted to explain, at some time or other, practically all the salient glacial features of north-central British Columbia. He suggested

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that the main gathering ground of this Cordilleran ice sheet was in north-central British Columbia between the Coast and Rocky Mountains and that the ice moved out from this centre in all directions (Dawson 1891, p. 27) which in the case of



Text-Fig. 1. Index map showing location of area referred to as North Central British Columbia.

the Omineca and Cariboo district would be southward. In later years most writers accepted Dawson's theory of Cordilleran glaciation, disagreeing with him only on minor details. The writers of this paper believe that the ice forming the Cordilleran ice sheet accumulated in the mountains, particularly the Coast Mountains, and that the ice moved eastward

across north-central British Columbia. In this paper they hope to show why such a conclusion is logical and also to describe in detail many of the glacial features of the region of which some are distinctive to Cordilleran glaciation, while others are common to all continental glaciation. The most important of these features are the widespread development of remarkable, nearly parallel drumlins and intervening depressions or groovings; three large compound eskers; and three large glacial-lake basins characterized by white silt deposits.

Our thanks are due to Prof. Richard Foster Flint, who read this paper critically.

#### PHYSIOGRAPHY

The area under discussion lies wholly within the western Cordillera and for conveniences may be divided into the following parts: Nechako Plateau, Omineca Mountains, Skeena Mountains, and Rocky Mountain Trench (Text-Fig. 2). The Coast Mountains lie west of the area; and the Rocky Mountains lie east of it.

Nechako Plateau extends from the Coast Mountains approximately 200 miles east to the Rocky Mountain Trench, and north from latitude 53 degrees for about 150 miles, and occupies some 30,000 square miles. The boundary between plateau and the Omineca and Skeena Mountains is arbitrarily drawn and parts of the areas included in each is in reality a transition zone between mountains and plateau. The Nechako Plateau may be subdivided into the plateau proper and the Nechako Plain. In the plateau proper the valleys are broad and the divides consist of rounded hills that rise 1,500 to 2,500 feet above the valley floors, with an occasional peak or small range of mountains rising as much as 4,000 feet. The Nechako Plain occupies an area of several thousand square miles on both sides of the Canadian National Railway between latitudes 122 and 125 degrees west. It has a maximum relief of only a few hundred feet and consists of a rolling till plain interspersed with flat glacial-lake basins. The main rivers have cut great post-Glacial channels into this plain, as much as 400 feet deep and in some places bedrock has been exposed. Elsewhere the plain is devoid of outcrop except for widely scattered rock knolls rising above the drift, which is from 100 to 400 feet thick.

The Omineca Mountains and the Cassiar Mountains constitute a continuous, northwesterly trending belt, extending from Nation River 400 miles north to Yukon Territory. The Omineca-Cassiar granitic batholith forms the core of these mountains, but the belt comprises a great number of ranges, most of them less than 1,000 square miles in area, separated from one another by wide transverse and lateral valleys several thousand feet deep. Individual peaks and ridges reach elevations of from 6,000 to 8,000 feet above sea-level but in any one range a uniformity of summits is normally found. The ranges show considerable variation in ruggedness; some are composed of ridges with relatively smooth crest lines; others are mainly a series of pinnacle-like peaks. This variation is due largely to the underlying bedrock, the more rugged ranges being composed of granitic and volcanic rocks and the smoother ranges of sedimentary strata. Small glaciers occur on some of the highest peaks.

The Skeena Mountains are composed of many individual mountains or mountain groups isolated from one another by wide, low areas or great valleys. Most of the peaks are highly dissected and some stand more than 7,500 feet above the valleys. Small glaciers are numerous.

The Rocky Mountain Trench is the great depression that lies directly west of the Rocky Mountains and forms their west boundary throughout most of their length, a distance of approximately 940 miles. It is a great, nearly flat-bottomed, parallel-sided trough, several thousand feet deep, and averaging from 2 to 12 miles wide. It extends from the forty-ninth parallel northwestward for 450 miles to the Grand Canyon of the Fraser River, where it ends abruptly, merging into the Nechako Plateau. However, it reappears as a distinct topographic feature 100 miles farther northwest, at the junction of the Pack and Parsnip Rivers, and continues northwestward another 325 miles in a straight line to Chee House on the Kechika River.

#### EVIDENCE OF GLACIATION

(Text-Fig. 2)

All of this part of British Columbia under discussion has undergone extensive glaciation during Pleistocene time. Except for a few widely scattered outcrops, till, as much as 400 feet thick in low-lying areas, covers much of the Nechako Plain,

most of the valleys and lower hills, and extends up the mountain slopes to elevations of 5,000 feet approximately. In a few places till was observed on flat topped mountains up to 6,000 feet in elevation. The surface of much of this till consists of nearly parallel drumlins and intervening groovings elongated in the direction of the ice movement. In the Omineca Mountains erratics occur up to elevations of 7,600 feet. In the Nechako Plateau and Plain three large compound eskers were observed superimposed on the till deposits. Also in this area abandoned glacial river channels, that cut through the till, were noted.

Large areas in the Nechako Plain comprise glacial-lake deposits, consisting of white silt, clay, and sand, over-lying the till ridges.

As indicated by the few striae observed on the tops of hills and ridges and in the Nechako Plain, the main ice movement west of the Rocky Mountain Trench was easterly. Striae also indicate, as would be expected, that wherever the ice was confined to valleys it moved along them but always in an easterly, southeasterly, and northeasterly direction. The distribution of till and erratics and the elongation of the nearly parallel drumlins and intervening groovings substantiate this direction of ice movement. The erratics are generally found east or southeast of their place of origin. An excellent example of this is found in the vicinity of a large granitic batholith that crosses much of the area from southeast to northwest. On the east side of this batholith the till boulders and erratics consist predominantly of granite, whereas on the west side the till is devoid of granite boulders and no granite erratics were observed.

In the vicinity of the Rocky Mountain Trench evidence has been found for a possibly earlier period of ice movement from the east, that is, from the Rocky Mountains. Some of the till found here is composed in a large part of rocks similar to formations exposed in the Rocky Mountains.

