UNIVERSITY OF CALGARY

THE DRUMMOND, HECTOR AND PEYTO GLACIERS--
THEIR WASTAGE AND DEPOSITS

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

CALGARY, ALBERTA

AUGUST, 1966

ABSTRACT

This study represents a part of the considerable field-work that has been undertaken since 1962 in the area of the upper Red Deer River valley. The purpose of the study is to establish a retreat record for the Rocky Mountain glaciers, the Drummond, Hector and Peyto, and to map and interpret recent glacial deposits.

Retreat records for each glacier were compiled from photographs, dendrochronological evidence, C14 dating and recent measurements of recession. The records show that in all cases the glaciers have been receding since the late 19th century, with approximately similar patterns of recession.

Deposits were mapped, using a descriptive-genetic classification, on the basis of textural and structural characteristics, form and field relations. Interpretation of the origin of glacial deposits followed observations of processes and field relations. In several cases widely-accepted terms for categories of glacial deposits were found to be inadequate in this study. The terms, such as "till" and "outwash" implied that only one process was responsible for a deposit, whereas several different processes, or a combination of them, may be responsible for the same deposit.

Field-mapping showed that most of the glacial deposits are located near the limit of recent glaciation. Few deposits have been formed in the area deglaciated in the last 50-60 years.

During the field-mapping, fabric measurements were taken mainly in unsorted glacial deposits near the glaciers. Interpretation of the results led to the conclusion that glacial deposits were largely derived from unsorted mass-wastage deposits. Fabrics in unsorted glacial deposits

located near mass-wastage deposits suggested much less influence by ice, during the formation of the deposit, than fabrics from unsorted glacial material deposited some distance from sources of mass-wastage debris, largely in the form of moraines.

Observations of deposits in the main Red Deer River valley and other mountain valleys have been made by members of the project, including Macpherson (1963) and the writer. Evidence suggests that important differences exist between deposits in the areas of pre-recent glaciation and those found near contemporary ice-sheets. One wonders if studies of process and deposits near relatively small contemporary glaciers may be less useful to our understanding of the processes and land-forms of former large-scale glaciations than is often imagined.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the help given him by Dr. J. G. Nelson of the Department of Geography, University of Calgary, Alberta. The study was part of the research on present and glacial process in the Red Deer River valley, conducted since 1962 with financial support from the National Research Council.

Further thanks are due to the following individuals and government departments for providing information and material of use in this study: Mr. A. MacQuarrie, Meteorological Office, McCall Field, Calgary; Mr. T. Drinkwater, Technical Division, Department of Lands and Forests, Government of Alberta, Edmonton; Mr. C. E. Hoganson, Computation and Control Section, Topographical Survey, Department of Mines and Technical Surveys, Ottawa; Mr. A. C. Tuttle, Chief Topographical Engineer, Department of Mines and Technical Surveys, Ottawa; Public Archives of Canada, Ottawa; Mr. E. Hall, Geological Survey of Canada; Dr. G. Østrem and Dr. J. Andrews, Geographical Branch, Department of Mines and Technical Surveys, Ottawa; Dr. W. O. Field and Dr. C. E. Heusser, American Geographical Society, New York; and Glenbow Foundation Library, Calgary.

The writer is indebted to the assistance of fellow graduates and to the following people, for help particularly during field operations: John Marsh, Roger Byrne, Marvin Sundstrom, Don Gardner, Peter Spear, Gerry Walsh, Ric Kunelius, Brian Sullivan and Clint Smith. Further thanks go to the administration and Wardens of Banff National Park who have been a great help to the Red Deer project as a whole for several years. The writer is grateful to Shirley Werner, Lorna Hurl and Bernard Kenny for assistance in producing this thesis.

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CHAPTER I

STUDY PLAN AND REVIEW OF RELATED RESEARCH

A large body of research has been carried out in the field of glacial geology and geomorphology in western Canada. However, most of the work, to date, has been restricted to the prairies and few geomorphologists have turned their attention to the Rocky Mountains. The purpose of this study is to establish a retreat record for three Rocky Mountain glaciers, the Drummond, the Hector and the Peyto (Figure 1.1) and to map and interpret the deposits in the vicinity of these ice-sheets.

The research was carried out as part of the Red Deer River Project organized by Dr. J. G. Nelson of the Geography Department, University of Calgary, Alberta. The writer became familiar with the mountain environment in general, and the Drummond Glacier in particular, whilst working for the project in 1964. The study plan was organized during the following academic year and the research formed part of the Red Deer project field work in 1965.

