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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

BULLETIN 206

GEOMORPHOLOGY AND MULTIPLE GLACIATION IN THE AREA OF BANFF, ALBERTA

Nathaniel W. Rutter

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Ottawa
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1972

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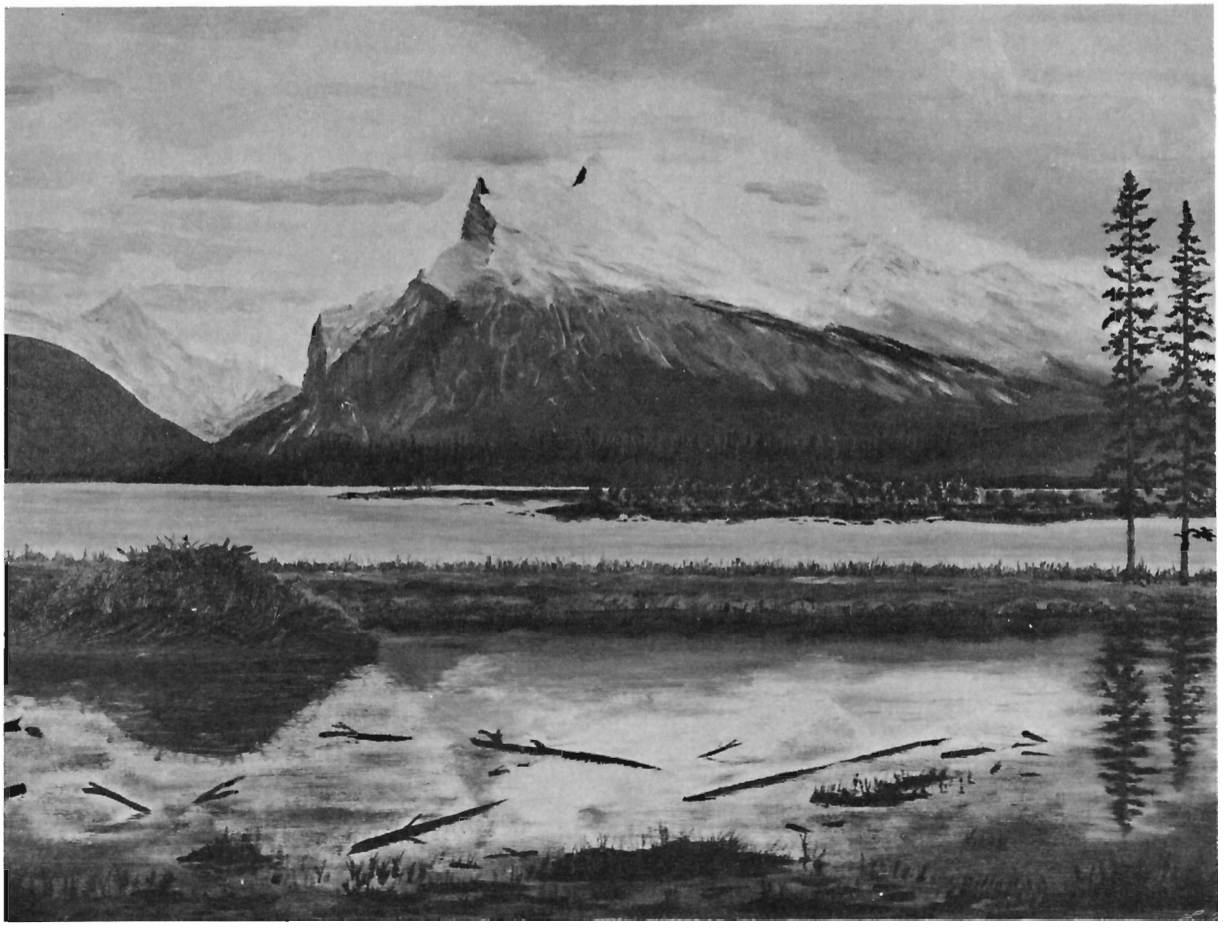

Frontispiece. Mount Rundle, Banff National Park, Alberta
(From an original oil painting by Lorne Roed).

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By
Nathaniel W. Rutter

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PREFACE

Although geological studies have been carried out in this part of the Rocky Mountains for more than a century, no detailed examination had been made of the Quaternary deposits and the recent landforms even though such knowledge is necessary for man's proper use and conservation of the area.

In this report the principal emphasis is placed on Pleistocene glaciation. The glacial deposits are described and the sequence of events is outlined including some reference to present-day processes of erosion and deposition.

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

Ottawa, August 31, 1970

BULLETIN 206 — Geomorphologie und wiederholte Vergletscherung des Banff-Gebiets (Alberta).

Von N. W. Rutter

Dieser Bericht befasst sich hauptsächlich mit der pleistozänen Vergletscherung. Es werden die Eisablagerungen beschrieben und einige Parallelen zu Erosions- und Ablagerungsvorgängen der Gegenwart gezogen.

БЮЛЛЕТЕНЬ 206 — Геоморфология и сложное оледенение в районе Банфа, Альберта

Н. У. Раттер

Главное внимание в этой работе уделяется плейстоценовому оледенению. Описываются ледниковые отложения и упоминаются процессы эрозии и отложений настоящего времени.

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GEOMORPHOLOGY AND MULTIPLE GLACIATION

IN THE AREA OF BANFF, ALBERTA

Abstract

Glacial deposits, consisting mainly of till and glaciofluvial deposits, indicate three or possibly four, major Winsconsin ice advances. Individual sections contain only limited parts of the total stratigraphic section, tills of two of the respective advances are not lithologically distinctive, and interstadial or interglacial deposits are lacking. Therefore, the stratigraphic succession on which the glacial chronology was based is constructed from many incomplete sections, with considerable reliance on the geomorphology and areal relationships of the deposits.

What is probably the earliest recorded glacial activity in the Banff area has been inferred from outwash underlying till deposited by the *Bow Valley* advance, although it is possible that this outwash may be associated with the overlying till. Widespread till deposits and breaks in slope at high elevations are the main evidence for the second, or *Bow Valley* advance, in which the ice extended well out into the Foothills. Ice-contact fluvial deposits, believed to have been originally kame moraines, indicate at least two intervals of glacier equilibrium during deglaciation. The *Canmore* advance extended from the vicinity of Banff probably out to the Foothills. This event is recorded by breaks in slope and by discontinuous patches of till over outwash deposited during the retreat of the *Bow Valley* ice. The fourth advance, the *Eisenhower Junction* advance, extended roughly as far as Eisenhower Junction. Evidence includes well-preserved ground and lateral moraines, breaks in slope, fresh cirques, and a terminal moraine. That a minor readvance followed is shown by till over ice-contact fluvial deposits laid down during the wastage of the *Eisenhower Junction* ice. A radiocarbon date of 9330±170 years B.P. (GSC-332), obtained in a nearby area, is correlated with the time of the *Eisenhower Junction* retreat.

Three stades of the Pinedale glaciation (late Wisconsin) in the northwestern United States are tentatively correlated with the *Bow Valley* advance, the *Canmore* advance, and the *Eisenhower Junction* advance.

The Altithermal interval is suggested by wind-blown material, containing a volcanic ash layer correlated with Mazama ash, overlying glacial deposits.

Résumé

La présence de dépôts glaciaires, constitués surtout de matériaux de moraine de fond (till) et de dépôts fluvio-glaciaires, indique la possibilité de trois ou quatre importantes avancées glaciaires du Wisconsin. Les coupes individuelles présentent seulement des parties limitées de l'ensemble de la coupe stratigraphique; les matériaux de moraine de fond de deux des avancées respectives ne sont pas distinctes lithologiquement et il n'existe pas de dépôts interstadiaires ou interglaciaires. Ainsi la succession stratigraphique, sur laquelle on a fondé la chronologie glaciaire, est composée de nombreuses coupes incomplètes et présente une étroite dépendance avec la géomorphologie et les relations locales des dépôts.

Ce qui, vraisemblablement, constitue l'activité glaciaire la plus ancienne connue dans la région de Banff, a été identifié à l'aide des dépôts fluvio-glaciaires sous-jacents aux matériaux de moraine de fond déposés par l'avancée de *Bow Valley*; il est toutefois possible que ces dépôts fluvio-glaciaires aient été formés en même temps que les matériaux de moraine de fond sus-jacents. Les dépôts étendus de ces matériaux et les ruptures de pente que l'on observe en hauteur sont les principales preuves de la deuxième avancée, ou avancée de *Bow Valley*, au cours de laquelle les glaces ont envahi les Foothills. La présence de dépôts fluviaux de contact glaciaire, que l'on estime

avoir été constitués à l'origine de moraines dont la nature des matériaux s'apparente aux kames, indique au moins deux intervalles de temps pendant lesquels a existé un équilibre des glaciers au cours de la déglaciation. L'avancée de *Canmore* s'est étendue des environs de Banff jusqu'aux Foothills probablement. Cette avancée est marquée par des ruptures de pente et des plaques de matériaux de moraine de fond sus-jacents aux dépôts fluvio-glaciaires constitués au cours du retrait des glaces de *Bow Valley*. La quatrième avancée, l'avancée de *Eisenhower Junction*, s'est étendue à peu près jusqu'à Eisenhower Junction. Les marques de cette avancée comprennent un sol bien préservé, des moraines latérales, des ruptures de pente, des cirques récents, et une moraine terminale. On constate qu'une nouvelle avancée moins importante a suivi, du fait de la présence de matériaux de moraine de fond recouvrant les dépôts fluviaux de contact glaciaire déposés au cours de la fonte des glaces de *Eisenhower Junction*. On a établi une corrélation entre une datation au radiocarbone de 9330±170 années B.P. (CGC-332) effectuée dans une zone proche, et l'époque de la régression des glaces de *Eisenhower Junction*.

On a tenté de rapprocher trois étapes de la glaciation Pinedale (fin du Wisconsin), au nord-ouest des États-Unis, avec les avancées de *Bow Valley*, *Canmore* et *Eisenhower Junction*.

On suppose l'existence d'un intervalle altithermal du fait de la présence de matériaux éoliens, contenant une couche de cendres volcaniques mises en relation avec les cendres de Mazama, qui recouvrent les dépôts glaciaires.

INTRODUCTION

Prior to the present study[1], detailed research of the Quaternary geology of the Banff area had not been undertaken. Probably the first person to make geological observations was James Hector, a scientist with the Palliser expedition, who noted the presence of what are now known to be glacial deposits throughout the Bow River country but attributed them to ice-rafting (Hector, 1861). The first detailed geological work in western Canada was carried out by G.M. Dawson and R.G. McConnell, who published, between 1875 and 1895, a series of papers on the western part of the Great Plains and the Rocky Mountains. In most of his papers, Dawson described the surficial deposits (Dawson, 1875, 1883, 1885, 1886, 1890a, 1890b; Dawson and McConnell, 1895); in the 1886 report he commented on drainage changes in the mountain sector of the Bow River, and later (1890a) proposed a correlative scheme between glaciation in the Canadian Cordillera and glaciation in the western Great Plains. McConnell (1887) and Ogilvie (1904) also proposed probable sequences of drainage changes of the mountain section of the Bow River, Wilcox (1899) noted a till sequence near Banff, and Coleman (1910) considered the relationship between the Cordilleran and Keewatin ice sheets. Geological reports of the Banff area since 1910 deal only briefly with aspects of Quaternary geology. These, as well as studies of the glacial geology and geomorphology of nearby areas and reports of the post glacial history and environments, are listed in Appendix 1 and are also included in the bibliography at the end of this report.

Surficial deposits were mapped by the author during 1963 and 1964 (Maps 1 and 2, *in pocket*), and the probable glacial history and Quaternary stratigraphy were determined. Many problems still remain unresolved but the general scheme of major late-Quaternary events presented here would seem to explain most of the erosional and depositional features of the surficial geology.

The study area lies within the eastern watershed of the Canadian Rocky Mountain sector of the Cordilleran physiographic province and includes the Wenkchemna Glacier, the Valley of the Ten Peaks, and the Bow River valley from its junction with the Valley of the Ten Peaks downstream to about Seebe (Fig. 1). It extends from 51°00'N to 51°30'N and from 115°00'W to 116°15'W, and is roughly 65 miles long and 1.5 miles wide. The various sections of the area are shown on the following National Topographic System maps:

82 N/1 E and W	82 O/3 E and W	82 O/5 E and W
82 N/8 E and W	82 O/4 E and W	82 O/6 E and W

[1] The results presented in this paper represent one facet of the research and field work carried out by Dr. Rutter in 1963 and 1964 under Project A-802 of the Canada Department of Forestry and Rural Development (East Slopes - Alberta - Watershed Research Program).

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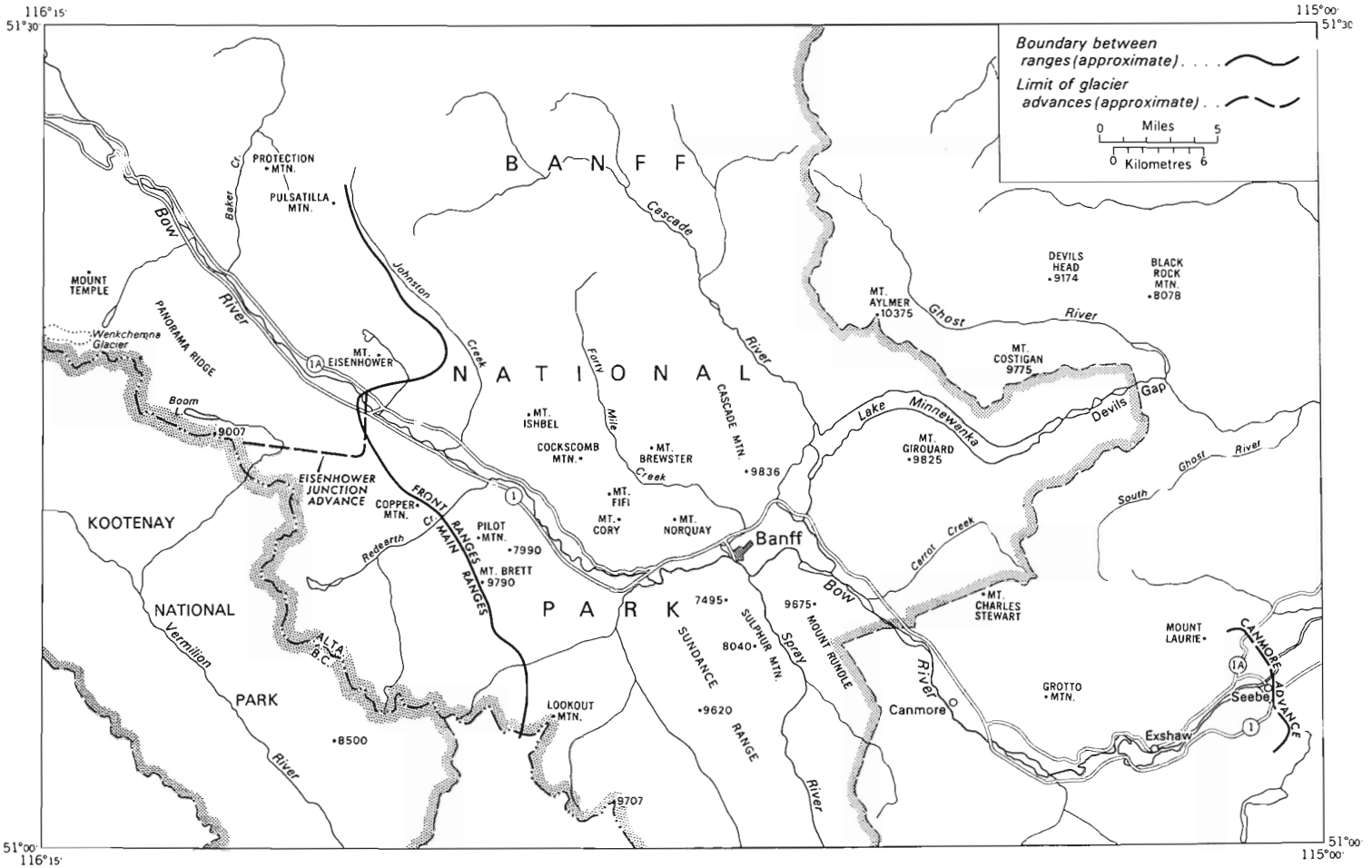


GSC

Figure 1. Index map of the Banff area, showing Main and Front Ranges and limit of Eisenhower Junction and Canmore glacial advances.

Interpretation from air photographs[1] (scale: 1:40,000) provided the preliminary mapping of the surficial geology and was followed by field investigations. The final interpretations were transferred to topographic maps (scale: 1:50,000). The only information that could be obtained from air photographs with any assurance of reliability was the limit of postglacial deposits such as alluvial fans, flood plain deposits, and talus slopes. The thick forest cover in the area masks most surficial deposits and hampers the identification of glacial deposits both in the field and on air photographs.

Exposures of surficial deposits are restricted to excavations along major highways and the valleys of the larger creeks and rivers. Vertical lithological sequences, fossils, and datable materials are scarce. The stratigraphy and geologic history was therefore established largely on the basis of the relationships between deposits and geomorphology.

Laboratory investigations of till and aeolian deposits included analyses of grain size, pebble roundness, pebble lithology, heavy and clay minerals, carbonate content, and dolomite-calcite ratios (carried out by the writer at the University of Alberta laboratories).

PHYSICAL CHARACTER OF THE AREA

The topography of the area is controlled principally by the structure of the bedrock as modified by glacial and subaerial erosion and deposition. The northwest-trending mountain ranges are separated by rivers and creeks that form a trellis drainage pattern in which the principal streams are subsequent for all or most of their courses. The mountains are rugged and provide a great variety of classical examples of such glacial alpine morphology as cols, arêtes, horns, cirques, hanging valleys, U-shaped valleys, and glacially polished surfaces. The highest mountains generally are between about 8,000 and 10,000 feet although the highest, Mount Temple, rises to 11,626 feet. Local relief varies between approximately 4,000 and 6,000 feet with respect to the Bow Valley floor. Intense postglacial subaerial erosion is rapidly modifying the existing landforms.