#### DRUMLINS AND PARALLEL GROOVINGS ...

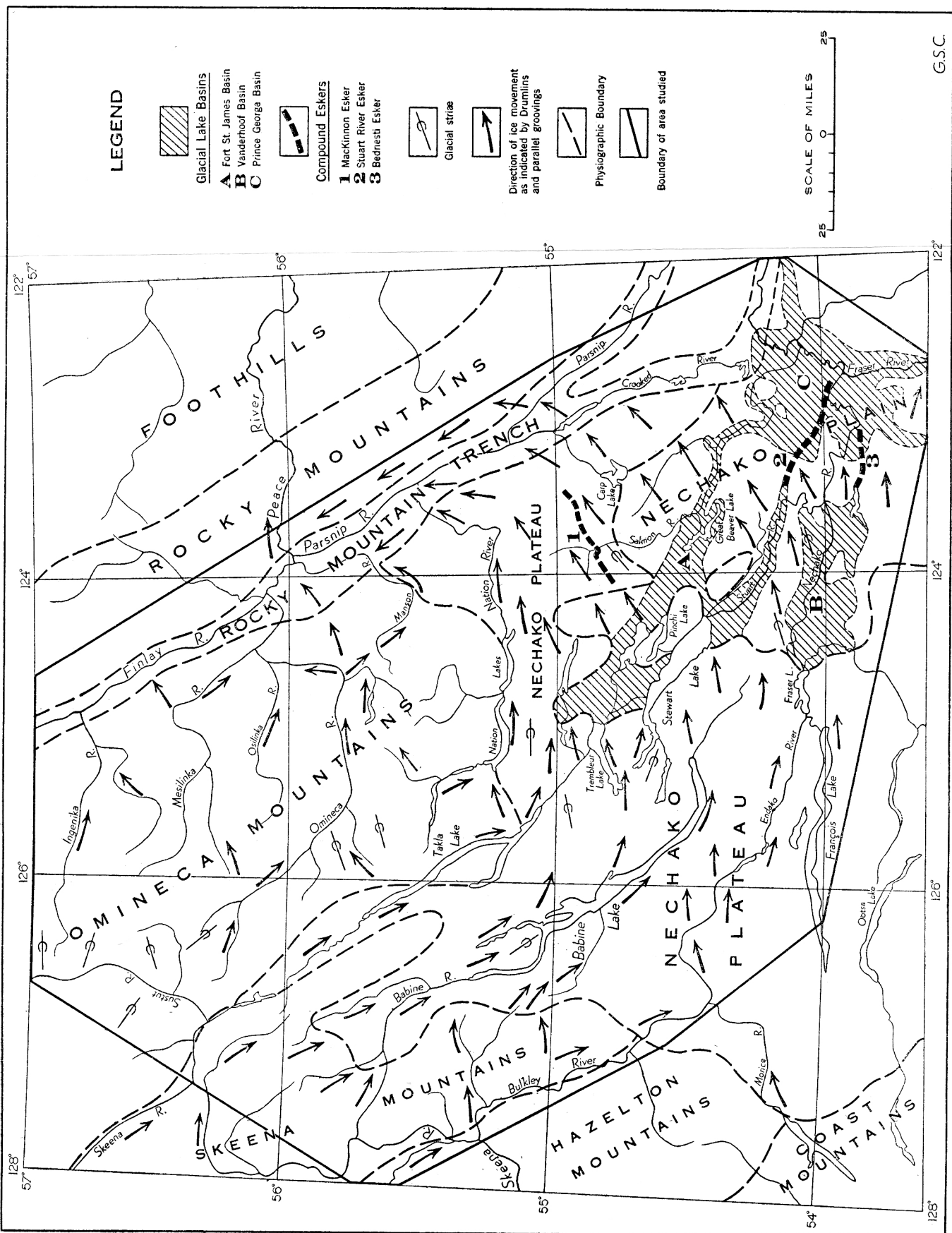
Nearly parallel drumlin-like ridges and intervening depressions or groovings are widespread in the part of north-central British Columbia under discussion (Pl. 1, Figs. 1 and 2; Pl. 2, Figs. 1 and 2; Pl. 3, Fig. 1). The term groovings has been suggested by the authors to distinguish them from normal glacial

grooves. In further discussion the drumlin-like ridges will be referred to as drumlins. These drumlins and groovings are generally confined to areas of less than 5,000 feet elevation and consequently are best developed in the major valleys and the low-lying Nechako Plain. In a recent soil survey in that part of the Nechako Plain centering around Prince George, Kelly and Farstad (1946, p. 9) observed and described these ridges as drumlins and referred to the area in which they predominated as a drumlinized till plain. As a result of considerable field investigations and a study of air photographs it is apparent that the term drumlinized till plain is applicable to large areas of ridges and groovings in the till in north-central British Columbia. For convenience the writers have applied the term to mountain valley areas as well as to the drumlinized part of the Nechako Plain, realizing full well the former do not constitute a plain. The shape and the size of the drumlins varies, and in places distinct ridges do not occur but only a poorly-defined grooving is present which cannot be recognized except with the aid of air photographs (Pl. 3, Fig. 1).

The drumlinized till plain consists essentially of parallel ridges of till and of gravel derived from the till (Pl. 1, Fig. 1; Pl. 2, Fig. 2). The till consists of well-rounded pebbles and boulders embedded in a grey to reddish-brown clay and sandy clay. Much of the gravel associated with the till occurs at the tops of ridges, grades downward into till, and is evidently till from which the clay and sandy clay have been removed by post-Glacial runoff. This gravel is rarely stratified but usually exhibits a rough sorting.

Stratified gravels and sand were observed at a few places in the till plain. They generally occur in lenticular beds and they probably represent interglacial outwash deposits.

The drumlins are most pronounced and best preserved in a large part of the Nechako Plain and along some of the major valleys in the Nechako Plateau and Omineca Mountains. 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 (Text-Fig. 3). They are generally from  $\frac{1}{2}$  to  $1\frac{1}{2}$  miles long, although a few were observed more than 2 miles long. Most of them are  $\frac{1}{4}$  mile or less wide, however, a few reach widths of  $\frac{1}{2}$  mile or more. They vary considerably



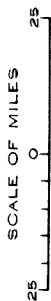
**LEGEND**

**Glacial Lake Basins**  
 A Fort St. James Basin  
 B Vanderhoof Basin  
 C Prince George Basin

**Compound Eskers**  
 1 MacKinnon Esker  
 2 Stuart River Esker  
 3 Bednesti Esker

**Glacial striae**  
 Direction of ice movement as indicated by Drumlins and parallel groovings

**Physiographic Boundary**  
 Boundary of area studied



Text-Fig. 2. Glacial map of North Central British Columbia.

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 (Pl. 1, Figs. 1 and 2; Pl. 2, Figs. 1 and 2) which are rarely observed except in air photographs. In some photographs two sets of intersecting longitudinal grooves were observed (Pl. 2, Fig. 2).

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 (Pl. 1, Figs. 1 and 2; Pl. 2, Figs. 1 and 2; Pl. 3, Fig. 1). 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.

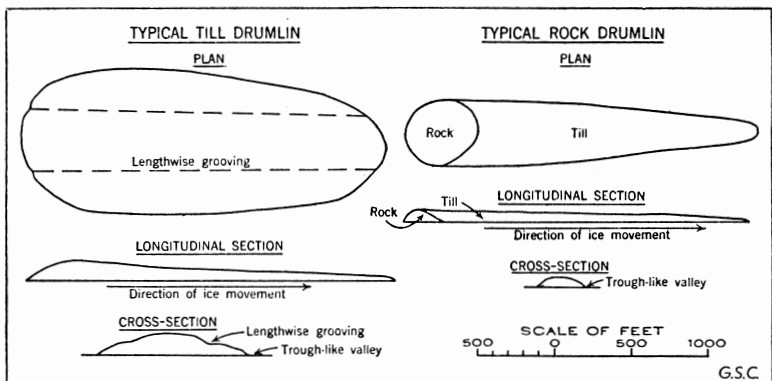
The intervening trough-like valleys are 50 to 150 feet deep and in places are up to one half mile wide (Pl. 1, Figs. 1 and 2; Pl. 2, Figs. 1 and 2, Pl. 3, Fig. 1). In many places valleys extend uninterrupted for as much as 6 miles but not necessarily in a straight line. The valley may bend around the 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.

In still other parts of the area, particularly the higher valleys, the tops of hills, and in the mountain passes as well as in the Parsnip and Skeena River valleys the drumlins are replaced by poorly defined parallel groovings (Pl. 3, Fig. 1). These groovings are shallow and discontinuous and are separated by long, low mounds of till rarely more than 25 feet high. All three types of drumlinized till plain topography merge into one another from place to place.