The record of recession of the three glaciers was compiled with varying degrees of detail in each case. The main evidence for frontal retreat was derived from photographs. Additional sources were tree-ring data, radio-carbon dates and finally, recession measurements made in the last few years. Measurements of ice-wastage in the Drummond Glacier have been made by the Red Deer Project since 1962 and have been published in several reports (Hattersley-Smith, 1963, 1964 and 1965; Gardner, Nelson and Ashwell, 1964; Nelson, Ashwell and Brunger, 1966).

The mapping and analysis of deposits constituted the main part of the field work. Air photographs taken by the Provincial Department

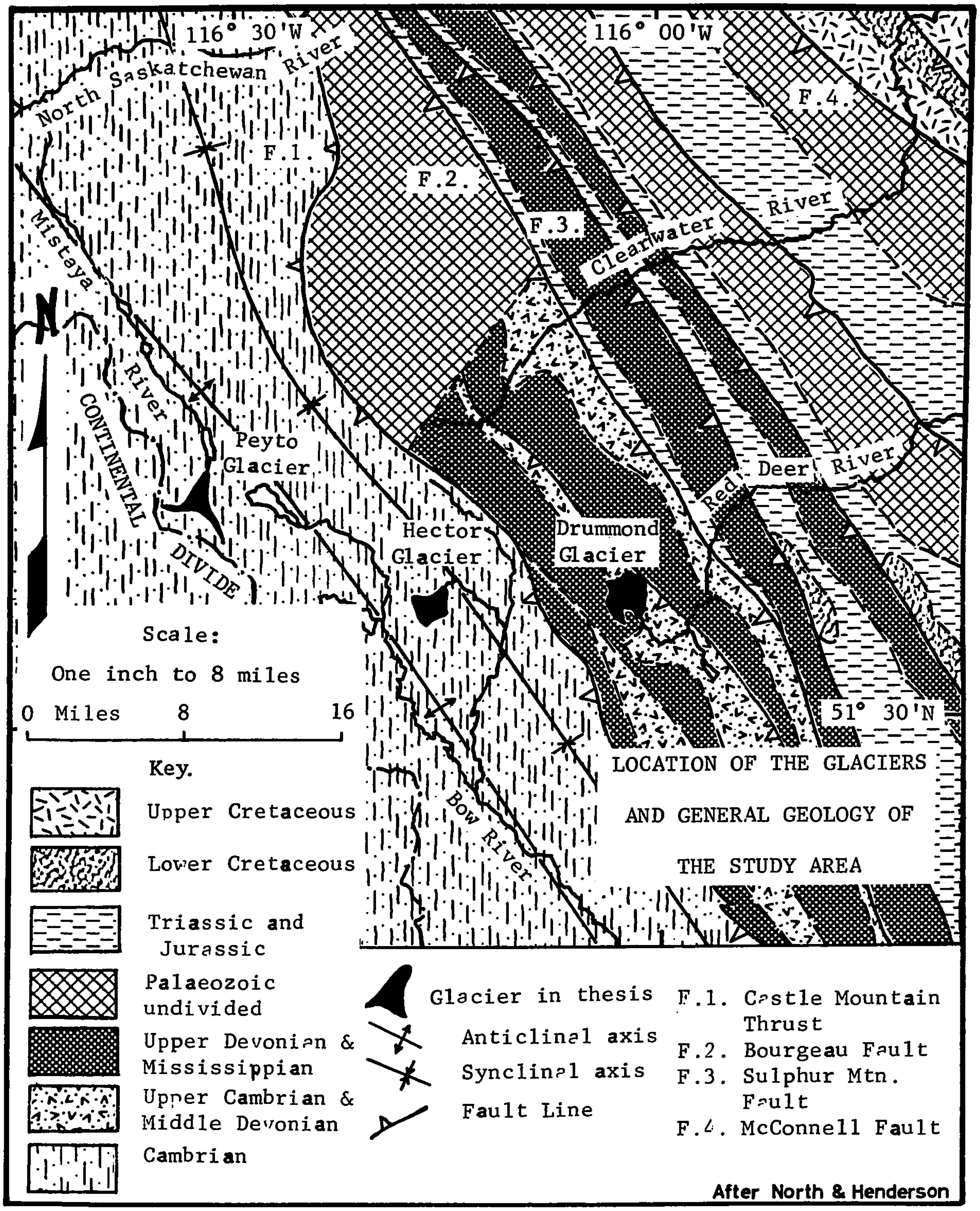
116° 30'W
116° 00'W
North Saskatchewan River
F.1.
F.2.
F.3.
F.4.
Clearwater River
Mistaya River
CONTINENTAL DIVIDE
Peyto Glacier
Hector Glacier
Drummond Glacier
Red Deer River
Bow River
51° 30'N
Scale:
One inch to 8 miles
0 Miles 8 16
LOCATION OF THE GLACIERS AND GENERAL GEOLOGY OF THE STUDY AREA
Key.
Upper Cretaceous
Lower Cretaceous
Triassic and Jurassic
Palaeozoic undivided
Upper Devonian & Mississippian
Upper Cambrian & Middle Devonian
Cambrian
Glacier in thesis
Anticlinal axis
Synclinal axis
Fault Line
F.1. Castle Mountain Thrust
F.2. Bourgeau Fault
F.3. Sulphur Mtn. Fault
F.4. McConnell Fault
After North & Henderson