BEDROCK

The study area includes two distinct geological areas (Fig. 1). The first extends roughly from the Kananaskis River up the Bow Valley to Eisenhower Junction and includes parts of the Front Ranges. The second begins at Eisenhower Junction and extends northwestward beyond the study area. It includes parts of the Main Ranges.

Mississippian and Devonian rocks consisting principally of resistant dolomite and limestone are, volumetrically, the most important rocks in the Front Ranges or first geological area. They form the major ridges, separated by the Bow River valley which is itself floored by weaker Mesozoic rocks composed predominantly of fine-grained clastic material. The mountain ridges have been formed by thrusting from the southwest, and the faults are often visible at the base of northeast exposures of the resistant mountains which have overridden and truncated weaker and younger rocks. The faults have a southwest dip of 30 to 45 degrees near the surface and a vertical stratigraphic displacement of many thousands of feet. The beds dip generally to the southwest at angles as great as 45 degrees because of the thrusts disrupting overturned folds. Anticlines, synclines, and minor folds, sometimes overturned, are present. Most of the major mountain ranges are composed principally of limestone and dolomite whereas the topographic lows consist mainly of shale, sandstone, and siltstone. Ordovician and Cambrian limestone and dolomite are found near the northeast base

[1] Alberta Department of Lands and Forests, Edmonton.

of the Sundance Range, and Cambrian limestone and dolomite appear above the major thrust zone near Exshaw.

In the Main Ranges or second geological area, the principal rocks are Cambrian carbonates and quartzitic sandstone. These relatively undisturbed older rocks have been faulted upward and outward along a major thrust plane. They outcrop on Mount Eisenhower and on the mountains to the west, at least as far as the Continental Divide. The two major structures in the area are the broad, northwest-trending synclines with axes along the mountain crests that border the Bow Valley on either side. In the topographic low that forms the floor of the valley is an anticline composed of Precambrian clastics.

Large bodies of igneous rocks do not occur in the study area. Sills, however, are found northwest of Eisenhower Junction (A. Akehurst, University of British Columbia, *pers. com.)*, and small-scale mineralization occurs along some fractures.

PHYSIOGRAPHIC UNITS

The area can be divided into two physiographic units: the Alpine Region and the Major Valleys Region (Fig. 2).

Alpine Region

The Alpine Region comprises the higher levels of the mountains bordering the valley of the Bow River and some of its tributaries. Its lower boundary corresponds roughly to the upper limits of two prominent glacial advances: the *Eisenhower Junction* advance in the northwestern part of the area and the *Canmore* advance in the southeast. The lower boundary lies at approximately 7,000 feet near Moraine Lake and drops to about 4,500 feet in the vicinity of Exshaw.

In the Main Ranges, from Eisenhower Junction northwestward, the strata are gently inclined. They have been eroded into a rugged but uniform bench-and-slope topography that has resulted in a series of crudely symmetrical valleys and, locally, castellated forms and delicate pillars of which Mount Eisenhower is an outstanding example.

In the Front Ranges southeast of Eisenhower Junction, the strata dip more steeply, and the narrow, inclined belts of contrasting lithology have been differentially eroded to produce slopes, serrated ridges, jagged peaks, and an overall decrease in elevation relative to the Main Ranges. In the Front Ranges these differences in structure and lithology result in asymmetrical valleys and it is commonly observed that the northeast wall of a valley is a dip slope (*see Frontispiece*), whereas the southwest wall or back slope exposes a variety of rocks, including relatively soft units.

The striking accordance of summits offers the only indication of any preglacial erosional surface.

Glaciers and Glacial Features

A few cirque glaciers are still found in the northwest part of the area, the most outstanding being the Wenkchemna Glacier, a reconstructed glacier of the horseshoe type, located above Moraine Lake at an altitude of between 6,400 and 8,000 feet. It nestles on the southern side of a prominent cirque and consists mainly of ice-cored moraine. Its firn limit lies at approximately 7,900 feet. Above Consolation and Boom Lakes, a few miles southeast of the Wenkchemna Glacier, there are cirque glaciers consisting mainly of stagnant ice. The one above Consolation Lakes has a northern exposure and its firn limit lies at roughly 8,000 feet; the one above Boom Lake has a southeastern exposure with its firn line at approximately 8,300 feet.

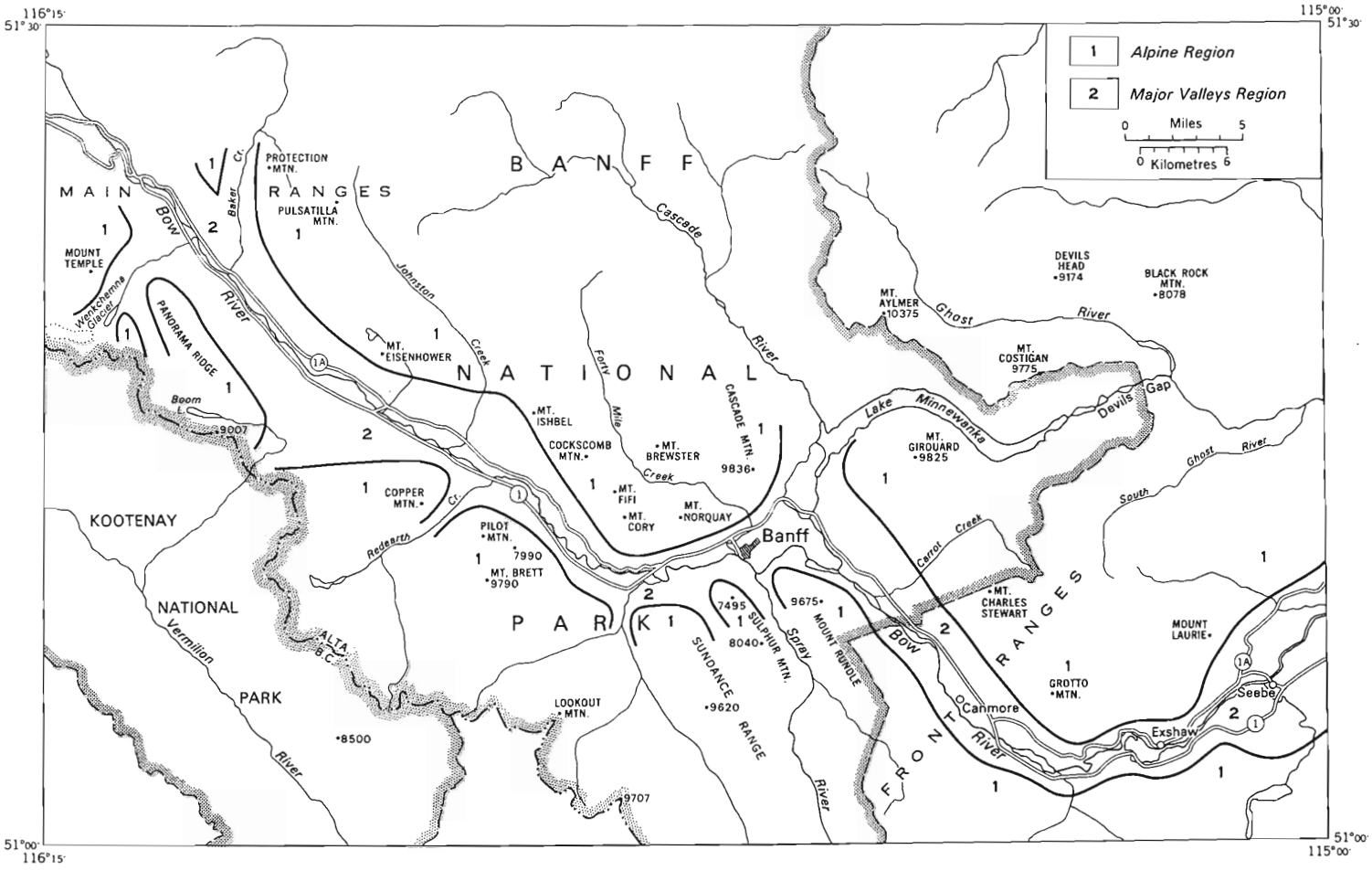


Figure 2. Physiographic regions of the Banff area, Alberta.

Figure 3. Stereopair of two or possibly three successive cirques, located 2 miles southeast of Protection Mountain (51°23'30"N, 116°00'00"W). *(201486)*

Small cirque glaciers are found in other locations in the northwestern part of the area as, for example, above Taylor Lake and Twin Lakes. Perennial patches of snow and ice are also present in some localities.

Cirques without glaciers are widespread. They increase in number and are better preserved toward the northwest, and more of them have developed on the north-facing side of the mountains. From the elevations of the cirque floors, former snowlines are estimated to have lain between 6,200 and 8,250 feet (*see* Table I), most being between 6,750 and 7,300 feet. In some valleys this range in elevation results mainly because there have been two or three cirques at different levels (Fig. 3 and Table I).

Cols, horns, arêtes, and U-shaped valleys are numerous and well developed in the northwestern part. Good examples of U-shaped valleys are found at Johnston Creek, in the Twin Lakes-Copper Mountain area, in the Massive Mountain area, and downstream from Taylor, Rockbound, O'Brien, and Boom Lakes.

Table I. *Estimated Elevation of Past Climatic Snowlines Derived from Cirque Floors, Each Group Located within a Single Valley*

	Snowline elevation (feet)		
Location of cirques	Lowest	Middle	Highest
Southeast exposure, Mount Eisenhower	±6,950	±7,250	±8,150
East-southeast exposure, Mount Eisenhower	±6,450	±7,150	±8,250
Northeast exposure, Mount Brett	±6,950	±7,250	±7,650
Eastern exposure, Mount Brett	±6,200	±7,250	±7,850

Lakes in the Alpine Region occupy basins of glacial origin and generally fall into two categories: rock-basin and moraine-dammed. Rock-basin lakes, represented by tarns, include Rockbound, Tower, O'Brien, Taylor, and Twin Lakes. Boom Lake is moraine-dammed. The only lake of non-glacial origin in this region is the artificial one above Canmore that was constructed to provide hydroelectric power.

Throughout this region, breaks-in-slope[1] are generally the main indicators of the upper limits of glacial advances. In some instances, however, it is difficult to determine whether these 'breaks' are the result of glaciation or a reflection of the bedrock structure. Lateral moraines are absent at the upper limits of glaciation.

Glacial depositional features are of minor importance throughout the Alpine Region. Hummocky moraine occurs near Tower Lake on the northeast side of Mount Eisenhower and toward the end of Boom Creek valley where the hummocks are poorly developed and show many irregularities, which probably reflect, in part, the bedrock topography. Thin beds of discontinuous till in various stages of modification are found on valley walls and in cirques. In addition, a number of outwash and alluvial terraces are present in the lower part of the U-shaped portion of Johnston Creek valley.

Frost Features and Mass-wasting Products

Frost features such as felsenmeer and polygonal ground are found on almost all fairly level surfaces above the timber line. Most of the material is highly angular and coarse grained, with dimensions greater than 25 mm. Of particular interest is the polygonal ground observed near Stuart Knob, about 2 miles northwest of Mount Eisenhower, believed to be active or recently active because of the fresh appearance of the stones and the lack of vegetation.

Mass-wasting processes, of which the most important products are rock glaciers and talus cones at the base of steep slopes, are active in the Alpine Region. Rock glaciers are evident on air photographs of the Twin Lakes-Copper Mountain region at elevations between 7,000 and 8,000 feet at the base of the

[1]Break-in-slope: a decrease in slope angle of the valley wall caused by lateral glacial stream activity eroding bedrock along the upper margin of a glacier.

back walls of some northerly-exposed cirques. Most are lobate and tongue-shaped, with width and length less than 1,400 feet. It is not known whether they are still active, but the steep slopes, available material, lack of vegetation, and present near-glacial climate suggest that they well may be.

Scars of ancient landslides are relatively common, the large gap on the southwest side of Protection Mountain being a good example.

Major Valleys Region

The Major Valleys Region includes the valleys of the Bow River and its major tributaries (*see* Fig. 2). It is primarily an area of both glacial and non-glacial aggradation.

The Bow River is subsequent for most of its length, but cuts across the regional strike of the bedrock near Banff and near Gap Lake. Whether the crosscutting indicates an antecedent, superimposed, or some other type of stream is not possible to say at present.

All the larger valleys, as well as the smaller valleys in the northwestern part of the area, are U-shaped, some of them hanging. In general, the larger the tributary, the lower its elevation above the floor of the Bow Valley. Upper limits of glacier ice are indicated by breaks-in-slope and by lateral moraines.

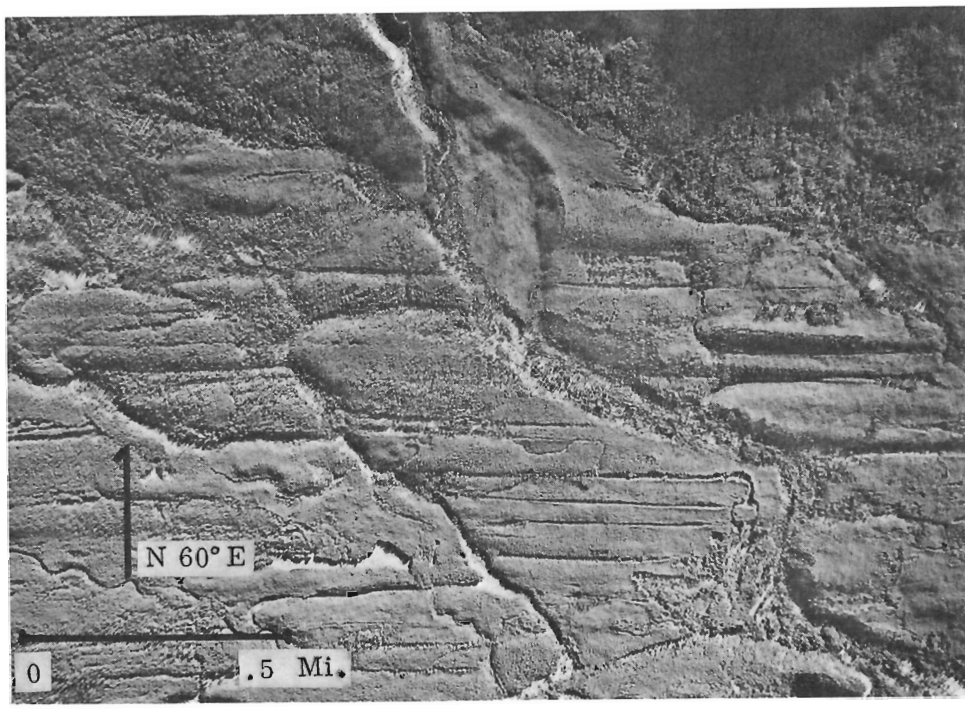


Figure 4. Low, parallel, erosional ridges and shallow depressions in till at Corral Creek near Lake Louise (outside study area). Glacier flowed from left to right. Forest-free zones exaggerate the sharpness of the breaks between ridges. *(201487)*

Glacial Features

Except for the flood plain and a few other small areas, the entire Bow Valley floor is covered with a blanket of till and glaciofluvial deposits. The deposits grade into one another with little or no apparent landform change. The surface features of the deposits, whether bedrock-controlled or not, generally run parallel or nearly parallel to the valley. A series of low, rolling, parallel ridges, separated from each other by shallow depressions sharply marked by forest-free zones, extend from beyond the northwest limits of the area for about four miles northwest of Eisenhower Junction (Fig. 4). These ridges are erosional forms, gradational between glacial flutings and drumlins. Most of them are located in till and, in many cases, their up-valley sections show greater local relief than their lower sections.

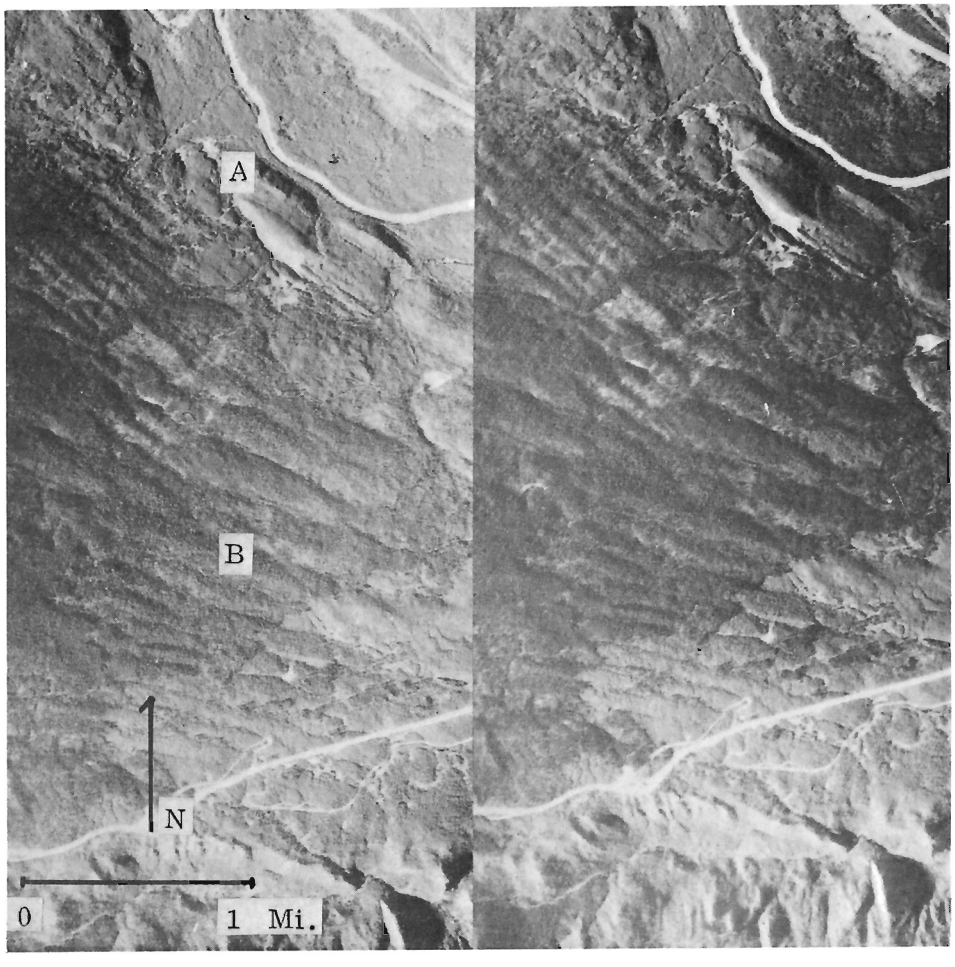


Figure 5. Stereopair showing ice-contact fluvial complex near Eisenhower Junction. Route 93 crosses the lower part of the photo and the Bow River is seen in the upper part. Erosional ridges in drift are located at A, abandoned side glacial stream channels at B. *(201488)*

Farther down-valley, on the south side of the Bow River near Eisenhower Junction, the morphology changes from one of ice moulding to one of deposition and of erosion by lateral glacial streams. Here a series of fairly straight and partially ridged 'steps' extend between the valley floor and the valley wall (Fig. 5). Similar features are also found on the north side of Boom Creek valley. It is difficult to determine the composition of the ridges because of the forest cover, but they are probably sorted glacial deposits formed by glaciofluvial reworking of the till during glacier retreat. Down-cutting is significant in places, as evidenced by depressions between ridges and steps. Near Eisenhower Junction, these prominent steps grade into glaciofluvial deposits, partly dissected by channels.