Widely interspersed among the drumlins of unconsolidated materials are ridges composed in part of bedrock (Pl. 3,



Text-Fig. 3. Drumlins.

Fig. 2). 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 there is a narrow ridge of till with steep sides (Text-Fig. 3). 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. They are best developed, near Carp Lake, near the headwaters of the Necoslie River, and near the south end of Babine Lake.

Wherever the slopes are gentle enough to prevent later sliding well-defined drumlins have been observed on hills up to the elevations of 4,000 feet, 1,500 feet or more feet above the valley floors. Between 4,000 to 5,000 feet only a few poorly

defined ridges occur, but shallow groovings are well marked in many places. Above 5,000 feet only the grooved type of topography has been observed.

The drumlins are elongated in the direction of ice movement and in the Omineca Mountains, where most of the ice moved along the valleys, the drumlins are largely valley features curving around the higher hills. As a rule the drumlins are best developed in areas where the ice flowed uphill and poorest developed in areas where the ice flowed downhill, parallel groovings being developed instead.

The parallelism of the drumlins and groovings in the direction of ice movement, corroborating the glacial striae, illustrates accurately the last movement of the ice in Pleistocene time (Text-Fig. 2). As indicated by drumlins and groovings the ice apparently moved eastward along the Nechako Valley and south and southeast down the valleys of Babine and Takla Lakes turning eastward through transverse gaps in the northeastern valley walls. When the ice flowing along the major valleys reached the Nechako Plain it moved easterly and northeasterly across the plain to the Rocky Mountains where it turned northwestward along Rocky Mountain Trench. In the Omineca Mountains the ice moved easterly and northeasterly along the valleys of the major rivers to the Rocky Mountain Trench.

#### ORIGIN OF DRUMLINS AND PARALLEL GROOVINGS

These parallel drumlins and depressions have been observed throughout the northern Cordilleran region of Canada by previous workers. However, neither their great number, at least ten thousand in the Nechako Plain alone and probably several hundred thousand in the whole of the Cordillera; nor their remarkable parallelism, consistent over the whole of the Nechako Plain, an area of 5,000 square miles, was fully realized until a study of the trimetrogon air photographs of the area was made. The northern Cordillera was photographed by the United States Army Air Forces in 1941 and 1942.

G. M. Dawson (1878 b, p. 101) was the first geologist to record these drumlins although he referred to them as moraines.

The first published record referring to these ridges as drumlins, was made by Kelly and Farstad (1946, p. 9).

Although the writers were not able to recognize two tills in

the field they believe that in view of other evidence and the observations of Lay (1941, p. 16) and Johnston (1926, p. 147) in the Cariboo region to the south that there were at least two major advances of the Cordilleran ice sheet in the greater part of the area under discussion. The last advance was from southwest to northeast. Also the origin of the parallel drumlins and intervening depressions is most readily explained by two major ice advances, the first one carrying a heavy load of debris, and the second carrying a relatively light load. This conclusion regarding the load of the two ice sheets is based on the following reasoning: It is believed that following the last advance of the ice the ice stagnated over a large area, as is evidenced by the lack of lateral and terminal moraines and the presence of kettles and eskers, rather than retreating along a front. In such an event the debris carried on and in the ice would be deposited haphazardly on the underlying surface as in a typical ground moraine. However the till surface now exposed is arranged in the form of parallel drumlins and intervening depressions and except for a few large erratics could not have been derived in such a manner. Therefore the conclusion has been reached that the last ice sheet was lightly loaded, in which case the great thickness of till constituting the drumlinized till plain must have been deposited by an earlier, heavily loaded ice sheet.

During the first advance of the ice a heavy mantle of till was deposited in the lower mountain valleys and in the Nechako Plateau and Plain. Possibly as this ice sheet retreated or more probably as the second ice sheet advanced the till was grooved and reshaped into drumlins. Two sets of groovings intersecting at a considerable angle were observed at places in the Nechako Plain and probably indicate local advances and retreats of the ice. The origin of the till drumlins was arrived at from a study of the rock drumlins interspersed among them in various places. These rock drumlins exhibit typical crag-and-tail characteristics and it is quite evident that they were formed by the ice pushing up against a rock outcrop, riding up and over it, and depositing a tail of debris behind it, this tail fading away at the lee end. At the same time the ice moving on both sides of the outcrop gouged out depressions parallel to the ice movement. The till drumlins parallel these rock drumlins and the two types never overlap one another.

In the case of the till drumlins it is believed that a knob of frozen till rather than a rock outcrop formed the buttress to the moving ice and that the ice rode up and over it and around it depositing a tail of material behind it forming the drumlins. The intervening depressions would be gouged out by the tongues of ice moving between two frozen hummocks and, as would be expected, these would be more regular and persistent than the drumlins. The shallow longitudinal groovings observed on the sides and tops of many individual till drumlins were probably gouged out by large boulders that were embedded in the base of the ice, in a similar manner to the production of striae on bedrock. Some of the erratics observed had a diameter of 15 to 20 feet.

The best till drumlins are found in flat areas and on slopes where the ice moved uphill. Where the ice moved steeply downhill as in many of the higher mountain valleys the drumlins are either very poorly developed or absent and only a faint grooving is found. Apparently the force of the ice was sufficient to destroy the projections of till.

#### ESKERS

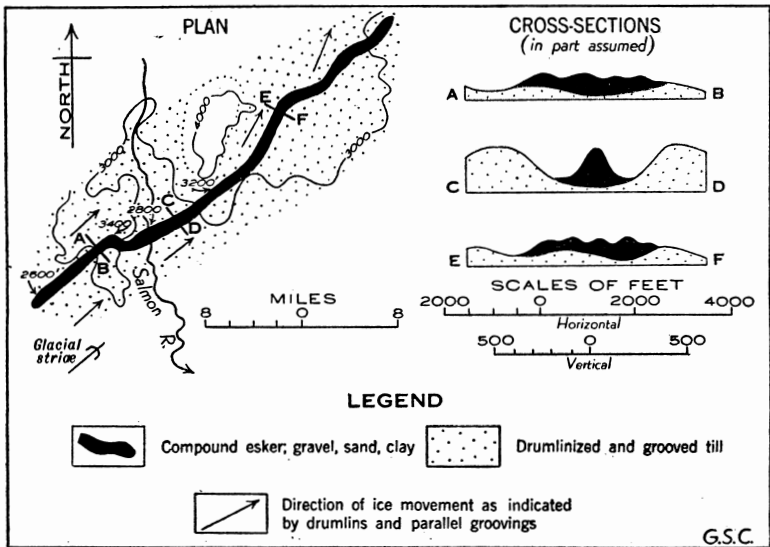
According to Flint (1947, p. 150) an esker is a long, narrow, ice-contact ridge, commonly sinuous and composed chiefly of stratified drift. In view of this definition no true eskers have been observed in the area under discussion, however, three glacial features in many ways similar to eskers and for lack of a distinctive name referred to as compound eskers were observed. Two occur in the Nechako Plain and one in the Nechako Plateau where it borders the plain on the north. From north to south these are: the northeasterly trending MacKinnon compound esker, 35 miles long and  $\frac{1}{4}$  to  $\frac{3}{4}$  of a mile wide; the easterly and southeasterly trending Stuart River compound esker, 25 miles long and 1 to  $2\frac{1}{2}$  miles wide; and the easterly trending Bednesti compound esker, 16 miles long and about  $\frac{1}{2}$  mile wide. All three are in a large part comprised of sub-parallel, reticulating ridges of gravel, sand, and silt surrounding elongated oval depressions and kettles. However they vary considerably in detail.