Figure 1.1

of Lands and Forests provided a basis for mapping. Topography and types of deposits were mapped in the area recently occupied by the glaciers. Classification and identification of deposits were based on the observed characteristics of structure, texture and topographic form. Lithology was not considered. However, the strata are not lithologically very different in the area near the glaciers. Fabric and pebble counts were taken at numerous sites near each glacier in order to estimate the fabric, texture and structure of deposits. Fabric analysis involved measurement of the orientation and dip of the axes of elongate pebbles in order to determine the mode of origin of the deposits. Differences of orientation and dip in fabric samples provide a basis for interpretation of different processes responsible for the deposits.

The upper Red Deer River valley had been previously studied by Macpherson (1963) who reported on the glacial geomorphology of the area. His work was carried out as part of the Red Deer Project and its specific purpose was "to describe the interpret in terms of process the landforms created during the deglaciation of the mountainous upper Red Deer River valley" (Macpherson, 1963, p. vi).

Macpherson's work was at least partly stimulated by the controversy that has developed in recent years with regard to the mode of ice-wastage of the Canadian prairies during the last deglaciation. Before about 1950, most workers had described and interpreted the glacial deposits of western Canada in a similar way to workers in Europe and the central and eastern United States. Underlying their approach to the geomorphology of the area was the belief that ice-wastage occurred primarily by a series of frontal retreat stages separated by periods of stillstand, i.e. periods of stationary ice-margin. During stillstand, moraines formed alongside the ice as a result of accumulation of material transported by the still-active glacier. Such end, or recessional, moraines have been mapped and interpreted by workers in many areas, including southern Alberta and northern Montana (Bretz, 1943) and the Waterton area of southern Alberta (Horberg, 1956).

The interpretation of western Canadian glacial geomorphology underwent a fundamental change after about 1950. Under the influence of Scandinavian research, chiefly by Mannerfelt (1945) and Hoppe (1952 and 1953), Canadian workers began to regard the glacial deposits of the prairies in a different light.

Both Mannerfelt and Hoppe had interpreted irregular, hummocky, glacial deposits in northern Sweden, as the products of stagnant or dead-ice deposition. Mannerfelt, the earlier worker, regarded the hummocky moraines as essentially frontal accumulations, although he was reluctant to classify them as end moraines, i.e. deposits formed during a still-stand of the ice. Hoppe completed appreciably more work on the hummocky deposits. Basing his conclusions largely on fabric analysis, Hoppe explained the "hummocky moraine terrain" as being, "formed underneath the ice through squeezing into basal cavities of moraine material which was soaked with water and therefore in a plastic state" (Hoppe, 1952, p. 54). In certain cases where "moraine ridges are found in isolated positions between dead-ice hollows, it appears more logical and natural to think of them as formed in crevasses." Hoppe interpreted these deposits as being products of dead or stagnant ice.

In western Canada, workers began to interpret glacial landforms in the light of the theories propounded in Scandinavia. Deposits and landforms of a similar kind were mapped and interpreted by such workers as Dyson (1952), Gravenor (1955), Bayrock (1956 and 1958), Gravenor and Kupsch (1959) and Stalker (1958 and 1960). These workers reached the general conclusion that the predominant form of ice-wastage in western Canada during the last major glaciation was that of widespread stagnation and melting in place.

In 1963, Macpherson attempted to show that certain of the ideas of ice-stagnation held for the prairies could be applied to the glaciation of the mountain section of the Red Deer River Valley. He mapped the Recent and Pleistocene deposits of the upper Red Deer River, using several different categories, including till, ice-proximous, outwash, lacustrine, alluvium, colluvium, alluvium-outwash, bedrock and deposits of unknown origin. Of particular importance to his study was the category of "ice-proximous" which Macpherson defined in the following way:

> At one end of the scale this material resembles till in that it exhibits little sorting or stratification and consists of a mixture of clay, silt, sand and gravel. At the other end of the scale the deposit may consist of well-sorted and comparatively well-stratified, sub-rounded to rounded gravels, with inclusions of sand lenses. This material is approaching the outwash category as regards degree of water-working.
> (Macpherson, 1963, p.9)

Macpherson mapped ice-proximous deposits as being the predominant type of material in the upper Red Deer Valley, (Macpherson, 1963, Figure 3) and noted that the deposits usually occurred in the form of hummocky topography or non-paired benches which parallel the river in places.