Northeast of Tunnel Mountain, parallel ridges, broader and longer than those just mentioned, occur on the surface of thick till beds (Fig. 6). The lineation continues sporadically from Tunnel Mountain to Gap Lake and, like that of the other erosional features mentioned, runs parallel to the valley. The ridges may reflect bedrock morphology in some areas but it is difficult to prove this because the bedrock generally strikes parallel to the till structures.

From Kananaskis to beyond Seebe is a region bordered by outwash gravels and dominated in its western part by kames, eskers and features which are probably crevasse fillings (Fig. 7). The best developed esker lies just west of the Kananaskis River and is approximately 150 feet wide and one-quarter of a mile long. Farther east numerous drumlins trend northeastward. They are a few hundred feet to a mile in length, forty to several hundred feet wide, and twenty to seventy feet high. The Bow River in this area is incised into bedrock and has a narrow, discontinuous flood plain. Bedrock terraces and meltwater channels are found on the lower parts of the bordering mountains.

Drainage into the Bow River valley is either by high gradient streams without flood plains or by low gradient streams with flood plains. Some of these streams flow in hanging valleys and have eroded deep, narrow canyons where they flow out into the main valleys. Outstanding examples are Johnston Canyon, Sundance Canyon, and the lower part of Redearth Creek.

Lakes in the Major Valleys Region occupy depressions of both glacial and non-glacial origin. Rock-basin lakes, the only ones of glacial origin, are exemplified by Lake Minnewanka and the two tarns forming Consolation Lakes. Lakes of non-glacial origin include Smith Lake, which is trapped in a former meltwater channel, and Vermilion Lakes and Lac des Arcs, which are flood-plain lakes. Moraine, Eiffel, and Lizard Lakes are dammed by landslides, and Gap Lake, Two Jack Lake, Johnston Lake, a reservoir, and an unnamed lake near Canmore are artificial.

Postglacial Features

Mass-wasting processes are active in the Major Valleys Region, with landslide deposits and talus as the most important results. Rock-creep, talus-creep, and soil-creep are active throughout the region.

One fairly recent landslide deposit, located near Johnston Canyon, includes debris deposited by slumping. It occupies an area of about two and one-half square miles and consists of broad, arcuate slip faces and irregular mounds similar to typical knob-and-kettle topography. The relatively fresh morphology and lack of glacial deposits on the surface indicate that the slide is postglacial.

Talus slopes free of vegetation, and therefore with a high rate of development, are scarce and are found only in the higher areas near the timber line. Talus with vegetation cover and with a slower rate of development is common on the steeper slopes of the main valleys.

Superimposed upon and truncating the glacial deposits in the Bow Valley are numerous *well-developed alluvial fans* actively forming from small tributary creeks, both perennial and intermittent. These fans vary considerably

in size, several being more than one and one-half miles wide. Northwest of the former settlement of Massive, alluvial fans are less developed and smaller than in stream beds of similar size in the southeast.

There are two areas of distinctive *sand dunes*. One, about one-third square mile in area, is situated on glaciolacustrine deposits two miles northeast of Banff. The dunes, irregular mounds with low relief, have been formed by down-valley winds and stabilized by vegetation. The second, consisting of not more than one-half square mile of similar dunes, lies adjacent to Lac des Arcs. These dunes form strips and patches along the banks of the Bow River and on islands south of the main channel. Although at the present time the dunes are partially stabilized by vegetation, the wind is still shifting the sand exposed by the fluctuating water level of the Bow River.

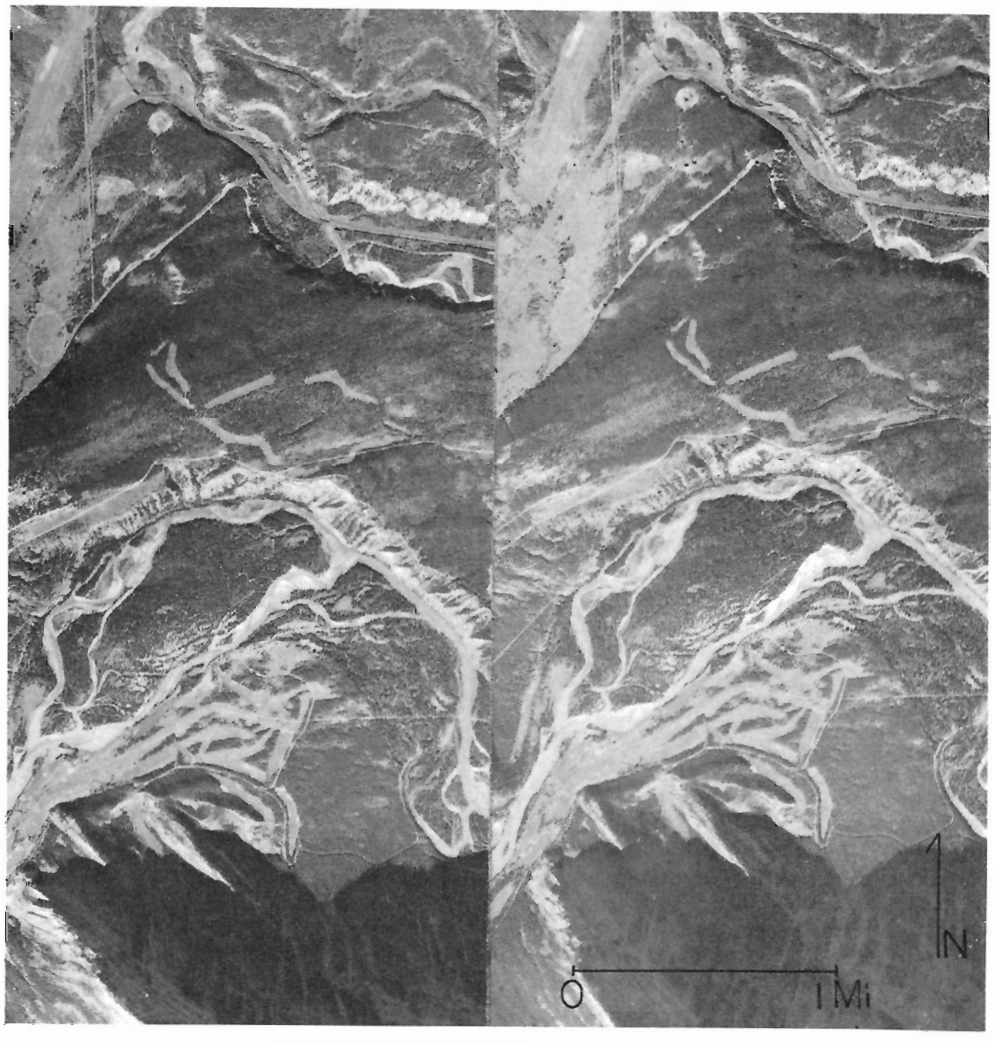


Figure 6. Stereopair showing large-scale erosional ridges and depressions in till beds on the northeast side of Tunnel Mountain near Banff. The Bow River lies near the centre of the photo. *(201489)*

DRAINAGE CHANGES

The ancestral drainage of the Bow River was probably much the same as that of today. Although the hypothesis that, in preglacial times, the Bow River may have flowed through the Lake Minnewanka valley has been suggested by several workers (Dawson, 1886; Ogilvie, 1904; Scherzer, 1907; Warren, 1927; Allan, 1943), they fail to cite proof. There is, however, evidence that, for a certain time during an interglacial period, the major drainage for the area as a whole was through the Lake Minnewanka Valley.

Figure 8 illustrates the more obvious drainage changes that occurred during the Pleistocene:

The Bow River flowed on the north side of Tunnel Mountain.

The Cascade River probably flowed down the central portion of the Cascade Valley.

A river from the Lake Minnewanka Valley may have paralleled Two Jack Lake and entered the Bow River east of Banff.

The Spray River flowed down Sundance Creek valley, entering the Bow River near Sundance Canyon.

The lower part of the Spray River valley was occupied by Goat Creek.

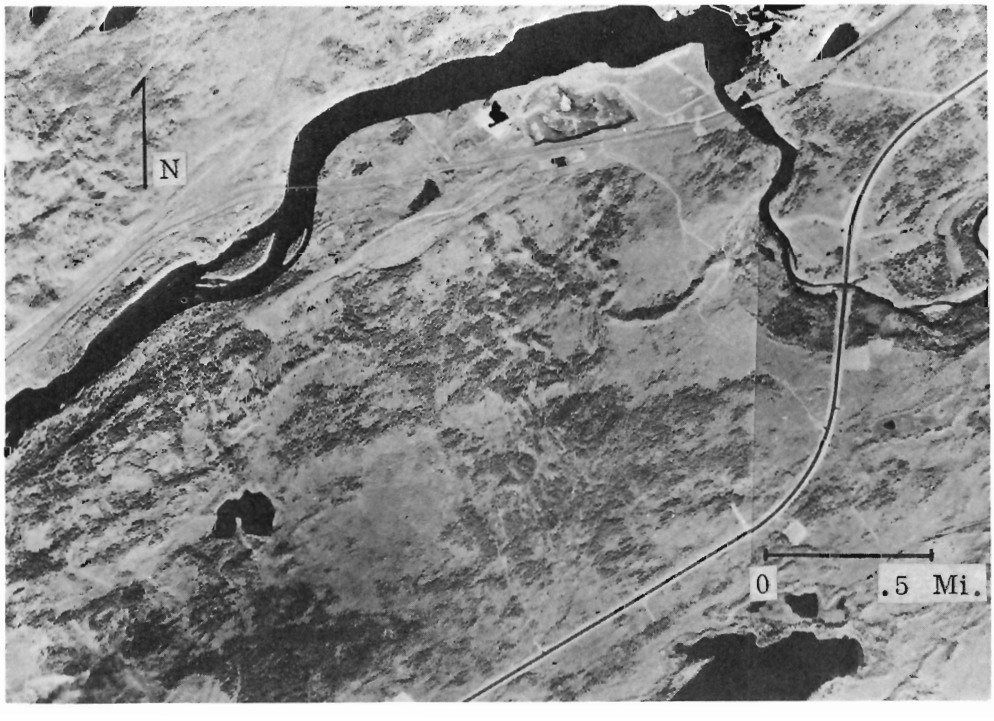


Figure 7. Kame region located between Kananaskis and Seebe. The surface landforms consist principally of kames, eskers, and what are considered to be crevasse fillings. The Bow River is seen in the upper part of the photo and Route No. 1 in the lower part. *(201490)*

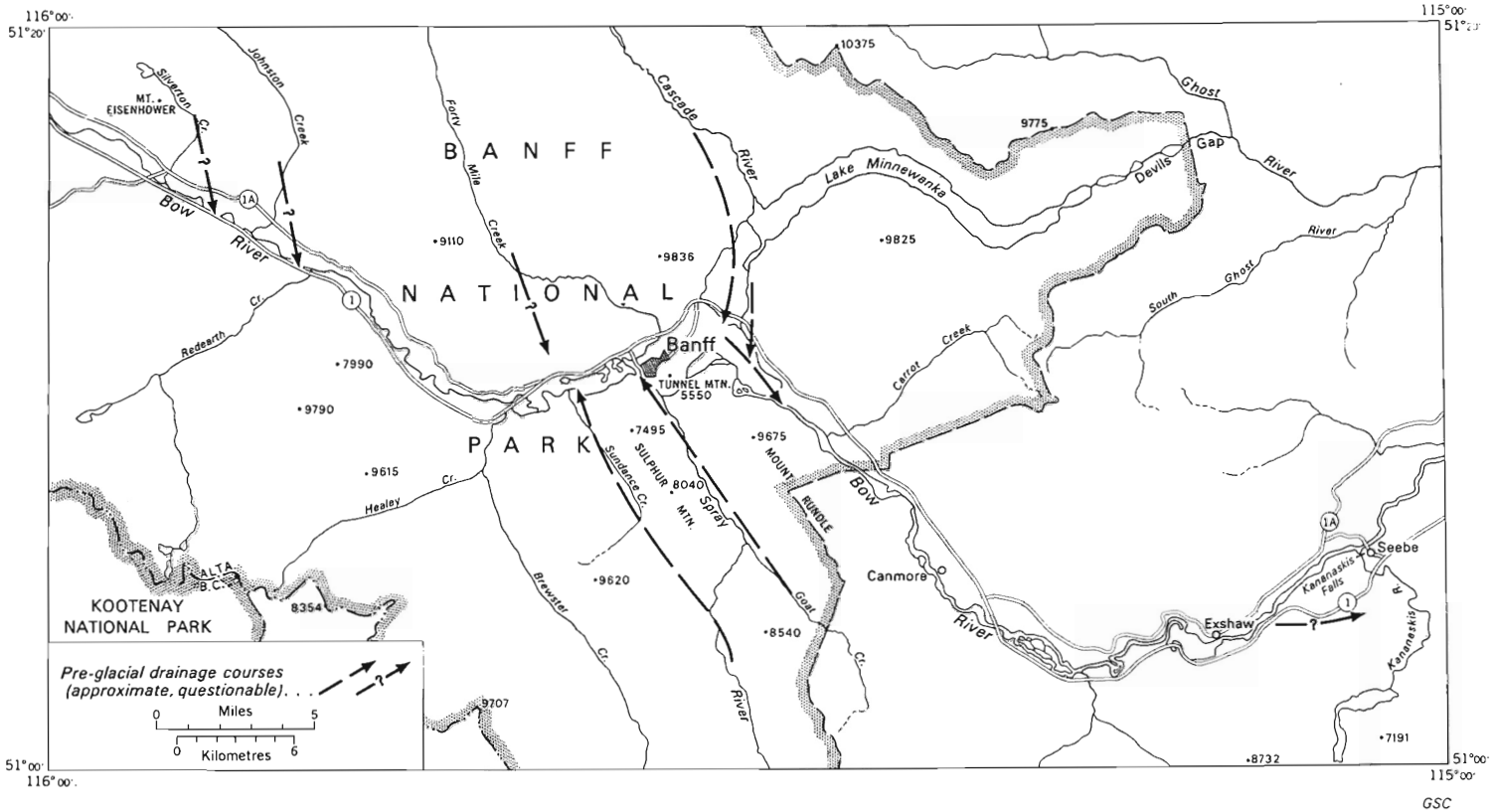


Figure 8. Former drainage courses in the Banff area, Alberta, modified during the Pleistocene.

Drainage courses of possible preglacial origin include: Silverton and Johnston Creeks, which entered the Bow at more acute angles; Forty Mile Creek, which passed through a gap west of its present route; and the Bow River, east of Exshaw, which flowed south of its present channel.

These earlier drainage routes have been postulated from geomorphic criteria only. They constitute abnormal drainage routes that would not form during the subaerial erosional cycle of a structurally controlled area such as this, unless glacial or other obstructions were present.

Before glaciation, the mountains in the Banff area were probably less rugged and had gentler slopes than those of today. The major valleys were probably V-shaped, relatively narrow, and had higher gradients and more restricted flood plains. Erosion apparently proceeded at a rapid rate in zones of low-resistant rocks, and many of the larger valleys are cut through weak Mesozoic shale and sandstone. Local relief was similar in pattern to that of the present time; it is probably more accentuated today as a result of glacial scouring.

GLACIATION

The principal emphasis in this study is placed on Pleistocene glaciation. Three major glacial events are recognized: the *Bow Valley* advance, the *Canmore* advance,[1] and the *Eisenhower Junction* advance (*see* Fig. 1 for outline of probable limits). Evidence of glacier activity prior to the *Bow Valley* advance[2] is discussed, but only the most obvious traces of neoglacial activity will be cited. Evidence for the three major advances consists primarily in the relationships between different types of glacial deposits, such as till over and adjacent to glaciofluvial deposits, and in geomorphic criteria such as breaks-in-slope caused by glacial erosion and by lateral glacial stream activity. Correlation aids, such as till successions, isotopic dating control, soil development, and weathering characteristics of deposits, are either scarce or altogether lacking.

Detailed analyses of undisturbed till were carried out on thirty-five unweathered samples collected at random sites in the Bow Valley (Table II, *in pocket*). These investigations included grain size analysis, studies of pebble roundness, pebble composition counts, heavy and clay mineral determinations, total carbonate content, and dolomite-calcite percentages. The purpose was to describe the lithology more fully, to determine beyond doubt the provenance of the till, and to identify individual till sheets. The results indicate that the factors considered are not adequate to distinguish individual till sheets. Differences in till lithology or texture were found to be directly related to the local bedrock. A till was therefore assigned to a certain advance according to its relationship with other evidence of that event.