#### MACKINNON COMPOUND ESKER

(Pl. 4, Fig. 1; Text-Fig. 4)

The MacKinnon compound esker, which is the most unusual

of the three, bears no relation to the topography of the country it traverses. Commencing at its southwestern end at an elevation of approximately 2,600 feet it rises about 800 feet in 8 miles to the top of a ridge and then drops about 600 feet in the next 4 miles to the valley of the Salmon River at an elevation of about 2,800 feet. Northeast of the Salmon River, along the remaining 23 miles of its length it shows



Text-Fig. 4. MacKinnon compound esker.

changes in elevations of several hundred feet. Throughout its length this compound esker lies on or occupies a depression in the drumlinized till deposits. From its southwest end for a distance of about 8 miles, it is nearly straight, about  $\frac{1}{2}$  mile wide, lies on top of the till plain, and consists of mounds of gravel, usually less than 25 feet high, and intervening shallow depressions. This part of the compound esker climbs the southwestern slope of a ridge and as previously stated rises about 800 feet. The next 4 miles of compound esker, which lies on the northeastern slope of this ridge and which drops about 600 feet, consists of a network of sub-parallel ridges composed of gravel, sand, and silt, trending along the length of the compound esker and enclosing deep, steep-sided depressions. The individual ridges are from  $\frac{1}{4}$  to  $\frac{1}{2}$  mile long and 75 to 100 feet high. Continuing northeast

along the compound esker, 2 miles east of the Salmon River these ridges finally unite into one long ridge, about 5 miles long, 150 feet high, and 500 feet wide. This ridge lies along the centre of a trough-like valley about 150 feet deep and one-half mile wide that has been cut into the drumlinized till plain. It consists of interbedded sand, gravel, and clay. At its northeastern end this ridge fingers out into a number of diverging small ridges which fade out to the northeast (Pl. 4, Fig. 1). The northeastern 16 miles of the MacKinnon compound esker is not as obvious as that part just described. However remnants of ridges have been observed along the trend of the esker and the topography is distinct from that of the underlying till plain.

It is generally believed by geologists that eskers are the deposits of glacial streams confined by walls of ice and left as ridges when the ice disappeared, and it is also believed that eskers are constructional rather than erosional features. The MacKinnon compound esker differs from a true esker in apparently being in part an erosional as well as in part a constructional feature. The deposits were carried and deposited by a glacial stream that probably flowed partly on the surface of the ice, partly in ice crevasses and partly through tunnels at the base of the ice. Along the central part of the compound esker the stream eroded a valley from the drumlinized till plain and in this valley the esker materials were deposited. Elsewhere along the compound esker they were laid down on top of the drumlinized till plain.

In detail this compound esker may have been formed somewhat as follows: After the material of the drumlinized till plain had been laid down and the ice sheet had commenced to melt, water probably flowed over the surface of the ice in a northeasterly direction accumulating in a surface channel, which commenced near the southwest end of the MacKinnon compound esker and extended 8 miles northeast to the top of the ridge previously described. This surface channel has been postulated for the following reasons: The improbability that water flowing at the base of the ice would climb the ridge, when in such a case it could have much more readily flowed to the southeast, the necessity of a reservoir to the southeast at least as high as the ridge in order to build up the needed hydro-

static pressure further along the compound esker, and the fact that the compound esker along this stretch appears to have been formed by material dropped into its present position. At the top of the ridge the ice probably contained a great many crevasses caused by a relatively thin sheet of ice moving over the top of the ridge and dropping into the valley to the northeast. Therefore following its easiest course the glacial stream would pour down through these crevasses to the base of the ice and flow along on or near the surface of the drumlinized till plain. The stream probably dropped 600 feet in four miles and in so doing it must have become torrential cutting a tunnel through the ice and in places cutting into the till plain itself as much as 150 feet. Such a channel in the till plain occurs along a 7 mile stretch of the compound esker lying to the northeast of the Salmon River. Along the last 16 miles of its course this glacial stream at the base of the ice and under hydrostatic pressure probably flowed uphill and as a result did not have any appreciable eroding power and therefore did not cut into the till plain. Due to continuous melting of the ice sheet at the surface and the destruction of the sheet at its base by the glacial stream the roof of the ice tunnel occupied by the stream must have finally collapsed dropping great blocks of ice into the course of the stream. At this stage there was undoubtedly a big reduction or a complete loss of hydrostatic pressure and great loads of materials were deposited in the channels flowing around and between the blocks of ice.

#### STUART RIVER COMPOUND ESKER

(Pl. 4, Fig. 2; Text-Fig. 5)

This compound esker which is from 1 to 2½ miles wide, is mainly a vein-like maze of steep-sided ridges and hills with deep elongated or circular depressions between. The size and shape of the ridges vary considerably in different parts of the compound esker. In its western portion it is comprised of rounded hills 50 to 75 feet high. Proceeding eastward these ridges become progressively longer and higher and near the 123rd meridian of longitude some are as much as 2 miles long and 150 feet high. East of the 123rd meridian the elongate ridges once more change to circular hills separated by kettles up to 150 feet deep. At its northwest end near the Stuart

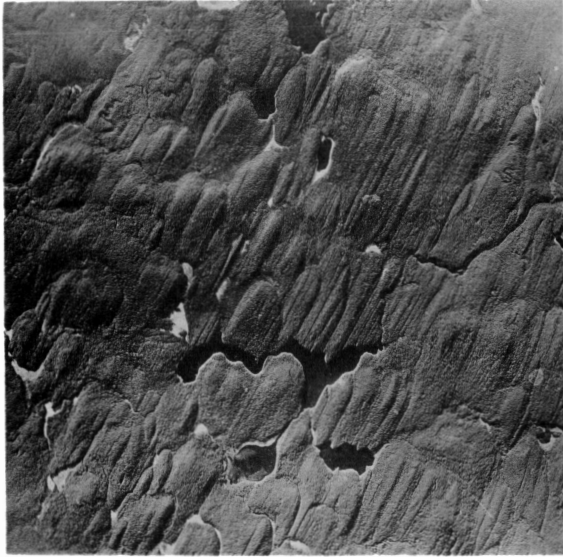


Fig. 1. PARALLEL DRUMLINS AND INTERVENING GROOVINGS NEAR SALMON RIVER.

Looking southwest. Direction of ice movement northeast.



Fig. 2. PARALLEL DRUMLINS AND INTERVENING GROOVINGS NEAR GREAT BEAVER LAKE.

Looking southwest. Direction of ice movement northeast. Note two sets of longitudinal grooves on the drumlins.