Macpherson states:

> The presence of much ice-proximous material, and the paucity of recessional moraines and associated outwash terrace systems, suggests the Red Deer Valley ice stagnated and melted in place over

> long stretches of the valley, rather than retreated in a series of stillstands.
>
> (Macpherson, 1963, p. 36)

Although Macpherson made no mention of it, there is at least one possible alternative mode of ice-wastage in the Red Deer Valley. Such a possibility was suggested in 1965 as follows:

> Little positive evidence for stagnation has been found in the Red Deer Valley, so that the ice may have retreated by some other means than a series of stillstands or stagnating. Possibly retreat was rapid and steady, primarily from above, and involved relatively clean ice, circumstances similar to those extant on the Drummond ice today.
>
> (Brunger, Ashwell, and Nelson, 1965)

The findings of Macpherson in the upper Red Deer were undoubtedly influenced by research of a similar nature that had been completed by Nelson in the Susquehanna Valley of Pennsylvania and New York, during 1959-60. Nelson mapped and interpreted the glacial and recent deposits of the valley and concluded:

> The lack of much outwash, and also of recessional moraine and terrace systems, the presence of some eskerine and conical ridges, and the super-position of tills over ice-proximous deposits all suggest that the Olean ice stagnated and melted primarily from above.
>
> (Nelson, 1965, p. 447)

Nelson also described and interpreted the landforms in the Morley Flats area of the Bow River valley, Alberta (Nelson, 1963). The level topography of the flats is interrupted by numerous sub-parallel linear ridges. On the basis of evidence of texture and structure of deposits, field relations and form, Nelson concluded that the ridges and plains surrounding them were the products of stagnation or melting of ice in place.

The purpose of this thesis is to study the pattern of recent ice-wastage and distribution and origin of deposits near the glaciers. Previous research in western Canada, including Macpherson's Red Deer

Valley study has been on glacial deposits of relative antiquity and far removed from glaciers. This study attempts to relate relatively recent deposits to the pattern of ice-wastage. By comparison of results from near the three glaciers, similarities of distribution and mode of origin of deposits are evident. The results are also useful in considering Macpherson's conclusions and the broader question of the mode of ice-wastage in the mountain valleys.

Geology

The thesis area includes the two main geological subdivisions in the Rockies east of the Continental Divide. The geology of the area was described by North and Henderson (1954), who distinguished between the Main Ranges sub-province, along the Divide, and the Front Ranges sub-province to the east. The sub-provinces are separated by a major fault zone termed the Castle Mountain Thrust. The line of the fault runs approximately in a north-north-west and south-south-east direction as can be seen in Figure 1.1. The Main Ranges sub-province lies west of the Castle Mountain Thrust Fault zone and includes many of the highest peaks in the Canadian Rockies and most of the glaciers. The Hector and the Peyto are both located in the sub-province. The strata comprising the Main Ranges have been relatively undisturbed compared to those in the Front Ranges. The eastern sector of the Main Ranges sub-province consists of gently folded rocks and erosion of these folds has produced "the high-shouldered, castellated peaks popularly thought of as typical 'Rocky Mountains'" (North and Henderson, 1954, p. 29).

The Front Range sub-province lies to the east of the Castle Mountain Thrust. A series of sub-parallel, west dipping thrust blocks are characteristic here. In the upper Red Deer River valley there are four thrust blocks each constituting one of the Front Ranges. The local geology of the three glaciers will be described in somewhat greater detail in Chapter II.

Regional Geomorphology

The river valleys in Banff Park area appear to have developed mainly along lines of geological weakness. For example, the upper Bow Valley is formed along the axis of an anticline and in the eastern ranges maximum erosion has occurred along fault lines and thrust planes . The general orientation of the thrust planes is reflected in the direction and parallelism of the majority of the valleys. Major streams such as the Bow and Red Deer occupy valleys developed across the dominant trend-lines.