EARLY GLACIAL ACTIVITY

The earliest glacial material recognized within the map-area is outwash gravel occurring beneath till of the Bow Valley advance (Fig. 9). This gravel is exposed in a number of places in the neighbourhood of Banff, and at one locality it appears to exceed 70 feet in thickness (Appendix 2, section 1). The gravel is assumed to relate to glacial activity separate from and older than the Bow Valley advance. Till, which is considered to have been deposited before the Bow Valley advance because of its stratigraphic position and high content of material derived directly from the local bedrock, is exposed just east of the map-area on the south side of Bow River about three miles southwest of Morley (51°08'N, 114°56'W). It is dark grey, more than 20 feet thick, rests

[1] Previously named the *Bow Valley* re-advance (Rutter, 1965, 1966a, 1966b).
[2] Previously named pre-*Bow Valley* advance (Rutter, 1965, 1966a).

on bedrock, and underlies a sequence of two outwash units separated by buff-coloured till. The dark colour of the lower till, caused by its high shale content, is different from that of any observed in the Rocky Mountain section of the Bow Valley.

BOW VALLEY ADVANCE

Stratigraphic and Geomorphic Evidence

The *Bow Valley* advance is the most extensive for which clearcut evidence is available in the Banff area. Widespread till deposits and breaks-in-slope, caused by glacial scouring and the action of lateral glacial streams, provide the principal evidence of this advance. It is inferred that the glaciers of this advance originated in the area of the Continental Divide and were confined almost entirely to valleys in which the flow of the ice was controlled by the topography. This resulted in a reticulate glacier pattern within the mountains, with the main glacier flowing down the Bow Valley and extending beyond the Front Ranges. During the maximum extent of this advance, the minimum ice thickness in the northwest part of the area was between about 1,600 and 2,600 feet.

The basic record of the *Bow Valley* advance is the thick till that is widespread on the floor of the Bow Valley from Eisenhower Junction to Exshaw. The exposure of this till on the southwest side of Cascade River about one-half mile southwest of the Banff power house (*see* Appendix 2, section 1, and Fig. 9) is designated as the type section.

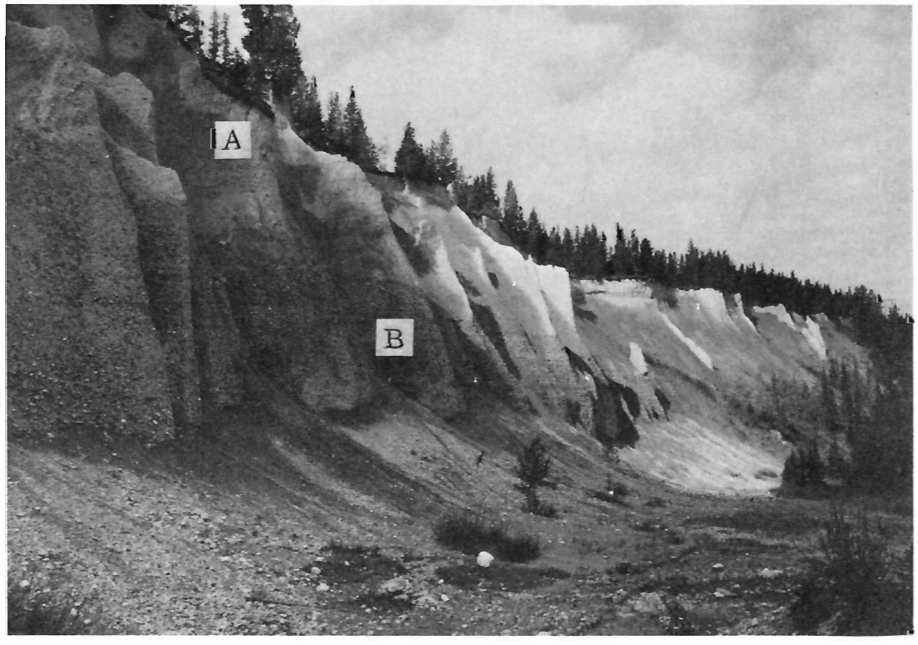


Figure 9. *Bow Valley* till (A) overlying pre-Bow Valley outwash gravels (B) about one-half mile southwest of the Banff power house on the southwest side of the Cascade River. View toward the west-southwest (51°11'40"N, 115°31'00"W). *(201491)*

In the vicinity of Banff the till overlies outwash gravel that has been inferred as dating from a separate, earlier glacial episode; elsewhere in the area the lower contact of the till has either not been seen or lies directly on bedrock. Commonly the till extends up to the ground surface and forms ridges and depressions of glacial origin, but in places it is covered by as much as 4 feet of gravel and sand. On valley walls it is modified by slope washing and masked by colluvium. Thus, the upper limit of the advance is inferred from erratics and, in places, from breaks-in-slope. In the lower part of the Bow Valley, southeast of the east gate of Banff National Park, till of the *Bow Valley* advance cannot be distinguished from younger till deposited during the subsequent *Canmore* advance.

The writer assumes that the highest indications of glacial activity, in the form of breaks-in-slope caused by glacial streams, date from the *Bow Valley* advance. However, the possibility cannot be eliminated that some of these features belong to older advances. The highest erratics found on Sulphur and Cascade Mountains are reported to lie at nearly 8,000 feet (Warren, 1927, p. 8). The writer found erratics at over 7,400 feet on Sulphur Mountain but none above 6,500 feet on the dip slope of Cascade Mountain. No glacial erratics were found on a saddle on Mount Rundle at 8,400 feet, on Grotto Mountain at about 8,800 feet, on a saddle near Mount Charles Stewart at 8,000 feet, or on Mount Eisenhower at about 8,700 feet. Breaks-in-slope occur at a maximum elevation of 8,200 feet in the Valley of the Ten Peaks area and a maximum of 7,600 feet on the east side of the Baker Creek valley (Table III). Therefore it would seem that the ice of the *Bow Valley* advance did not reach elevations of more than 8,000 feet in the main valley, and was only slightly higher in the major tributary valleys to the southwest.

Ice-contact deposits, believed originally to be kame moraines, indicate at least two intervals of equilibrium in the Bow Valley during the glacial retreat following the *Bow Valley* advance. One deposit, near the town of Banff, probably represents the interval before the *Canmore* advance during which a thin tongue of ice, approximately 750 feet thick, extended down the valley roughly as far as the Kananaskis River. This event is suggested by breaks-in-slope and discontinuous patches of till deposited over outwash during the retreat that followed the *Bow Valley* advance.

About one and one-half miles northwest of Canmore, ice-contact fluvial deposits grade into outwash plains both up-valley and down-valley. Near the confluence of the Bow and Cascade Rivers, about four miles east of Banff, ice-contact outwash grades into Bow Valley till upstream and into an outwash plain downstream. This occurrence of ice-contact outwash is believed to represent the limit of retreat following the *Bow Valley* advance. Thus, the ice-contact deposits probably formed kames before they were eroded.

A continuous outwash plain, interrupted only by crosscutting creeks and minor alluvial and ice-contact deposits, extends along the northeast side of the Bow River from 4 miles east of Banff to Gap Lake. The outwash has a minimum depth of 59 feet near Carrot Creek (Fig. 10; Appendix 2, section 5), and is 99 feet thick about three miles southeast of Canmore (Fig. 11; Appendix 2, section 6).

Underlying or bordering the outwash are till remnants that fit the description of Bow Valley till, but which could have been deposited earlier. One occurrence, 12 feet thick, outcrops along a canyon wall about three and one-half miles north-northwest of Canmore, and an outcrop about 65 feet high and nearly one-fifth of a mile long is visible at creek level about one and one-half miles southwest of Grotto Mountain.

Table III. *Upper Limits of the Bow Valley Advance as Indicated by Breaks-in-slope, and Approximate Ice Thicknesses (maximum and minimum elevations refer to the same break-in-slope but at different locations)*

Location	Length of break-in-slope (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
North side of the Valley of the Ten Peaks	2	8,200	6,200	questionable	2,200
Circumscribing Panorama Ridge	4 1/2	8,000	7,100	fair	2,600 (Bow Valley) 1,600 (Consolation Valley)
East side of Baker Creek Valley	1	7,600	7,400	good	2,000
East side of Baker Creek Valley	3/4	7,300	7,100	fair	2,000

Figure 10. Outwash gravel exposed along the northwest side of Carrot Creek about six miles southeast of Banff. View looking northwest (51°09'10"N, 115°24'40"W). *(201492)*

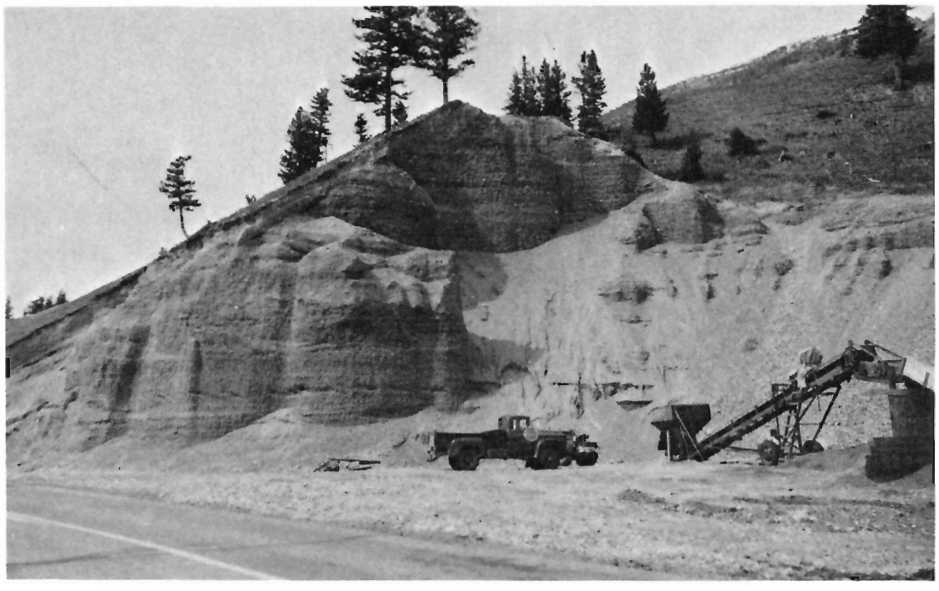


Figure 11. Outwash gravel exposed along the northeast side of Route 1A about three miles southeast of Canmore. View looking north (51°04'10"N, 115°17'50"W). *(201493)*

Lithology

Till

Bow Valley till is compact, with rare patches and lenses of silt, sand, and gravel. The gravel-sized fraction of the till comprises from 5 to 30 per cent of the total, averaging approximately 20 per cent. The finer fraction is composed mainly of a calcareous sandy clay loam, light olive-grey (5Y6/1) where it is unoxidized and yellowish grey (5Y7/2) where it is oxidized. The gravel-sized material commonly displays a weak fabric in which the long axes of the particles lie approximately parallel to the direction of glacier movement. The gravel fragments range from subangular to rounded (*see* Krumbein, 1941, for scale), with most of the material being either subangular or subrounded and showing no obvious differences according to rock type (Table II). Many of the stones display striated surfaces. Dolomite and limestone predominate, with lesser amounts of quartzitic sandstone, quartzite, chert, shale, and pebble-conglomerate (Fig. 12; Table II). Pebbles of altered basic, igneous, phaneritic rock, believed to be derived from the Crowsfoot dyke (Smith, 1963) that outcrops in the Bow Valley northwest of the study area, are found occasionally. Mesozoic shale, siltstone, and sandstone, the principal bedrock types of the valley floor southeast of Eisenhower Junction, are rare in the gravel-sized fraction of the till probably because of the low resistance of these rock types to mechanical disintegration.

Bow Valley till falls mainly in the clay loam, loam, sandy clay loam, and sandy loam categories (Figs. 13, 14; Table II). Plotting of the percentage of clay, silt, and sand of samples according to their position in the Bow Valley indicates that there is no possibility of using grain size as criteria in distinguishing till of the respective advances (Fig. 15).

Heavy minerals never exceed 0.5 per cent within the 0.074 mm to 2 mm grain size of the Bow Valley till (Table II). All the heavy minerals identified,

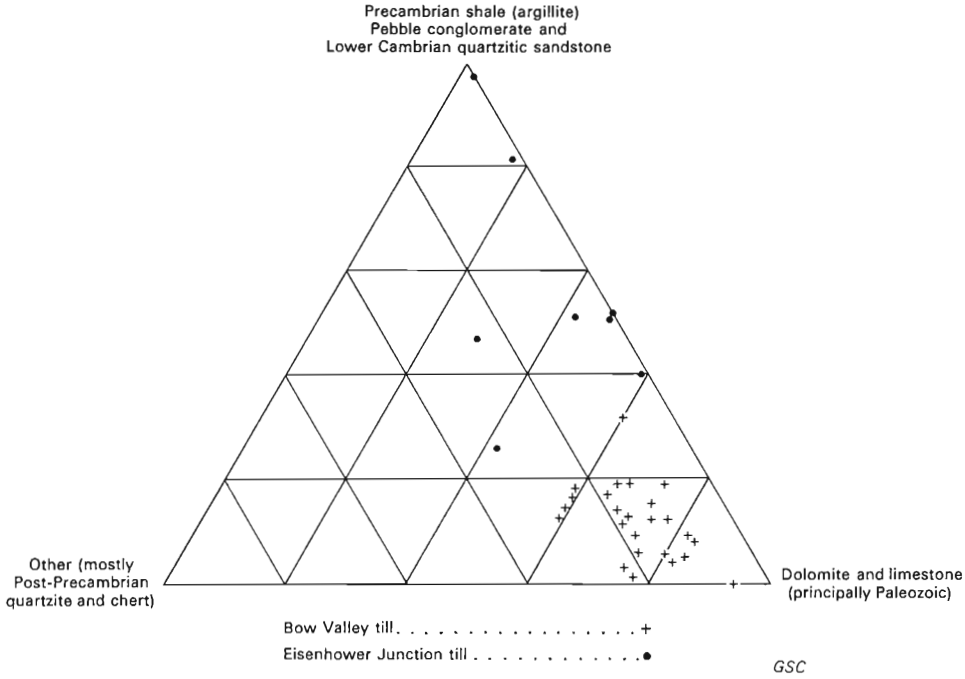


Figure 12. Pebble composition of tills. One hundred pebbles were randomly collected from till at each site. Pebbles vary between 4 and 64 mm.

with the exception of hypersthene and possibly some augite, could be derived from local bedrock such as the Spray River Formation and the upper part of the Gog Group. The hypersthene and augite consist of euhedral grains, with glass shards protruding from the surfaces of most hypersthene grains. The occurrence suggests a volcanic ash origin.

Clay minerals identified in Bow Valley till are chlorite and 'illite'- a term used here to include any mica-like clay mineral. Generally, more illite is present (Figs. 16, 17, 18).

The carbonate content of the less than 0.074 mm size fraction of Bow Valley till is high, most samples containing over 50 per cent (Fig. 15; Table II). A plot of the total amount of carbonate from Bow Valley till samples versus the location of the sample in the Bow Valley suggests a slight increase in carbonate content down-valley. This trend is a reflection of the bedrock, as carbonate rocks are more abundant in the southeastern than in the northwestern part of the area.

Laboratory study of the tills reveals no material that could not have been derived locally. The absence of distinctive rock types such as granodiorite, granite, syenite, and monzonite that occur within 40 miles southwest of the Continental Divide, indicates that there was little or no movement of ice from that area. Therefore, glaciers that extended into the Banff area must have originated in the Rocky Mountains.

Glaciofluvial Deposits

Outwash deposited during the retreat of the ice of the *Bow Valley* advance is composed mainly of gravels, although sand and silt lenses and beds

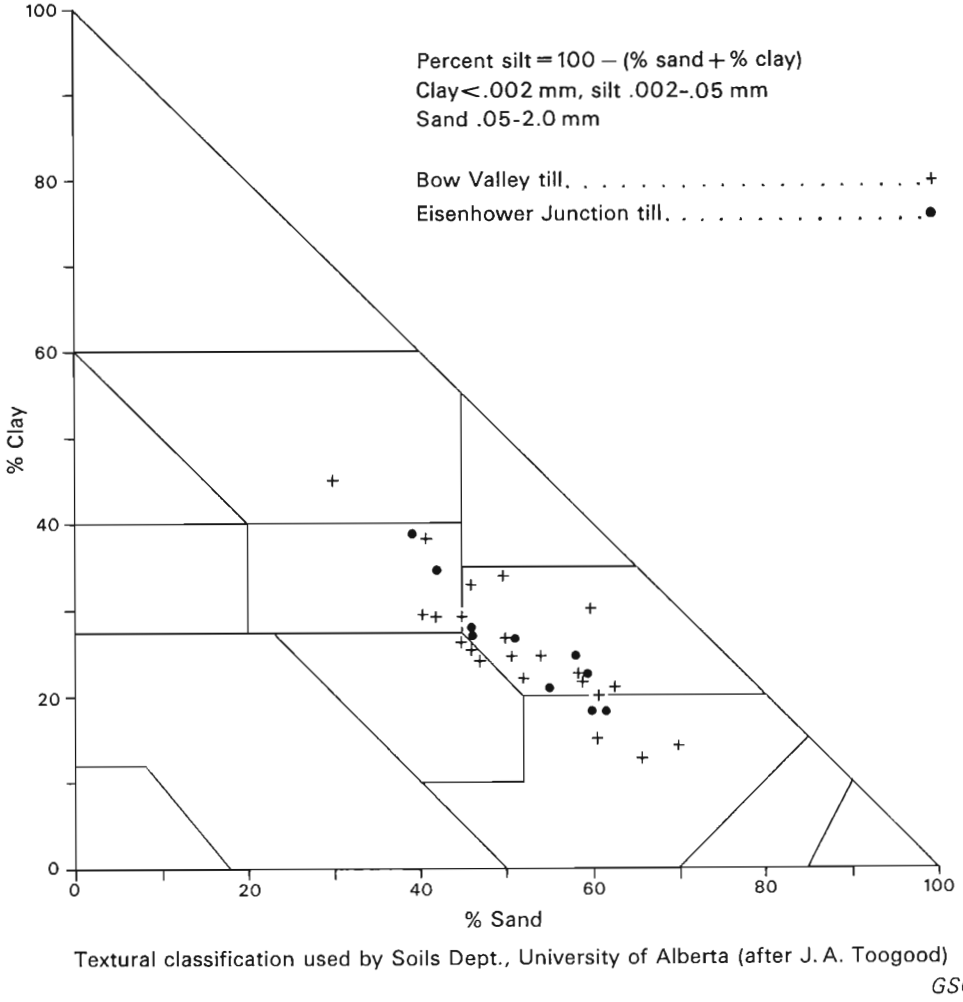


Figure 13. Textural classification of *Bow Valley* and *Eisenhower Junction* till samples in the <2.0 mm size fraction, carbonates not included.

are common. The gravels are grey or greyish brown and consist mainly of unconsolidated, poorly to well-sorted dolomite and limestone pebbles, mostly subrounded to rounded. Strata dip gently down-valley, with crossbedding common. The degree of sorting increases down-valley, with an accompanying increase in the number of sand and silt beds.