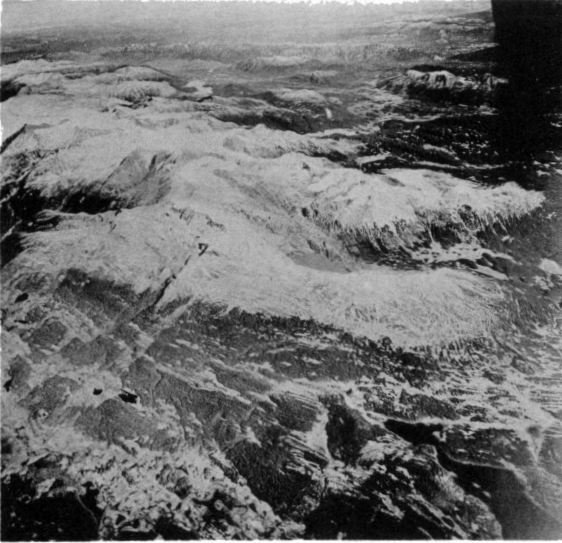


Fig. 1. GROOVINGS IN SKEENA MOUNTAINS.

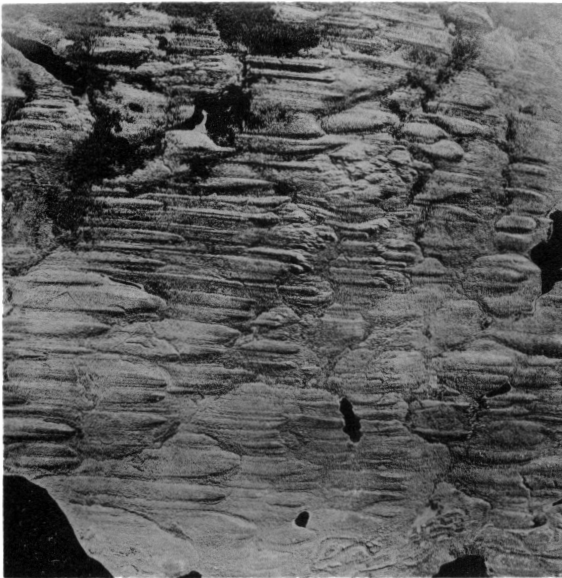


Fig. 2. PARALLEL ROCK AND TILL DRUMLINS AND INTERVENING GROOVINGS SOUTH OF CARP LAKE.  
Direction of ice movement from right to left.



Fig. 1. MACKINNON COMPOUND ESKER EAST OF SALMON RIVER.  
The single ridge in the centre of the photograph occupies a trough-like valley  
150 feet deep.

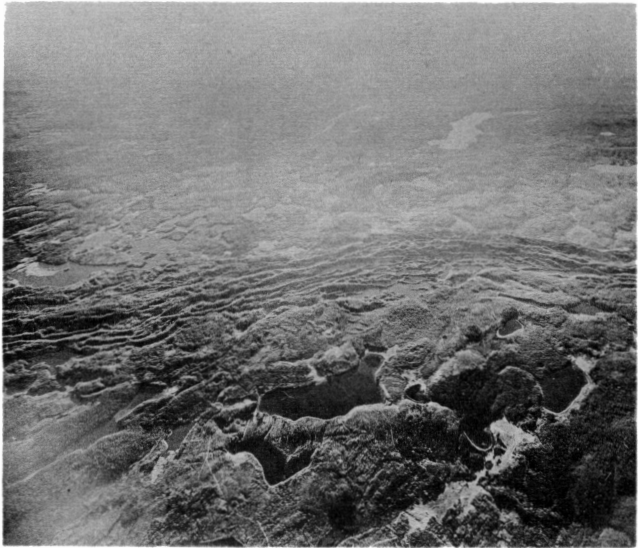
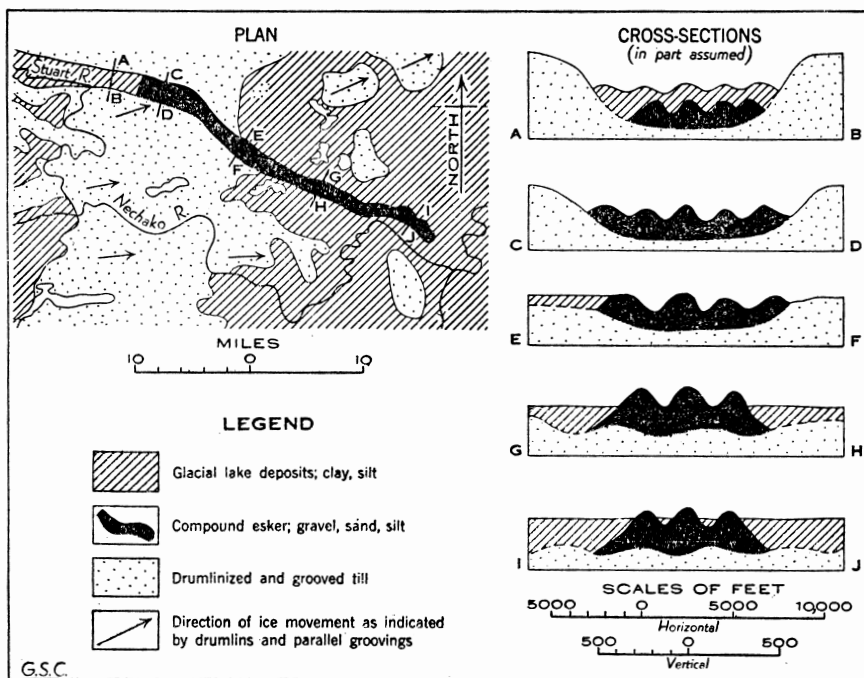


Fig. 2. STUART RIVER COMPOUND ESKER.

River the ridges lie in a valley and are 200 feet below the level of the drumlinized till plain; near Taginchil Lake they are at the same level as the till plain; and near the 123rd parallel they stand 150 feet above the deposits of the Prince George glacial-lake basin and these apparently overlie the till. The esker deposits near Prince George would appear to be at least 250 feet thick. The sediments comprising the Stuart River



Text-Fig. 5. Stuart River compound esker.

compound esker consist of interbedded gravel, sand, silt, and minor clay. The sand and silt exhibit good crossbedding and the silt is usually finely laminated. Boulders up to 6 inches in diameter occur in the gravel, although the average is less than 2 inches. Faulting was observed, one fault having a vertical displacement of 55 feet.

As in the case of the MacKinnon compound esker the Stuart River compound esker is in part an erosional and in part a constructional feature. It is believed to represent in part at stages in its development a pre-Glacial and a inter-Glacial channel of the Stuart River joining the present Stuart River

at its big bend with the Nechako River at Prince George. It may also have acted as a drainage channel between the Fort St. James and Prince George glacial-lake basins during a later stage in its history, although most of the glacial-lake deposits lie on top of the compound esker deposits. This compound esker has a general but not a uniform slope from the west to the east, the elevation of its surface at the west end is about 2,250 feet and at its east end about 2,100. The highest point in between is probably below 2,300. The Stuart River valley between Fort St. James and the big bend 35 miles to the southeast appears to be pre-Glacial in origin, whereas the Stuart River valley from the big bend to the Nechako River is undoubtedly post-Glacial in origin. As previously stated the pre-Glacial channel of the Stuart River probably extended southeast from the big bend to the Nechako River along the course of the Stuart River compound esker. In its western part the compound esker lies along a valley that forms a continuation of the present upper Stuart River valley.

The history of the development of this compound esker may have been somewhat as follows: The deposits of the drumlinized till plain were probably laid down during the first major advance of the ice partly filling in the pre-Glacial valley of the Stuart River. Following the retreat of this ice the Stuart River probably cut a channel through the till from Stuart Lake southeast to the Nechako River at Prince George following the present valley of the Stuart River to the big bend and the course of the Stuart River compound esker beyond the big bend, although this cannot be proven in its eastern portion as the proposed channel is buried beneath glacial-lake deposits. A second major advance of the ice sheet must have covered this channel and apparently during the melting and decay of this ice the channel formed a tunnel, up to  $2\frac{1}{2}$  miles wide, at the base of the ice for a glacial stream, which probably was flowing under hydrostatic pressure. Possibly at no time was this tunnel entirely filled with water but contained in addition great blocks of ice and ridges of frozen sediments. As sediments were deposited along the course of this under ice stream they must have filled the inter-Glacial Stuart River channel-way along its eastern part causing the glacial stream to erode a tunnel into the overlying ice and thus depositing sediments

above the level of the till plain as a true esker would. However, before the western part of the inter-Glacial Stuart River valley became filled in the roof of ice tunnel apparently collapsed blocking the glacial stream along most of its course. As melting continued the blocks of ice along the course of the compound esker would melt thus forming its present topography. During the maximum development of the Fort St. James glacial-lake basin the Stuart River valley down to the big bend and the western part of the valley of the compound esker apparently formed an arm of this lake. Apparently the easiest outlet from this lake was along the present course of the Stuart River from the big bend to the Nechako River.

#### BEDNESTI COMPOUND ESKER

The Bednesti compound esker consists of a vein-like network of ridges  $\frac{1}{4}$  to  $2\frac{1}{2}$  miles long, a few hundred feet wide and 100 to 150 feet high separated by kettles and resting on top of the drumlinized till plain but in part buried beneath the silt and clay of the Prince George glacial-lake basin. The western end of the Bednesti compound esker is represented by an eroded channel extending from Cluculz Lake to Bednesti Lake. The well-defined ridges begin at Bednesti Lake and extend eastward. These ridges are composed of gravel and sand and lie on top of the drumlinized till plain.

This Bednesti compound esker is more nearly like a true esker than the others under discussion. It differs mainly in the reticulate arrangement of the ridges composing it.

#### GLACIAL LAKE BASINS

(Text-Fig. 2)

Deposits of clay, silt, sand, and gravel representing depositions in irregular-shaped, temporary glacial-lake basins during the final stages of glaciation are widespread. The three largest basins are Fort St. James basin, about 850 square miles in area; Vanderhoof basin, approximately 450 square miles in area; and Prince George basin, with an area of at least 800 square miles. In addition to these three large basins several smaller basins, of which the Carp Lake basin is the most important, have been observed. The topography of these depositional basins varies from flat, in areas in which there are a considerable thickness of glacial lake sediments, to undulating

or hilly, where there is only a thin mantle of sediments overlying the drumlinized till plain or bedrock. In many places areas of drumlins project through the lake deposits and apparently represent islands in the old glacial-lakes. The main basins occupy natural depressions in the drumlinized till plain and were not eroded from the plain. However, long arms of these basins, such as those along the upper Stuart River and the lower Salmon River, probably represent channels of glacial rivers that were eroded through the till plain and were later dammed, forming part of the depositional basins. In most places the average elevation of the surrounding till plain is about 150 feet above that of the glacial-lake basins. However, in places the till plain rises abruptly as much as 300 feet above the lake basins and at other places they grade imperceptibly into one another. The approximate elevations of the Fort St. James basin range from 2,200 to 2,600 feet, of the Vanderhoof basin from 2,200 to 2,500 feet, and of the Prince George basin from 2,000 to 2,500 feet.

The glacial-lake deposits consist of interbedded silt, clay, sand, and all intermediate gradations, and subordinate gravel. The fine sediments grade into one another both laterally and vertically. As good sections were observed in only a very few localities it is difficult to measure the total thickness of the deposits. They are at least 100 feet thick in the Fort St. James basin, 260 feet in the Vanderhoof basin, and 220 feet in the Prince George basin. The maximum thickness of these lake beds probably exceeds 400 feet. Silt and sand predominate in the Fort St. James basin, silt and clay in the Vanderhoof basin, and clay in the Prince George basin indicating progressively finer sediments the farther from the mountains in the direction of ice movement. Sand and gravel predominate along the margins of the basins and they probably represent beach deposits, resulting from a modification of the adjoining till by melt-water or wave action. Much of the sand and silt, especially in the Fort St. James and Vanderhoof basins, exhibits good cross-bedding and were probably laid down as deltaic beds at the mouth of glacial streams feeding the lakes. Near the borders of the lake basins pebbles up to two inches in diameter and occasional boulders up to one foot in diameter are found scattered throughout the clay and silt beds.

The silts or "white silts" as they were called by G. M. Dawson are the most conspicuous of the glacial-lake deposits, although they are not as widespread as a casual examination would indicate. They are mainly cream white to buff and in a few places grey and brown. These silts which are composed mainly of feldspathic rock flour, are finely stratified in parallel laminations a fraction of an inch to several inches, less commonly a foot or more in thickness. They grade laterally and vertically into sand and clay. Ripple marks are fairly common. In the Vanderhoof and Prince George basins the main silt deposits appear to lie above the main clay deposits.

The clays are usually light grey to grey brown commonly in alternating bands. In places they are bluish-grey. Varves up to one foot or more thick are common in the clays near Prince George.

The sands vary from very fine to coarse. They are widespread in the Fort St. James basin and near Great Beaver Lake large areas of sand dunes were seen.

#### ORIGIN OF GLACIAL LAKES

The glacial-lake deposits are found in the lower part of the area under discussion. These depressions, now occupied in part by the valleys of the Nechako, Stuart, Salmon, and Fraser Rivers, and Stuart, Pinchi, Tezzeron, Great Beaver, Cluculz, and many smaller lakes, are believed to be pre-Glacial in origin. Outcrops of Tertiary sedimentary formations appear to be, in a large part, limited to these low-lying areas. During glaciation a mantle of till was deposited in these depressions. However, the general area of depression was preserved and reflected on the surface of the ice.

The last advance of the Cordilleran ice sheet was probably followed by a period of stagnation and decay of the ice in the Nechako Plateau and Plain. During this stage the large pre-Glacial depressions in the drumlinized till plain acted as collection basins for melt-water forming temporary glacial lakes. At first these basins may have been formed largely on the top of the ice but certainly at later stages the water rested on till. Much of the shoreline of these lake basins is comprised of gravelly wave-washed till and island-like areas of similar till are common. The lakes were to a lesser extent

confined by ice walls. Much ice floated in the lake waters as is evidenced by the abundance of ice-rafted boulders and small patches of ice-rafted till.

These lake deposits are in many places crossbedded and show rapid gradations from clay to silt to sand to gravel suggesting that they are in a large part deltaic in origin, deposited in the deltas of glacial rivers that fed the lakes. The Stuart River and Bednesti compound eskers at one stage in their development probably represent two of these rivers. Others probably occupied much the same position as the present day rivers. As the ice dams forming part of the shorelines of these lakes melted the lake levels were lowered and their bottoms exposed. And at this time the Fraser, Nechako, Stuart, and Salmon River began to excavate their post-Glacial channels and to build terraces along their banks. These channels have cut several hundred feet up to the present.