The ice-contact fluvial deposits representing equilibrium phases following the *Bow Valley* advance are at least 100 feet thick and are composed principally of grey, poorly to well-sorted, unconsolidated gravels dipping steeply in a variety of directions, but mainly southeastward. Pebble-sized material, with various degrees of rounding, dominates. The lithology of the pebbles is closely similar to that of the pebbles in till of the same general area.

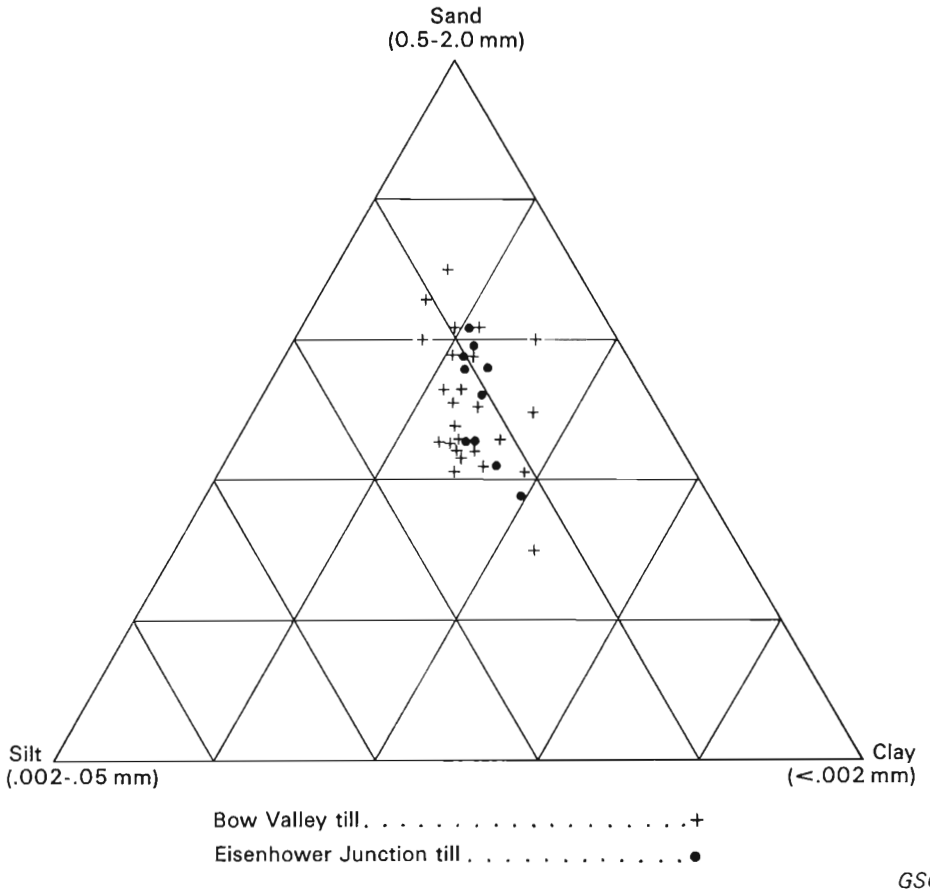


Figure 14. Textural classification of the <2.0 mm size fraction of *Bow Valley* and *Eisenhower Junction* till samples. Carbonates removed before analysis have not been included.

CANMORE ADVANCE

Stratigraphic and Geomorphic Evidence

It was indicated earlier in this paper that, following the *Bow Valley* advance, the main glacier retreated to the area of Banff and then advanced again. The basic evidence for this advance takes the form of thin discontinuous patches of till (not mapped) overlying the outwash that had been laid down during the retreat of the *Bow Valley* ice. The continuous ground moraine with erosional ridges (Fig. 6) found southeast of the confluence of the Bow and Cascade Rivers, is also attributed to this advance although, as stressed earlier, this till could not be distinguished lithologically from Bow Valley till.

Along one discontinuous line on the southwest side of the Bow Valley, breaks-in-slope caused by glacial erosion and the action of lateral glacial streams support the inference that this *Canmore* advance is, in fact, a 'Bow Valley readvance'. Near the boundary of the Banff National Park, the breaks lie at a maximum height of 5,300 feet and, near Canmore, at a maximum height

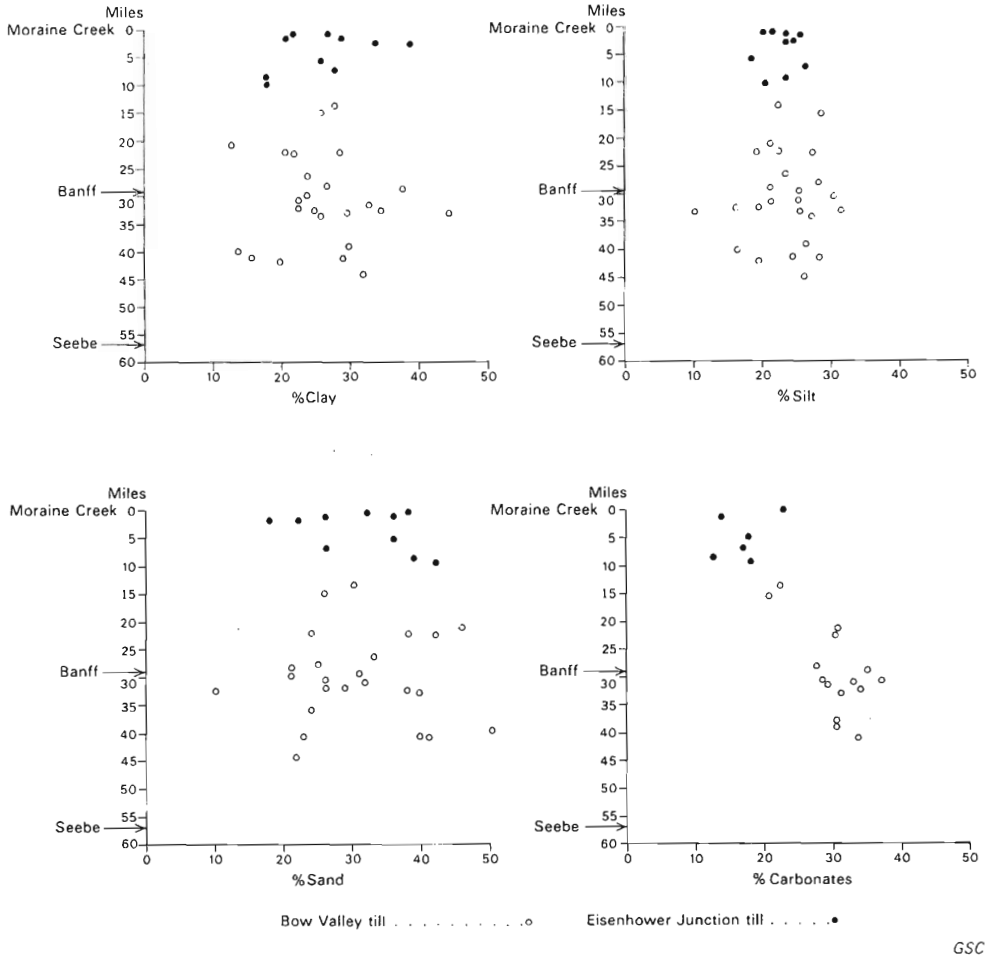


Figure 15. Grain size and carbonate content of *Bow Valley* and *Eisenhower Junction* till samples plotted against location in Bow Valley. Hydrometer analysis of clay, silt, and sand was made on the <2.0 mm size fraction after the removal of carbonate.

of 5,100 feet (Fig. 19; Table IV). It is doubtful that these breaks were caused by older glacial activity because they are more prominent than breaks equated to older advances and occur at elevations and locations compatible with the till patches over outwash that are the principal evidence for this advance.

Kames, eskers, and what appear to be crevasse fillings, located in the plain between Kananaskis and Seebe, were probably formed during the deglaciation following the *Canmore* advance (Fig. 7) and may represent the terminal zone. They blanket the surface and are surrounded by outwash deposits. The thickness of these deposits varies, as shown by two representative sections measuring 24 feet and 11 feet respectively (Appendix 2, sections 3 and 4). In a shale pit near Kananaskis Falls the deposits are underlain by truncated bedrock and overlain by outwash about six feet thick. During the deglaciation following this advance, the Bow River probably began cutting its present course through this zone for the river is youthful, as evidenced by its restricted flood plain and bedrock channel.

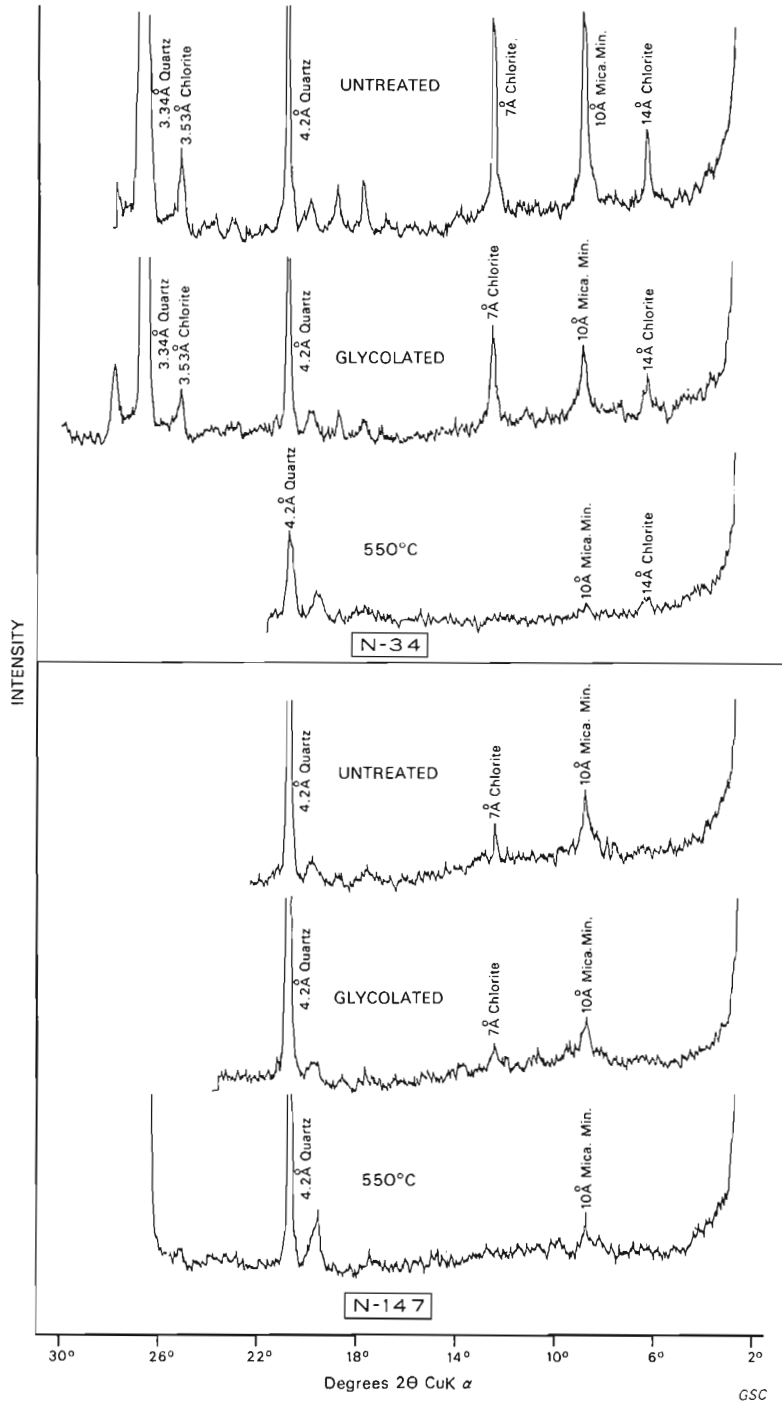


Figure 16. X-ray diffraction patterns of typical till samples. N-147, *Bow Valley*; N-34, *Eisenhower Junction*. Analysis was made on a water-cooled diffraction unit at the University of Alberta.

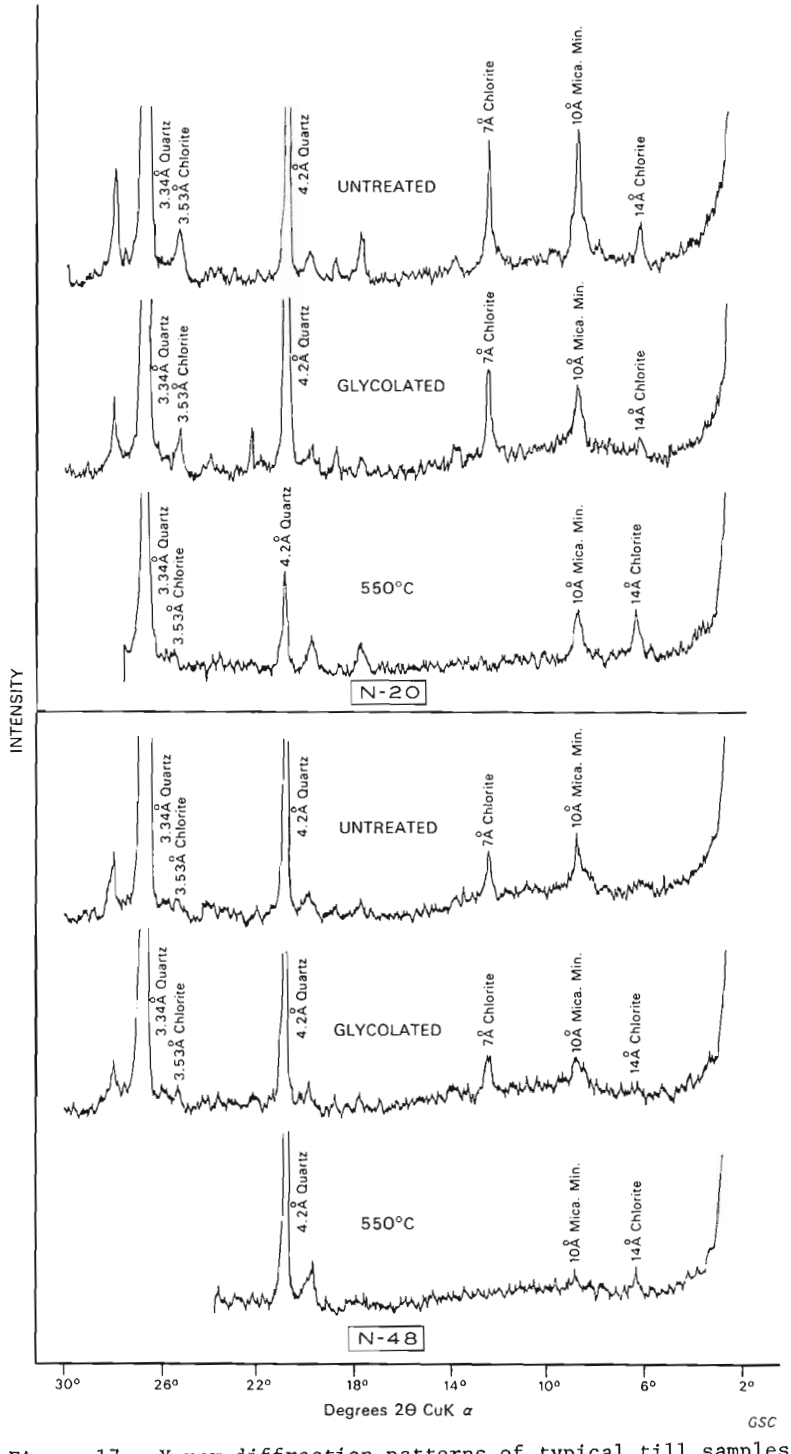


Figure 17. X-ray diffraction patterns of typical till samples. N-48, *Bow Valley*; N-20, *Eisenhower Junction*. Analysis was made on a water-cooled diffraction unit at the University of Alberta.