## GLACIAL HISTORY

### PREVIOUS WORK

*G. M. Dawson:* Dawson was the first geologist to study the effects of glaciation in north-central British Columbia and the glacial history of this area as suggested by him is as follows: The Cordilleran glacier has a length of nearly 1,200 miles extending from north of the Yukon-British Columbia boundary to south of the International Boundary at the forty-ninth parallel. The ice formed first on the northern Coast Mountains and the high ranges of the interior of British Columbia between the fifty-fifth and fifty-ninth parallels of north latitude. The ice flowed outward from this area in all directions. In the early stages before the ice sheet reached its maximum thickness the ice followed the valleys but as glaciation became more intense the ice formed a great sheet moving southeast and northwest between the Coast Mountains and the Rocky Mountains. The ice must have reached a maximum thickness of over 6,000 feet above the main valleys. During the maximum development of the Cordilleran glacier the Cordilleran region probably stood at a level considerably higher than it now does, and the eventual retreat or more likely the decay, of the Cordilleran glacier was contemporaneous with, if not caused by, a subsidence of the region. The first effect of the decay of the ice sheet was the formation of englacial

lakes in central British Columbia, and along the borders of these lakes terraces composed of material resembling boulder clay were formed. Along the retreating front of the glacier, and subject to a certain amount of rearrangement by the water which washed its base, boulder clay appears to have been laid down indistinguishable from the boulder clay attributed to the englacial lakes. Following this period of subsidence was a period of re-elevation and a second maximum of glaciation. During this period of re-elevation most of the higher terraces of British Columbia were formed and some of the previously formed boulder clay was removed from the larger valleys. Following the maximum of this second period of glaciation came a second subsidence, less than the first but sufficient to depress the Cordilleran region 2,500 feet below the existing elevations. At this stage the white silt deposits of central British Columbia were formed. These are fine, uniform, well-bedded arenaceous, clayey deposits laid down in tranquil waters of considerable depth. Their material was supplied by streams and rivers discharging from glaciers not far removed. The final decrease of the ice must apparently have been due to some general cause connected with the close of the Glacial epoch as a whole, for simultaneously with the ultimate retreat or disappearance of the glaciers, the elevation of the Cordilleran region was resumed, till it eventually reached the level which it now possesses. Two principal periods of glaciation are here postulated, because evidence of more than two has not been obtained in any particular region in the Cordillera. *G. S. Malloch*: In 1909 Malloch (1910, p. 128) studied the glacial deposits along the upper Fraser River between Prince George and Tete Jaune Cache. He suggested the deposits were formed by two sets of glaciers; the first of which descended into the Interior Plateau from the Rocky Mountains and the second from the mountains to the west. He recognized two tills separated by a band of gravel. The older till is composed of boulders of Rocky Mountain formations and the younger till clay is characterized by granitic and volcanic fragments from the west.

*W. A. Johnston*: In 1926 Johnston (1926, p. 147), summarized the glacial history of north-central British Columbia as follows: "Evidence found in a field examination of parts of

Cariboo and Cassiar districts, British Columbia, indicates, as was held by G. M. Dawson, that one or more ice sheets existed during Pleistocene time in central British Columbia and that the general direction of the movement of the ice was towards the south. The ice sheet at its maximum stage, however, probably did not average much more than 3,000 feet in thickness and had little motion as a whole, probably because it was hemmed in by mountain ranges. For long periods of time during the Pleistocene, valley glaciers that coalesced on the lower ground to form ice sheets of less extent than the main ice sheet existed and were the chief agents of erosion and deposition by the ice. The term "Cordilleran system of intermontaine, piedmont and valley glaciers" probably better describes conditions that existed than the simple term "Cordilleran glacier" proposed by G. M. Dawson in 1888 and generally adopted since that time. The occurrence of two till sheets, with, in places, pay-streaks of placer gold and oxidized and partly cemented gravels between them, the occurrence of lava flows in Sitkine Valley that are probably Pleistocene in age and are separated in places by gravels, resembling glacial gravels, and evidence of extensive stream erosion during Pleistocene time, indicate that there was at least one interglacial period in British Columbia."

*F. A. Kerr:* According to Kerr (1934, p. 22) glaciation in northern British Columbia may be divided into four types, namely: "Alpine, intense alpine, mountain ice sheet, and continental ice sheet. During alpine glaciation glaciers were limited in extent as at present time and followed normal water gradients.

In intense alpine stages the glaciers were more extensive and accumulation of ice in axial areas of such systems as the Coast Mountains became so great that all major valleys including trans-range valleys were blocked with ice and in these as well as elsewhere the ice moved outward from the axial areas. During mountain ice-sheet stages ice was so extensive that mountain 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" on the east side of the northern Coast Mountains. In

that portion of north-central British Columbia under discussion in this paper Kerr believed there had been more than one advance of a continental ice sheet and that the last sheet moved in an easterly and southeasterly direction.

#### A SUGGESTED GLACIAL HISTORY AS BASED ON PRESENT WORK

Assuming that conditions of precipitation in the Pleistocene period were similar to those existing today, it is apparent that in central British Columbia much the greatest accumulation of ice was on the Coast Mountains. Ice also accumulated, although to a much lesser extent, on the Rocky Mountains, Omineca Mountains, and other ranges of the north-central interior of British Columbia. Relatively little, if any, glacier ice formed in the Nechako Plateau and Plain. As the mountain ice fields grew the ice flowed out from them in all directions at first largely confined to valleys. In the Coast and Rocky Mountains this movement was mainly easterly and westerly and in the Omineca and other interior ranges mainly northerly and southerly. These large valley glaciers coalesced in the low lying Nechako Plateau and Plain. As glaciation continued, ice piled up until most of central British Columbia was covered with a great sheet of ice of varying thickness. A few of the higher peaks and ridges either projected through the ice or were not far below the surface of the ice, and apparently at no one time was the ice thick enough to flow indiscriminately over mountain and valley. In the mountainous areas the movement of the ice was confined largely to the valleys although some evidence of former movement across the summits of the ranges forming the Omineca Mountains was observed. This movement was in general from west to east. However, during the maximum development of the Cordilleran glacier the ice moved across the low-lying Nechako Plateau and Plain in a general easterly and northeasterly direction (Text-Fig. 2). Apparently, as would be expected, the ice flowing easterly from the Coast Mountains, much the greatest source of ice, controlled the movement of the ice from the Coast Mountains to the Rocky Mountains. At the stages of maximum glaciation the amount of ice supplied by the Rocky Mountains and interior ranges was relatively small and did not affect the movement of the ice sheet.

At least two major advances of the Cordilleran ice sheet have been recognized in the Nechako Plateau and Plain. The recession of the ice between these two major advances may have been limited to these low-lying areas. During the first advance of the ice most of the rock debris was eroded from the weathered outcrop and deposited in the low-lying areas, the greatest accumulation of till being in the Nechako Plain. Most of the till consists of material derived from the west, however near the western base of the Rocky Mountains some till composed of material from these mountains was observed. The first major advance of the ice was probably in the main from west to east, although most of the evidence for such a conclusion was obliterated by a later advance.

Following the first major advance of the Cordilleran ice sheet with its resultant scouring of bedrock a recession of the ice sheet occurred in the Nechako Plateau and Plain. Dawson (1891, p. 41) suggested that during this recession glacial lakes were formed and he attributed some of the terraces to these. The authors of this paper have obtained no evidence to confirm nor refute this theory of Dawson's.

This recession was followed by a re-advance of the ice across the Nechako Plateau and Plain. It is this later advance of the ice that may be traced by the trend of the drumlins and striae, and at the close of which the compound eskers and glacial lakes were formed (Text-Fig. 2). In comparison to the earlier ice advance this later ice advance apparently carried a relatively much lighter load of till, and instead of dropping a heavy mantle of till as the first advance did it mainly rearranged the earlier till into drumlins as was suggested in the discussion on the origin of the drumlins. As is evidenced by the elongation of the drumlins and the parallel groovings the ice in general moved from the Coast Mountains east to the Rocky Mountains. In detail the movement, particularly at the base of the ice, was much more variable, the underlying topography being the governing feature. In the area under discussion the ice flowed southeasterly down such valleys as Babine and Takla. Wherever possible the ice flowed easterly through gaps in the eastern walls of these valleys, apparently as a result of ice pressure from the west. The easterly flowing ice moved down the valleys of the Mesilinka, Osilinka, Omineca,

and Nation Rivers into the valley of the Parsnip River. At the southern end of Babine and Takla valleys the southeasterly moving ice met a great stream of easterly and northeasterly ice moving along the Nechako valley and across the Nechako Plateau. The two streams of ice formed a great confluent piedmont glacier that moved easterly and northeasterly across the Nechako Plain to the Rocky Mountain Trench where this ice sheet met the westerly moving glaciers from the Rocky Mountains. However, this great glacier from the west, being much the larger, overrode the smaller Rocky Mountain glaciers and moved upwards over the low western spurs of the Rockies. The Rocky Mountains acted as a barrier and turned the ice sheet northwesterly down the valley of the Parsnip River. The authors do not believe the ice moved across the Rocky Mountains although no ground observations were made in these mountains.

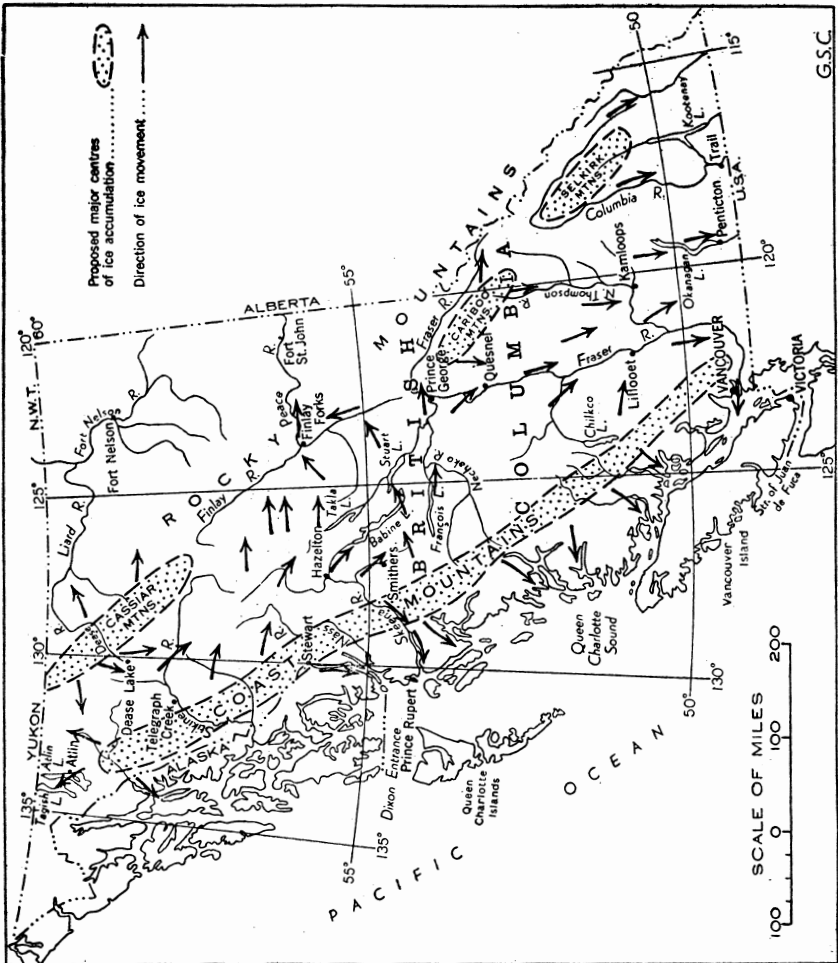
This last advance of the ice was apparently followed by stagnation and decay of the ice sheet in the Nechako Plain and Plateau. This conclusion is based on the presence of compound eskers and kettles and the redundant absence of lateral and terminal moraines. According to Flint when all these conditions exist together they are indicative of stagnant ice although no single condition by itself is sufficient evidence of former stagnant ice. During this decay the compound eskers and glacial lakes in the low-lying areas were probably formed in some such manner as previously suggested under the discussion of these features. In the more mountainous regions the ice probably retreated in the normal manner and what are believed to be recessional moraines were observed in many of the major valleys.

No evidence has been obtained to prove or disprove Dawson's (1891) theories on the subsidence of the Cordillera. However, the authors do not believe it necessary to postulate a great subsidence such as Dawson suggested in order to explain the glacial features observed. The terraced character of many valleys he considered were the result of wave action during the subsidence of the landmass. However these terraces may be kame terraces formed by lateral streams flowing along the sides of a glacier during the thinning and decay of the ice.

## GLACIATION IN BRITISH COLUMBIA

(Text-Fig. 6)

Watson, and Mathews (1944, p. 36), working just south of the British Columbia—Yukon boundary, concluded that the centre of the Cordilleran ice sheet was along the axis of the



Text-Fig. 6. Glacial map of British Columbia showing ice movement.

Cassiar Mountains, which lie to the east of the Coast Mountains, and that the ice moved west and southwest across the Stikine Plateau to the Coast Mountains. Some evidence was obtained for an earlier east and northeast movement. Kerr (1934, p. 21) believed that in northern British Columbia;

between the 57th and 59th parallels of latitude, that the centre of the Cordilleran ice sheet was on the east side of the northern Coast Mountains and that the ice moved southerly and southeasterly and across the Stikine Plateau and southwesterly through the Coast Mountains. Hedley and Holland (1944, p. 31) state that the general ice movement on the east slopes of the Cassiar Mountains was eastward. As already stated the authors of this paper believe that the centre of the Cordilleran ice sheet in central British Columbia was on the Coast Mountains and that the ice moved easterly across the Nechako Plateau and Mountains. The centre may have been on the eastern part of the Coast Mountains and some ice may have moved west through the mountains. In southern British Columbia the main gathering grounds for the Cordilleran ice sheet appears to be the Coast Mountains, Selkirk Mountains, and probably the Cariboo Mountains and the ice moved southerly across the southern interior plateau and westerly through the Coast Mountains. In view of the above it is quite obvious that the Cordilleran ice sheet had not one centre of accumulation, but several major centres and numerous minor centres, the location of each being governed by precipitation and topography. Possibly the greatest area of ice accumulation were on the portions of the Coast Mountains lying opposite Queen Charlotte Sound and Dixon Entrance, the only parts of the Coast Mountains not protected by islands to the west and consequently, areas of great precipitation. The ice flowing easterly from these areas greatly exceeded in mass any other sources of ice and overrode them. Nowhere else in British Columbia did the ice flow to the east for such a great distance.

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