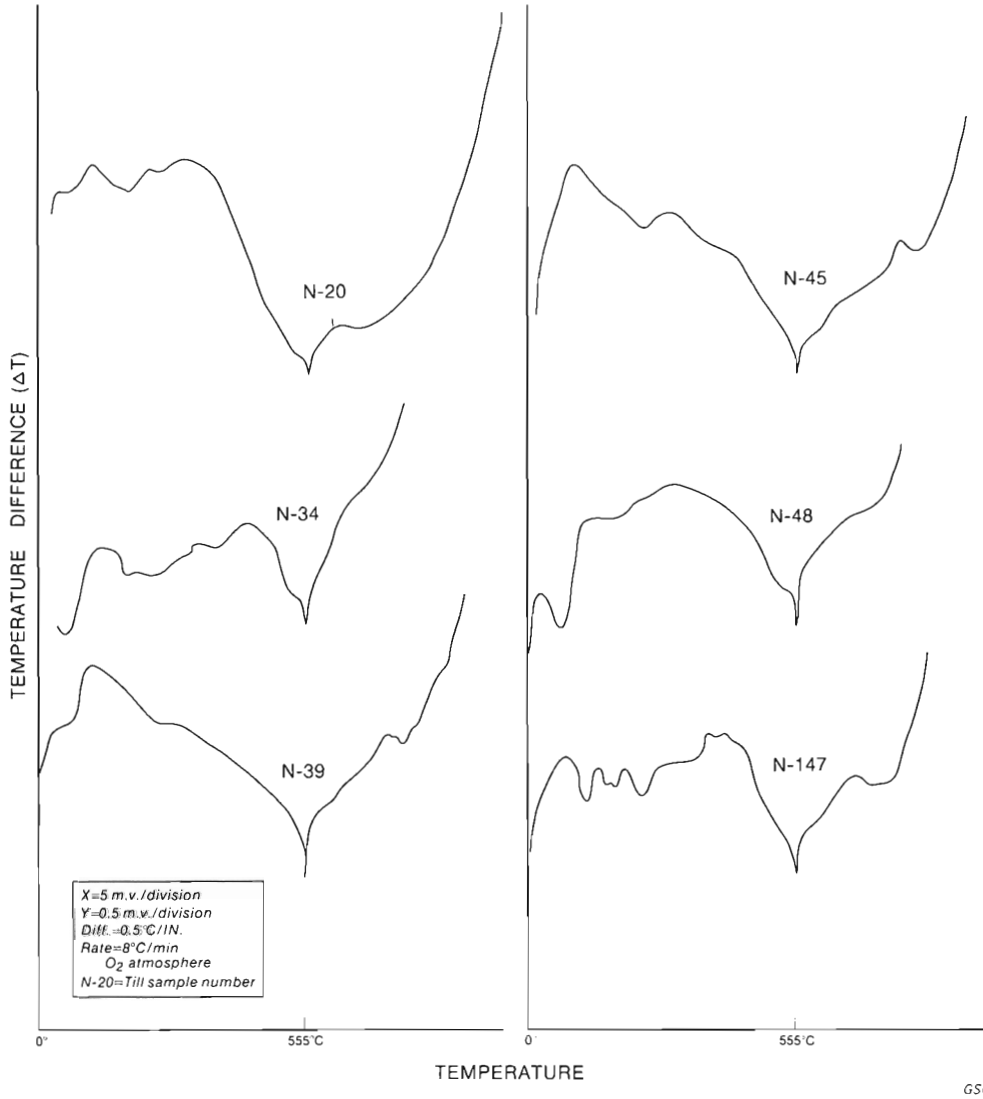


Figure 18. Differential thermal analysis patterns of six typical till samples. N-48, N-147, *Bow Valley*; N-20, N-34, N-45, *Eisenhower Junction*.

Little outwash was deposited within the Bow River valley during the *Canmore* retreat. However, outwash forms high bluffs along the Cascade River north of Route 1 near the Lake Minnewanka Valley, where it is estimated to be over 100 feet thick. Its extent and relationship to other deposits is not clear. Minor amounts of outwash were observed on terraces in the lower part of the U-shaped portion of Johnston Creek valley, in the lower part of Cascade Valley, and in association with lake deposits at the lower end of the Spray Valley.

Extensive glaciolacustrine sand deposits, some reworked by wind, occur 2 miles northeast of Banff, near the town dump. More than 40 feet of sand overlies stratified gravel that, in turn, lies on either *Bow Valley* till or

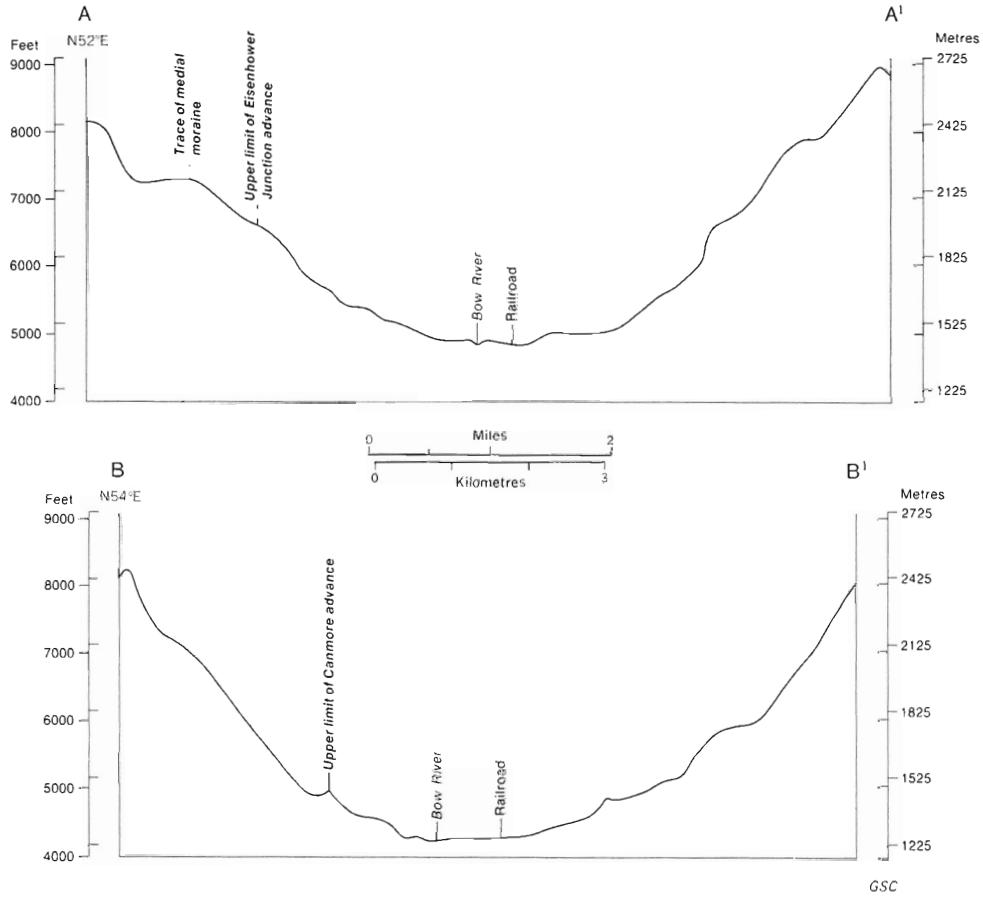


Figure 19. Topographic cross-sections of the Bow River valley showing breaks-in-slope caused by different glacial advances. Position of sections are shown on surficial geology map (*in pocket*).

pre-*Bow Valley* outwash. Sand patches, probably belonging to these deposits, overlie outwash gravels north of the Cascade River. The thickness and location of the deposits suggest that the former lake in which they were laid down was partially dammed by ice, probably during the final deglaciation following the *Canmore* advance.

Other lake deposits that may have been laid down at the same time are located in the valley of the Spray River about a mile upstream from the confluence with the Bow River. They occur up-valley from thick outwash deposits that may represent an end moraine.

Remnant lacustrine deposits, overlain by aeolian sand, are exposed on bluffs along the north shore of Lac des Arcs and on bars and a spit in the lake. Just south of Exshaw the lacustrine aeolian deposits combined are about fifty feet thick. The lacustrine deposits may have been laid down after the recession of the *Canmore* ice.

The most obvious drainage changes in the study area probably took place during the *Canmore* deglaciation (*see* Fig. 8). This conclusion is inferred from the well-preserved morphology of the drainage routes and from the fact that this was the last time the Bow River was glaciated south of Eisenhower Junction (Fig. 1).

Table IV. *Upper Limits of the Canmore Advance as Indicated by Breaks-in-slope, and Approximate Ice Thicknesses (maximum and minimum elevations refer to the same break-in-slope but at different locations)*

Location	Length of break-in-slope (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
Park boundary, southwest side Bow valley	1 3/4	5,300	5,000	very good	750
Near Canmore, southwest side Bow valley	1	4,950	4,800	very good	500
Near Canmore, southwest side Bow valley	2 1/4	5,100	4,700	very good	750

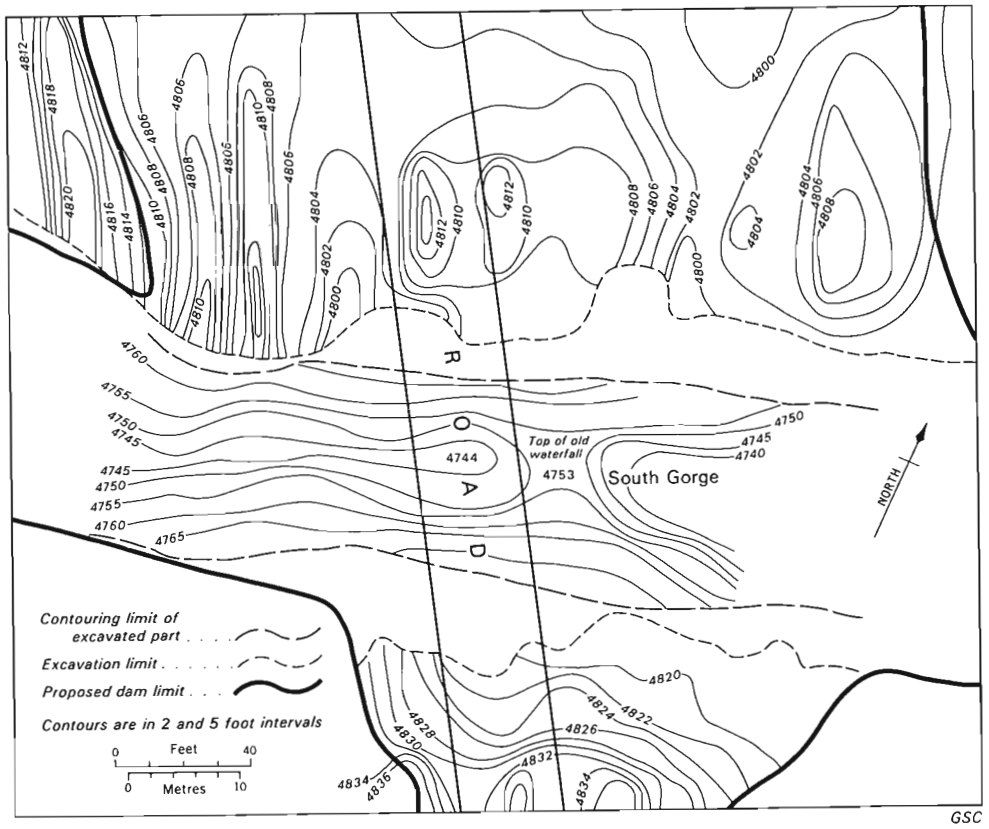


Figure 20. Contour map of excavated, abandoned stream canyon and face of old waterfall near outlet of the Cascade River from Lake Minnewanka (51°14'30"N, 115°29'40"W).

During deglaciation, a lateral glacial stream followed the present route of the Bow River around the south side of Tunnel Mountain, which was then part of Mount Rundle, and eventually eroded its channel down to the level of the present river, thus isolating Tunnel Mountain. At about this time, drainage changes were also taking place in the Lake Minnewanka area. A lateral glacial stream excavated a bedrock channel in the northeastern part of the Cascade Valley and flowed into the Lake Minnewanka Valley. This permanently shifted the Cascade River away from the centre of the valley in this area.

An abandoned canyon and the waterfall face of a stream that flowed into the valley of Lake Minnewanka were uncovered by the Calgary Power Company in the early 1940s during the construction of a dam at the point where the present Cascade River leaves Lake Minnewanka (Figs. 20, 21). Meltwater from the glacier in Cascade Valley must have begun eroding this canyon and flowing into Lake Minnewanka Valley when the northeast flank of the *Canmore* glacier was at least as high as the bedrock above the canyon and the old waterfall. The top of this waterfall is at an elevation of 4,753 feet. The floor of Devils Gap at the eastern end of Lake Minnewanka has an elevation of 5,050 feet; therefore, in order that meltwater from the Cascade Valley glacier could flow out of the Lake Minnewanka Valley from east to west through the recently uncovered canyon, either the floor of Devils Gap was at least 297 feet lower than it is today, or the water level must have been that much higher.

Figure 21.

Face of old waterfall uncovered during dam construction near outlet of the Cascade River from Lake Minnewanka. View looking west (51°14'30"N, 115°29' 40"W). *(201494)*

The following sequence of events could offer an explanation. Before the Cascade Valley glacier thinned to the point at which the waterfall and canyon developed, the northeastward-receding Minnewanka glacier could have acted as a dam to form glacial Lake Minnewanka. Glacial drift at the eastern end may also have contributed to later damming since remnants of glacial drift are present in Devils Gap today. When the dam broke, erosion of till and probably of bedrock took place near Devils Gap. As the water level was lowered, the canyon formed but its poor development suggests that it was probably short-lived. As the energy level decreased further, aggradation near Devils Gap shifted the drainage westward.

Minor drainage changes of Forty Mile, Silverton, and Johnston Creeks probably also took place at this time (Fig. 8).

Extensive deglaciation followed the *Canmore* advance and probably only a few of the more protected cirques still contained ice at the beginning of the *Eisenhower Junction* advance.

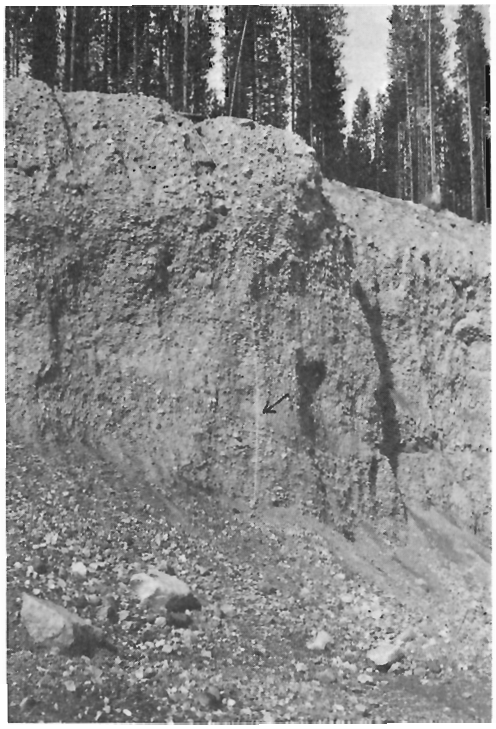


Figure 22.

Eisenhower Junction ice-contact fluvial deposits with what may be overlying till located about a mile southwest of Eisenhower Junction (51°15'40"N, 115°56'40"W). View looking north. Dip of beds in the outwash is generally toward the southeast. Note tape for scale. *(201495)*

Lithology

Glaciofluvial Deposits

The lithology of the kames, eskers, and apparent crevasse fillings is similar to that of other glaciofluvial deposits described for the area, and consists of greyish, unconsolidated, poorly to moderately well sorted gravels. Limestone and dolomite pebbles with varying degrees of roundness comprise most of the inclusions. The beds dip steeply in a variety of directions and are often truncated between successive layers.

Lacustrine Deposits

Lacustrine sediments near Banff consist of medium-grained, brownish grey, calcareous sand, well sorted and mixed with minor amounts of fine- and coarse-grained sand and silt and clay. Individual beds are about 15 mm thick, with some very thin crossbedding and cross-laminations. No gravel-sized material is present except near the contacts with other deposits.

On the north side of Lac des Arcs, lacustrine material is buff coloured, calcareous, well-sorted, silty sand with minor inclusions of clay-sized material. The sand is laminated to thinly laminated, with occasional ripple-marks. Locally it contains gastropods and wood fragments. Lacustrine sediments in the Spray Valley are similar but generally finer grained than in the Lac des Arcs area and they contain scattered pebbles.

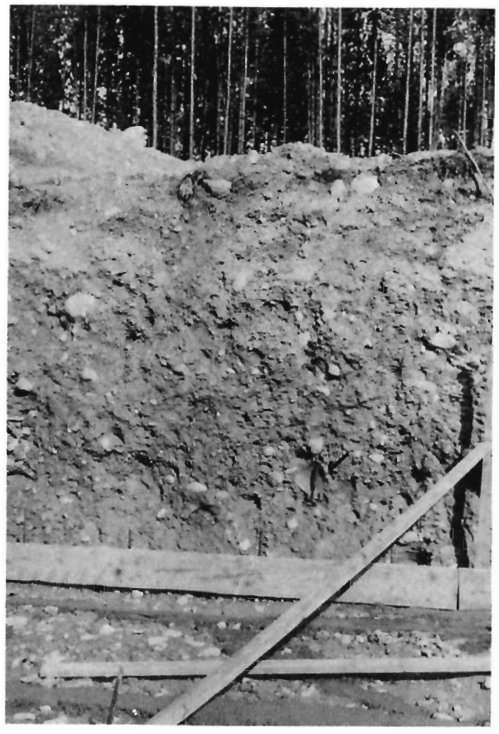


Figure 23.

Eisenhower Junction till just north of Pipestone Creek near Lake Louise townsite (outside of mapped area). Note hammer for scale (51°25'45"N, 116°10'45"W). *(201496)*

EISENHOWER JUNCTION ADVANCE

After an interval of relatively complete deglaciation, glaciers once again invaded the Banff area. Evidence for this includes well-preserved ground and lateral moraines, breaks-in-slope, terminal moraines, and fresh cirques. Ice originating in the area of the Continental Divide formed a major glacier that flowed down the Bow Valley as far as Eisenhower Junction. At its maximum extent, this ice was about 1,900 feet thick in the Bow Valley opposite Panorama Ridge. Most tributary valleys northwest of Eisenhower Junction supported glaciers that contributed ice to the major valley glacier, whereas certain cirques and glacial troughs in the vicinity of Eisenhower Junction apparently supported ones that did not reach the main glacier. The *Eisenhower Junction* advance represents the last major appearance of ice in the study area of the Bow Valley (*see* Fig. 1). Breaks-in-slope and till over glaciofluvial deposits of the *Eisenhower Junction* advance terminal moraine show that a minor readvance followed the retreat of this ice.

Stratigraphic and Geomorphic Evidence

Near Eisenhower Junction, till grades into a glaciofluvial complex (Fig. 6) that includes a series of lateral glacial stream channels and a terminal moraine consisting principally of glaciofluvial deposits. The *Eisenhower Junction* advance is defined by this terminal moraine. Outcrops of the material forming the moraine occur west of Eisenhower Junction, with a particularly fine example about 43 feet thick located on the south side of Route 93 in a gravel

Table V. *Upper Limits of the Eisenhower Junction Advance as Indicated by Lateral Moraines or Breaks-in-slope, and Approximate Ice Thicknesses*
(maximum and minimum elevations refer to the same lateral moraine or break-in-slope, but at different locations)

Location	Length of break-in-slope or lateral moraine (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
Northwest side, Valley of the Ten Peaks	4 1/2	7,500	6,000	very good	1,050
West side, Panorama Ridge	3	7,100	6,850	very good	600
Southwest side, Bow Valley	7	6,750	6,200	very good	1,900 1,500
West side, Baker Creek valley	2 3/4 (min.)	6,900	5,500	good	1,100
East side, Baker Creek valley	1 3/4	6,700	6,400	fair	1,100
East side, Baker Creek valley	1/2	7,000	6,600	fair	1,800

pit about a mile southwest of Eisenhower Junction (Fig. 22; Appendix 2, section 2). Although the lower contact is not seen in most of the exposures, the deposits lie directly on bedrock toward the southeast limit of the deposit. The thickness of the glaciofluvial deposits varies considerably; the section exposed in the gravel pit measures about 43 feet and is typical. The lithology varies from poorly sorted to well-sorted gravel with minor occurrences of sand, silt, and clay.

Ground and lateral moraines consisting mainly of till, deposited extensively in the Bow Valley and in its tributaries northwest of Eisenhower Junction, are correlated with this advance. The few good surface till outcrops are generally less than 20 feet thick, and overlie bedrock (Fig. 23). Because most of the Eisenhower Junction till rests on bedrock different from that of Bow Valley till, its lithology, also, is different and suggests a source in the vicinity of the Continental Divide, probably at the head of the Bow Valley, in certain cirques in the northwestern part of the study area. A well-developed U-shaped valley in the Altrude Creek area indicates that the ice probably crossed the Divide there.

The upper limit of the *Eisenhower Junction* ice is marked by lateral moraines in Consolation Valley and the Valley of the Ten Peaks, and by breaks-in-slope on the southwest side of Bow Valley (Fig. 19, Table V). Secondary evidence appears as breaks-in-slope in the Baker Creek valley and on the northeast side of the Bow Valley. A prominent ridge about two miles long and varying between 6,500 and 5,900 feet elevation extends from the Tower of Babel into the Bow Valley. It is a remnant of the medial moraine between the glaciers of the Valley of the Ten Peaks and that of Consolation Valley.

Fresh cirques, with floors between 6,000 and 7,000 feet elevation, probably formed or were rejuvenated during the *Eisenhower Junction* advance. In valleys with cirque successions, the lowermost cirque has here been equated to this advance, a conclusion based on relative freshness and on the fact that the elevations are consistent with those of the single cirques used as supporting evidence for this glaciation.

The morphology of the cirques and positions of the end moraines indicate that, in many cases, the cirque glaciers did not reach the major valley glacier during the advance. Good examples occur in the Twin Lakes - Copper Mountain and Massive Mountain areas where a number of cirque glaciers extended into a pre-*Eisenhower Junction* glaciated surface, eroding it nearly at right angles. Near Taylor and O'Brien Lakes, features that may be end moraines are found above the upper limit of the *Eisenhower Junction* ice in the Bow Valley.

Till patches overlying glaciofluvial deposits of the terminal moraine suggest a minor readvance during the general retreat of the *Eisenhower Junction* ice. Poorly defined breaks-in-slope observed on the northeast walls of both the Baker Creek and Bow River valleys, at lower elevations than those equated to the *Eisenhower Junction* advance, have been correlated by the writer to this activity. About three miles south of Eisenhower Junction, several cirques that supported ice during the *Eisenhower Junction* advance appear to have had their main depressions modified by glacial erosion and glacial stream activity; this may have taken place during this minor readvance.

The material damming the northeast end of Moraine Lake was deposited by a landslide and is not an end moraine as the name of the lake might suggest (Belyea, 1960, p. 35). The material is locally derived rubble with at least two generations of sliding indicated by the relative degrees of weathering and by the superposition of deposits.

It could be argued that the glaciofluvial complex does not mark the limit of the *Eisenhower Junction* advance but rather an equilibrium phase in the general retreat of a glacier that extended farther down the valley - possibly the major glacier of the *Canmore* advance. However, the interpretation outlined above is supported by the following evidence:

No lateral moraines or extensive breaks-in-slope appear down-valley from Eisenhower Junction as far as Banff.

Fresh cirques are located only in the vicinity of, or northwest of Eisenhower Junction. If the *Eisenhower Junction* advance had extended beyond the boundaries proposed here, related cirques and glacial troughs would probably be abundant southeast of Eisenhower Junction.

Alluvial fans from tributary creeks flowing into the Bow Valley are less well developed upstream from near Eisenhower Junction than they are downstream, suggesting relatively less time for the development of upstream fans.

From the northwestern boundary of the study area downstream to about Eisenhower Junction, the Bow River meanders only slightly, and its flood plain is gravel-covered and varies in width between about one-third and three-quarters of a mile. The average gradient in this 20-mile span is 20 feet per mile.

From Eisenhower Junction to Seebe, the eastern limit of the study area, the gradient averages only 5.5 feet per mile, the river meanders widely and is partly braided, and the width of the flood plain averages about one mile, suggesting more development time here than in the stretch northwest of Eisenhower Junction.

In these last two items of evidence, the two areas discussed are underlain by different bedrock structures. It may be that the differential rate of erosion of each area has contributed to differences in the development of the flood plain and the alluvial fans.

Lithology

Till

Eisenhower Junction till, like that of the *Bow Valley*, has a mainly calcareous, sandy, clay loam matrix that is light olive-grey (5Y6/1) when unoxidized and yellowish grey (5Y7/2) when oxidized. Similarly, the gravel sized fraction consists mainly of subangular to subrounded fragments, many with striations and oriented with their long axes approximately parallel to the direction of glacier movement. It differs from *Bow Valley* till in that it contains 10 to 35 per cent gravel-sized material, the average being approximately 25 per cent, composed predominantly of quartzitic sandstone, with lesser amounts of dolomite, shale, limestone, chert, and quartzite, and minor pebble-conglomerate.

Laboratory analyses of *Eisenhower Junction* till are presented in Figures 12 to 18, Figure 24, and Table II. The percentages of various components differ greatly from *Bow Valley* till, whereas the texture remains about the same. Quartzitic sandstone in *Eisenhower Junction* till is not as well rounded as in *Bow Valley* till, probably because of a shorter distance of transport. There is no apparent difference in the degree of roundness of carbonate stones in the two tills; this may be because carbonates, having lower resistance to abrasion, reach roundness maturity relatively fast.

Glaciofluvial Deposits

The terminal moraine of the *Eisenhower Junction* advance consists almost exclusively of ice-contact fluvial deposits of gravel, sand, and silt. The sand and silt, which comprise roughly 50 per cent of the total volume, occur as large lenses within the gravel. The gravel is greyish, poorly to moderately sorted, with subangular to angular pebble-sized material; it is composed mainly

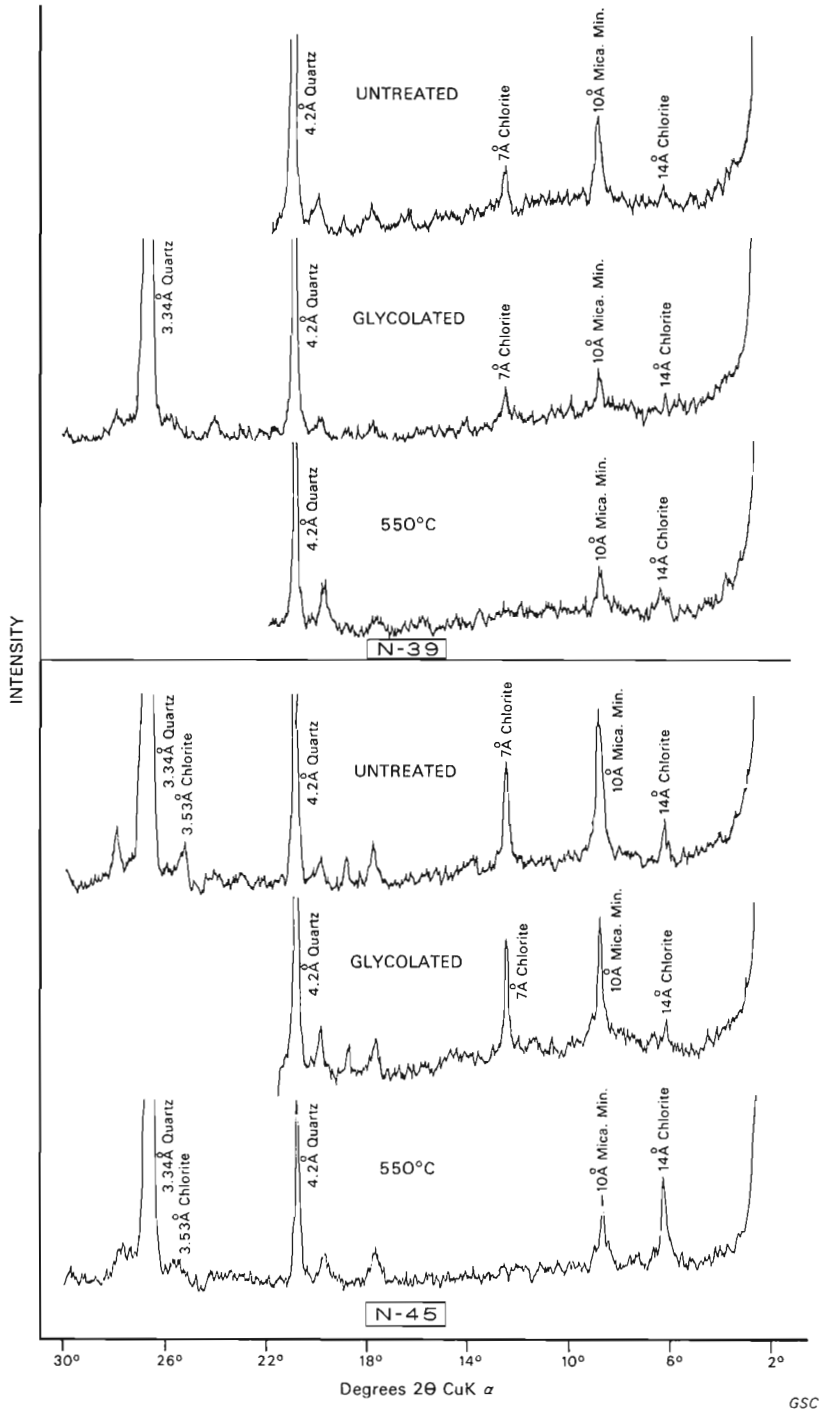


Figure 24. X-ray diffraction patterns of typical *Eisenhower Junction* till samples N-39, N-45. Analysis was made on a Philips water-cooled diffraction unit at the University of Alberta.

of limestone, dolomite, and quartzitic sandstone. The strata of the moraine have a variable dip of between 5 and 10 degrees S35°E.

POST-EISENHOWER JUNCTION GLACIER ACTIVITY

The *Eisenhower Junction* advance represents the last time ice flowed in the Bow River valley in the field area of this report. There is, however, evidence for limited advances during Neoglacial time. The writer did not concentrate on this recent activity and therefore only the most obvious evidence will be cited.

One possible Neoglacial moraine is a forest-covered till deposit that rises gently above the southeast side of Moraine Lake and extends as far as the ice-cored terminal moraine of the Wenkchemna Glacier. Two juxtaposed, forested, end moraines that protrude from the toe of the Horseshoe Glacier just northwest of the Valley of the Ten Peaks, are also probably Neoglacial. Similar moraines are found in Larch Valley about a mile north of the Wenkchemna Glacier (L.A. Bayrock, Research Council of Alberta, pers. com. 1964). Ice-cored end moraines, believed to represent a relatively recent advance, border the Wenkchemna Glacier and the glaciers at the head of Consolation and Boom Creek valleys.

Scherzer (1907, p. 68, 69) noted two distinct composite 'moraines' adjacent to, and partly underlying, the ice-cored moraine of the Wenkchemna Glacier and named them the Bear-den moraines. For the following reasons they are interpreted here as two or more generations of landslide deposits:

Large blocks are predominant; fine-grained material is almost absent.

The material (greenish and reddish argillite and quartzite) is locally derived.

Scars in the bedrock on the south wall of the valley indicate the source of the material.

POSTGLACIAL DEPOSITS

The Bow River flood plain and channel contain the chief deposits of recent alluvium in the area. The sediments are mostly gravel, but lenses and patches of sand, silt, and clay also occur. The deepest drillhole in Bow River alluvium, located on the southwest side of the Bow River bridge on Route 1 about four miles west of Banff, penetrated 200 feet of sediment, mostly silty sand and gravel.

The principal landslide deposits have already been mentioned. Postglacial talus consisting principally of angular rubble, and alluvial fans and related alluvium composed mainly of poorly sorted, angular and subangular gravels with minor quantities of sand, silt, and clay, are common throughout the area. Less extensive deposits mapped as colluvium consist of bedrock rubble and some alluvium. Pond and swamp deposits consist of silt, clay, and muck.

Aeolian sand occurs in small patches on glacial drift throughout much of the study area but constitutes a unit of mappable size only along the south shore of the Bow River, 2 miles east of Exshaw. Its deposition began soon after the *Canmore* deglaciation. Although most of these deposits are stabilized today, some shifting by wind still occurs. Layers of Mazama volcanic ash were observed in a few of these deposits.

Most deposits in the area are well-sorted, buff-coloured, calcareous, mainly unstratified, silty, fine-grained sand with some platy parting. An analyzed sample from a patch overlying outwash near the southwest end of Lake Minnewanka (51°14'00"N, 115°31'30"W) contained more than 58 per cent carbonates, with the remainder being mainly quartz. When the carbonates were removed, the grain size distribution showed 6 per cent clay, 48 per cent silt, and 46 per

cent sand. Heavy minerals consist mainly of zircon, tourmaline, and chlorite, with lesser amounts of diopside and hornblende. The clay minerals are chlorite and illite.

The premise that these are aeolian and not lacustrine deposits is based on the following points:

The deposits fill gullies, cover minor depressions, and adhere to steep slopes in an area where lake deposits would be unlikely to occur.

The deposits are not clearly stratified.

Some outcrops occur in close proximity to wind-blown sand, usually to leeward.

The sorting is similar to that of loess (Fig. 25).

CHRONOLOGY

The number of glacial advances that took place in the Banff area before those discussed here has been impossible to determine. Geochronological control and the well-preserved state of glacial sediments in this area of high erosion suggest that all recognized glacial advances are relatively young, probably of classical or preclassical Wisconsin age. The presence in the tills of fresh heavy minerals such as hypersthene support this conclusion.

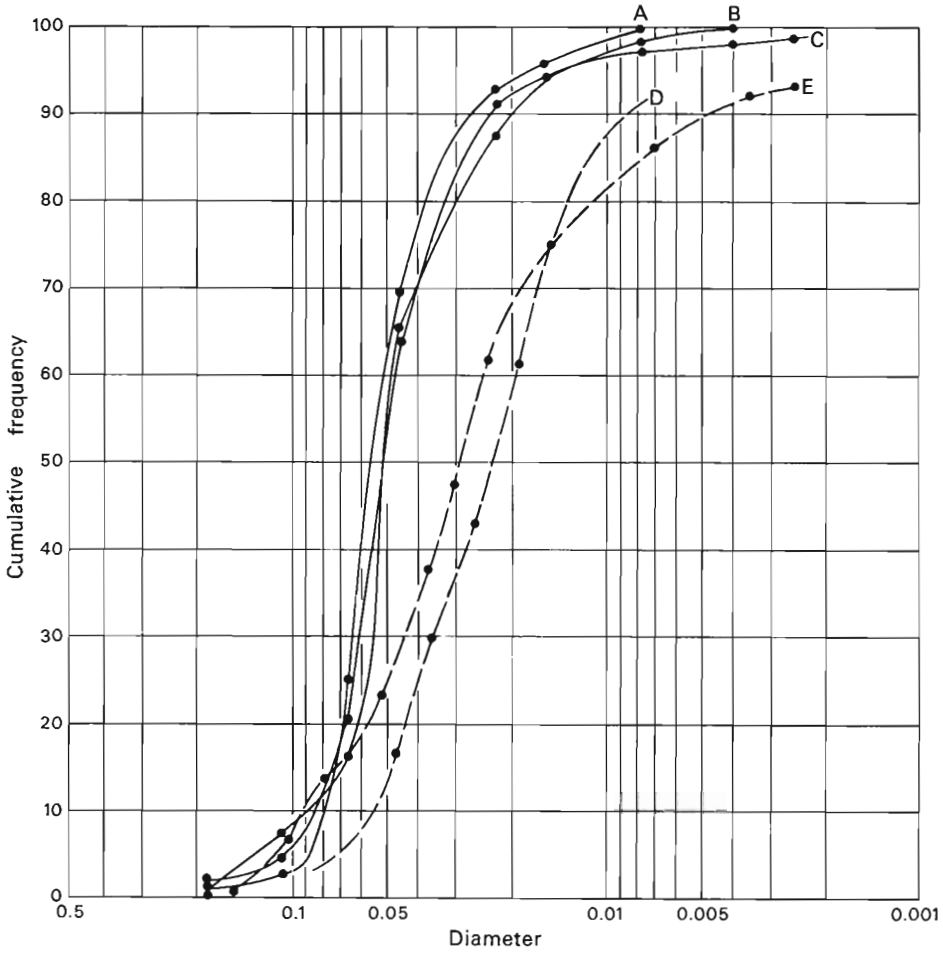
Emerged lake sediments, located on the north side of Lac des Arcs, contain fossils identified as *Discus cronkhitei* (Newcomb) and *Discus shimeki* (Pilsbry). These only indicate that the deposits are Quaternary and that the climate may have been much the same as it is today, possibly warmer or cooler, but not drier (R. Green, Research Council of Alberta, *pers. com.*).

Peat for radiocarbon dating was collected from a glaciated bedrock bench about 400 feet above the Bow River about two miles southeast of Canmore (51°03'00"N, 115°18'40"W). The sample was collected at the base of a 4 and one-half foot section of peat resting on bedrock and overlain by 6 inches of lake silt, dated at 5560±130 years B.P. (GSC-360). As will be shown, peat accumulation evidently began after the *Eisenhower Junction* advance and hence the radiocarbon date is of little value.

Although material for absolute age dating of the *Eisenhower Junction* advance has not been found in the Banff area, a site on the north side of the North Saskatchewan River, beside the bridge on Route 93 in Banff National Park (51°58'N, 116°43'W), yielded charcoal dated at 9,330±170 years B.P. (GSC-332; Westgate and Dreimanis, 1967) and may help in dating this advance. The sample site is located less than 20 miles from the east-west divide that separates the North Saskatchewan drainage system from that of the Bow River drainage. Large chunks of charcoal were collected from a 2- to 8-foot loess section which underlay layers of Bridge River and Mazama ash and overlay glacial outwash. It appears that the section is complete and that the lithology represents the latest glacial deposits in this part of the North Saskatchewan River valley. The stratigraphy suggests a deglaciation phase.

The deposits of the *Eisenhower Junction* advance and the glaciofluvial deposits of the Saskatchewan River area occupy comparable positions in their respective valleys in relation to the Continental Divide. The valleys are located close together and lie in the same climatic zone, and would therefore probably have had a closely similar late-glacial history. Accordingly, the date obtained from the Saskatchewan River locality, regarded as minimum for deglaciation of the area, serves as a minimum date for the deglaciation that followed the *Eisenhower Junction* advance.

Single volcanic ash layers are found in several places in the Banff area. Good exposures occur near the 'Hoodoos' east of Banff, at the Banff dump (Fig. 26), and just west of Exshaw along Route 1A. As they all appear in



A Sample N-01
B Sample N-02
C Sample N-70
D Loess from Fairbanks, Alaska (Pewe 1955)
E Loess from Rock Island, Illinois (Pewe 1955)

GSC

Figure 25. Cumulative-frequency curves of three aeolian samples from the Banff area. Curves of loess from Fairbanks, Alaska, and Rock Island, Illinois are included for comparison. Carbonates have not been removed. For sample locations see map of surficial geology (*in pocket*).

wind-blown deposits lying near the present surface and as all are about three inches thick, they are believed to represent the same ash fall. According to H.A. Powers of the United States Geological Survey, the 'Hoodoos' sample resembles Mazama ash (A.MacS. Stalker, *pers. com.*, 1966) as does that found in the Banff dump (J.A. Westgate, *pers. com.*, 1966). Therefore, if the ash in the study area is Mazama its date would be roughly 6,000 to 7,000 years B.P. (Powers and Wilcox, 1964, p. 1335), which agrees with the dated sample from the

Banff National Park section. As the ash is associated with wind-blown material, it appears to have fallen during a time of sparse vegetation, and this could mean a drier, warmer period, perhaps near the beginning of the Altithermal. The date of the ash agrees with the dates presently accepted for the Altithermal-6,500 to 4,000 years B.P. (Richmond, 1965, p. 227).

As mentioned previously, evidence for Neoglacial advances is restricted to heads of valleys and cirques. Comparison with the histories of other glaciers in the Canadian Rockies suggests that the ice-cored, end moraines of the Wenkchemna Glacier probably resulted from the recession that followed a nineteenth century advance (Heusser, 1956). When compared with the map prepared in 1904 by Scherzer (1907), the moraine appears to have changed very little, morphologically, since. If the advance were earlier than the nineteenth century, more disintegration of the ice-cored moraine would be expected, with vegetation taking hold as in the earlier moraines on the Robson Glacier (Heusser, 1956, p. 276).

CORRELATION

Although correlation of events over great distances may be hazardous, it is interesting to make a tentative one between the Quaternary events of the Banff area and parts of the late Wisconsin stratigraphy of the United States Rocky Mountains.

The three stades of the Pinedale Glaciation in late Wisconsin times are correlated by the writer with the *Bow Valley* advance, the *Canmore Valley* advance, and the *Eisenhower Junction* advance. The dating control, as well as the freshness and good preservation of the deposits, would seem to permit such

Figure 26. Volcanic ash layer in wind-blown sand (A) and above lacustrine sand and silt (B) near the Banff town dump (51°12'00"N, 115°31'40"W). View looking north. *(201497)*

correlation, and the following indirect evidence adds to its validity:

Moraines of the early and middle stades of the Pinedale Glaciation outline large piedmont lobes at the mountain front in north-central Montana (Richmond, 1965, p.224). In the Banff area, evidence suggests that the glaciers of the *Bow Valley* and *Canmore* advances flowed beyond the Front Ranges, forming piedmont lobes that possibly merged with continental ice.

Moraines of early and middle stades of the Pinedale Glaciation commonly lie close together in the United States Rocky Mountains, whereas the moraines of the late stade lie at some distance up-valley (Richmond, 1965, p. 224). In the Banff area, the *Bow Valley* and *Canmore* advances flowed out of the mountains, and the *Eisenhower Junction* advance terminated well up the valley (*see* Fig. 1).

If Richmond's curve of the average altitude of the Recent and late Pleistocene end moraines in the United States Rocky Mountains (Richmond, 1965, p. 224) is extended to the 51st parallel (Banff area), the end moraines of the Pinedale stades should fall at altitudes of about 4,000, 4,600, and 4,800 feet respectively. During the *Bow Valley* advance the ice extended to at least 4,000 feet, during the *Canmore* advance to about 4,200 feet, and during the *Eisenhower Junction* advance to about 4,750 feet.

During the interstade separating the early and middle stades of the Pinedale Glaciation, recession of the glaciers varied from almost nothing to a few kilometres (Richmond, 1965, p. 226), which indicates that glaciers did not completely leave the major valleys. In the Banff area, the glacier of the *Bow Valley* advance did not leave the valley but receded roughly to the Banff townsite before the readvance.

In the United States Rocky Mountains, the Altithermal is represented by an immature zonal soil and a volcanic ash layer (Mazama ash) in the soil or on the surface (Richmond, 1965, p. 225, 226). Organic matter above or below the ash in Oregon and Washington was dated at about 6,000 years B.P. In the Banff area, Mazama ash is associated with wind-blown deposits probably belonging to the Altithermal.

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APPENDIX 1

Reports published since 1910 dealing with aspects of Quaternary geology in the Banff and nearby areas

Allan (1914, 1917) Daly (1915) Stewart (1919) Rutherford (1927) Beach (1943) Bostock (1948)	Various aspects of Quaternary geology in the area of Banff
Warren (1927) MacKay (1940) Belyea (1960)	Descriptions of the glacial scenery, glacial drift, and drainage changes in the Bow, Cascade, and Spray Rivers, and notes on the height at which erratics are found in the area of Banff
Nichols (1931)	Terminal moraines in Jumpingpound-- Wildcat Hills area
Horberg (1954) Wagner (1966) Wagner and Eschmann (1966)	Detailed glacial geological reports on parts of southwestern Alberta affected by both continental and Cordilleran ice
Tharin (1960) Morgan (1966)	Glacial geology of the Calgary area
Stalker (1963)	Sections east of Crowsnest Pass, some of which include both continental and Cordilleran glacial sediments
Jennings (1951)	Sunwapta Pass Region-- glacial geomorphology and its stratigraphic implications
Nelson (1963)	Morley Flats area-- geomorphology
McPherson (1963)	Upper Red Deer River valley--geomorphology

Scherzer (1907)	Outline of recent glacial history of Banff area based on data from recent moraines of the Wenkchemna, Asulkan, Illecilliwaet, Victoria, and Yoho glaciers.
Heusser (1956)	Reconstruction of postglacial environments from evaluation of available glacier data combined with data from other disciplines, notably botany

APPENDIX 2

Till Sections

Section 1. Powerhouse section - Bow Valley till overlying glacial outwash (51°11'40"N, 115°31'00"W).

		Thickness (feet)	Depth of base (feet)
Soil:		2	2
Till:	Light olive-grey (5Y6/1) yellowish grey (5Y7/2) when oxidized; firm; unsorted; 80 per cent calcareous; sandy clay loam; 15 to 20 per cent gravel, angular to well rounded (mostly subangular) pebbles, some striated and oriented with their long axes parallel or nearly parallel to the direction of glacier movement; mode 10 to 40 mm, less than 1 per cent boulders; mostly limestone and dolomite stones with lesser amounts of quartzitic sandstone, quartzite, and chert.	19	21
Gravel:	Grey-brown; moderately sorted; 85 per cent pebble sized or larger; mode 20 to 40 mm; rock-type as above.	2	23
Till:	As till above.	80	103
Gravel:	Grey-brown; poorly to moderately sorted; 80 per cent pebble sized or larger, mode 10 to 40 mm; angular to well rounded, mainly subrounded; partly graded, poorly bedded; few boulders over 1 foot; dip S55°E less than 3 degrees; rock-types same as till above.	37	140
	Covered.	33+	173+

Section 2. Ice-contact fluvial deposits - *Eisenhower Junction* advance (51°15'40"N, 115°56'40"W).

Gravel:	Grey-brown; very poorly sorted; 50 per cent pebble sized or larger (10 per cent boulders, 15 per cent cobbles, 25 per cent pebbles); mode about 75 mm; largest boulder 4 feet long; subangular to subrounded fragments; poorly bedded; fragments	12	12

		Thickness (feet)	Depth of base (feet)
Gravel: (cont.)	consist mainly of shale (argillite), quartzitic sandstone, limestone, and dolomite; regional dip S35°E, 5 to 10 degrees.		
Gravel:	Grey-brown; poorly sorted; 60 per cent pebble sized or larger (55 per cent pebbles); mode about 75 mm; largest boulder 1 foot; subangular to subrounded fragments; dip and rock types as above.	7	19
(A) Gravel:	Grey-brown; moderately sorted; 80 per cent small pebbles to granules; mode 6 to 12 mm; largest pebble 80 mm; mainly subrounded fragments; 20 per cent sand-sized or finer; dip S60°E, 24 degrees; rock types as above.	1	20
(B) Gravel:	Light brown; moderately sorted; 50 per cent pebble sized or larger (mainly pebble sized); mode about 40 mm; rare boulders; mainly subrounded; dip and rock types as above.	.7	20.7
Gravel:	Similar to (A) above.	0.6	21.3
Gravel:	Similar to (B) above, but more poorly sorted.	3	24.3
Gravel:	Similar to (A) above.	1	25.3
Sand:	Brownish grey; 20 per cent pebbles; trace of cobbles; moderately to well sorted; mostly medium to very coarse sand; crossbedding; rock types as above.	4	29.3
Gravel:	Similar to (B) above but poorly sorted.	5	34.3
	Covered.	9+	43.3+

Section 3. Kame deposits - near Loder's Lime Ltd. north of Route 1A (51°04'40"N, 115°07'20"W).

Soil:	With pebbles and boulders.	0.5	0.5
Pebbly sand:	Poorly sorted.	1.3	1.8
Gravel:	Unconformable with above; grey; sandy; moderately sorted; 85 per cent pebble sized or larger; largest pebble 6 inches long; fragments generally well	2.1	3.9

		Thickness (feet)	Depth of base (feet)
Gravel: (cont.)	rounded; 15 per cent sand; rock types mainly limestone and dolomite; dip N52°E, ±35 degrees.		
Pebbly sand:	Poorly sorted.	1.4	5.3
	Covered.	6+	11.3+
Section 4.	Kame deposits - northeast of Bow River just west of Kananaskis Falls (51°05'50"N, 115°03'50"W).		
Soil:		0.2	0.2
Gravel:	Grey, sandy; moderately sorted; about 85 per cent pebbles; mode 10 to 25 mm; few boulders 1½ feet long; subangular to well rounded fragments; rock types mainly dolomite and limestone; fairly flat-lying.	0.7	0.9
Gravel:	Unconformable with above; light grey; moderately sorted; 70 per cent pebble sized or larger; mode 20 to 40 mm; few boulders larger than 6 inches; fragments angular to subrounded; calcareous cement common; dip S80°E, 10 to 20 per cent; rock types as above.	2.5	3.4
Gravel:	Grey; sandy; moderate to well sorted; 85 per cent to 95 per cent pebbles; mode 15 to 25 mm; subangular to rounded pebbles; calcareous cement; dip S80°E, 10 to 20 per cent; rock types as above.	2.6	6.0
Gravel:	As above but mode about 15 mm.	1.6	7.6
Gravel:	Grey; poorly sorted; mainly boulders (up to 10 inches); mode 4 inches; angular to rounded; some pebbles and sand; dip and rock types as above.	0.7	8.3
(A) Sand:	Some pebbles and granules; dip as above.	0.4	8.7
Gravel:	Light grey; mainly pebbles; mode 50 mm; remainder mainly sand and granules; dip and rock types as above.	0.3	9.0
Sand:	As (A) above.	0.4	9.4
Gravel:	Light grey, sandy; poorly to moderately sorted; 70 per cent pebbles; mode 25 mm; few cobbles up to 7 inches; dip and rock types as above.	0.8	10.2

		Thickness (feet)	Depth of base (feet)
Gravel:	Light grey; sandy; well sorted; 85 per cent pebbles; up to 25 mm; mode 15 mm; dip and rock types as above.	0.6	10.8
Gravel:	Grey; sandy; moderately sorted; 85 per cent pebbles; mode 25 mm; some boulders up to 4 inches; dip and rock types as above.	1.3	12.1
Gravel:	Grey; 50 per cent pebbles; 50 per cent granules and finer; moderate to well sorted; pebbles 4 mm to 40 mm; mode 15 mm; subangular to rounded; rock types and dip as above.	2.5	14.6
Gravel:	Grey; sandy; moderately sorted; 85 per cent to 90 per cent pebbles; mode 7 to 25 mm; few cobbles up to 5 inches; subangular to rounded; dip and rock types as above.	5.5	20.1
Gravel:	Grey; sandy; poorly sorted; 50 per cent boulders; mode 6 inches; boulders up to 1 foot, subangular to well rounded; 20 per cent pebbles, 25 mm mode; subangular to rounded; dip and rock types as above.	1	21.1
Gravel:	Covered in part.	3.7+	24.8+
Section 5.	Non-ice-contact outwash - northwest side of Carrot Creek about 6 miles southeast of Banff townsite (51°09'10"N, 115°25'40"W).		
Soil:		1	1
(A) Till (possibly mudflow)	Light olive-grey; firm; unsorted; 90 per cent calcareous, less than 4 mm; 10 per cent pebble sized or greater; mode 15 to 25 mm; subangular to well rounded fragments; mainly subrounded; less than 1 per cent boulders up to 1½ feet; poorly defined orientation of pebbles; rock types consist mainly of limestone, dolomite, quartzitic sandstone, quartzite, and chert; fairly flat lying.	5	6
Gravel and Sand:	Alternating bands (1-3 inches) of sand and gravel; gravel mainly pebbles poorly to moderately sorted, mode 15 to 25 mm; subangular to subrounded; sand, fine to coarse with scattered pebbles; some clay lenses (3 mm).	1.5	7.5

		Thickness (feet)	Depth of base (feet)
(B) Gravel:	Grey-brown; poorly sorted; 60 to 70 per cent pebble sized or larger; mode 50 to 75 mm; subangular to subrounded; poorly bedded; rock types as above.	10	17.5
Sand:	Pebbles common; medium brown; fine grained.	4	21.5
Till: (possibly mudflow)	As (A) above, but 85 per cent less than 4 mm; mode of large-size fraction about 40 mm; a few ½ to 1 inch interbedded sand lenses.	9	30.5
Gravel:	As (B) above but mode of large sized fraction 25 to 40 mm.	2.5	33
Gravel:	Grey-brown; some sand; very poorly sorted; 65 pebble sized or larger; mode about 4 inches; less than 1 per cent boulders, up to 1½ feet in diameter; subangular; rare band (1-2 inches) of pebbles with no fine material, rock types as above.	22	55
	Covered.	4+	59+
Section 6.	Non-ice-contact outwash - northwest side of Route 1A about three miles southeast of Canmore (51°04'10"N, 115°17'50"W).		
Gravel:	Vertical cliff, inaccessible for description.	51	51
(A) Gravel:	Grey-brown; sandy; moderately to well sorted; 65 to 75 per cent pebbles, mode 15 to 25 mm; subangular to well rounded; rock types mainly limestone, dolomite, quartzitic sandstone, quartzite, and chert; fairly flat lying.	2	53
Gravel:	Mainly well-sorted granule-sized material, dip and rock types as above.	0.5	53.5
Gravel:	As (A) above.	3	56.5
Gravel:	Grey-brown; poorly sorted; 80 per cent pebble sized or larger; mode about 50 mm; up to 6 inches cobbles; subangular to well rounded; dip and rock types as above	2.5	59

		Thickness (feet)	Depth of base (feet)
Sand:	Grey-brown; 45 per cent pebbles; mode 25 to 50 mm; subangular to well rounded; dip and rock types as above.	0.5	59.5
Gravel:	As (A) above.	2.6	62.1
Gravel:	Grey-brown; 75 per cent pebble sized or larger; mode less than 7 mm; subangular to well rounded pebbles; crossbedded; dip 15 degrees, S70°E; rock types as above.	2.4	64.5
Gravel:	As (A) above.	17.8	82.3
Sand:	Lens; crossbedding.	1.6	83.9
Gravel:	As (A) above.	5	88.9
	Covered.	10+	98.9+

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195 Petrology and structure of Thor-Odin gneiss dome, Shuswap metamorphic complex, B. C., *by* J. E. Reesor and J. M. Moore, Jr., $2.50 (M42-195)

196 Glacial geomorphology and Pleistocene history of central British Columbia, *by* H. W. Tipper, $4.00 (M42-196)

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198 Geology and petrology of the Manicouagan resurgent caldera, Quebec, *by* K. L. Currie, $3.00 (M42-198)

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