Superimposed upon the pre-Pleistocene landscape are the many effects of the Pleistocene glaciation and post-Pleistocene conditions. Cordilleran ice may have advanced several times through mountain valleys, and beyond, to the foothills and plains. Flint (1957, p. 306) suggested that the Rockies were never completely covered by ice during the Pleistocene. Many of the present valleys have a "U"-shaped cross-profile, possible evidence of glacial erosion. The valley bottoms are, on the other hand, frequently filled with glacial deposits. Laycock (1957, p. 434) stated that over 600 feet of such material occurs in the Ghost River valley, tributary to the Bow. The original valley form may thus have been considerably different to the present owing to the depth of deposits. Questions relating to the present and past geomorphic processes will be discussed further in the section of interpretation of recent deposits around the glaciers.

Hydrology

The Rocky Mountain glaciers were once thought to be important factors in the water resources of the prairies. In 1945, the Dominion Water and Power Bureau instituted a large-scale annual survey of glacier tongues, in response to fears that the ice-sheets were rapidly shrinking and a water shortage was imminent. Partly as a result of the measurements, Collier was able to show that the glaciers are responsible for relatively little of the total water draining into the east-flowing river basins of Alberta (Collier, 1957). The proportion of water they contribute is approximately 10-20% of the stream flow close to the glacier. The ice-sheets, therefore, will not affect the water budget very much if they continue to disappear. Of far greater importance is the precipitation in the Rockies, particularly the snow fall of winter and spring. The major proportion of the prairie rivers have their source in the mountains. Fluctuations in snowfall in the Rockies may cause marked changes in the hydrology of western Canada.

In spite of the seemingly minor importance of the glaciers for water-supply in terms of the total volume of water, the study of glacier fluctuations may assume importance, if ever-increasing demands on water resources reaches a critical level. Already fears of water shortages and of misuse of water supplies are being voiced. In order to avoid such misfortunes, it is of primary importance to obtain an accurate idea of the water resources in existence. Glacier variation studies contribute to this aim. The Geographical Branch of the Canadian Government is at present engaged in a study, in connection with the International Hydrological Decade, to determine the mass-balance of glaciers in the western cordillera.

CHAPTER II

WASTAGE OF THE GLACIERS

In this chapter a brief introduction describing the characteristics of glaciation in western Canada will precede a more detailed study of the recession patterns of the Drummond, Hector and Peyto Glaciers. Recession data will be compared with data for nearby glaciers and an attempt made to correlate recession with climatic data of temperature and precipitation for nearby stations.

The glaciers in this study are located in the eastern Rocky Mountains (Figure 1.1). The investigation is primarily concerned with the recent history of the glaciers. The term ' recent history', although imprecise, refers to the last major glacial advance and subsequent recession which is believed to have been synonymous with the "little ice age" (Heusser 1961) in much of western North America. Heusser (1961) stated that glaciers in the Canadian Rockies had experienced three of the four most recent advances considered to have occurred in North America. Heusser's chronology corresponds closely with Ahlmann's (1953) summary of recent world trends. Ahlmann suggested that the regeneration of ice-sheets began about 500 B.C. and was followed by centuries of glacier growth until the period of maximum advance, between the first half of the 18th century and about 1900.

The Drummond, Hector and Peyto Glaciers have a broadly similar environment from geological and climatic aspects although they differ in altitude; Drummond, 8000 feet, Hector, 7800 feet and Peyto, 6800 feet above sea level. The individual environment of the glaciers will be discussed in greater detail in the following section.

Environments of The Glaciers

1. Drummond Glacier

The Drummond, the easternmost of the three glaciers, has been described as follows:

> The Drummond Glacier is situated at the headwaters of the Red Deer River in the front ranges of the Canadian Rockies. The icefield covers approximately 10 square miles and lies at an altitude of between 8,000 to 10,000 feet above sea level. The icefield is dome-shaped, fairly uniform at the surface, and is remarkably free of crevasses. It is enclosed in an amphitheatre of peaks which includes Pipestone and Cyclone Mountains as well as Mount Drummond. Of the peaks making up this amphitheatre there are at least six which exceed 10,000 feet in altitude.
>
> (Gardner, Nelson and Ashwell, 1963, p. 137)

The geological conditions in the vicinity of the Drummond Glacier and the other two glaciers are known only in barest detail. The trend of the thrust faults on the eastern ranges of the Rockies is from north-north-west to south-south-east. Outcrops of Cambrian, Upper Devonian and Mississippian strata are parallel to the fault trend in the Drummond Glacier area. Dolomitic limestone, limestone, shale and fine sandstones are the main rock types. The strata dip in a west-south-westward direction and possess varying resistance to erosion; consequently numerous ridges of more resistant rock have been formed.

2. Hector Glacier

The Hector is situated further west than the Drummond, in the range of mountains on the east side of the upper reaches of the Bow River Valley (Figure 1.1). The névé area of the glacier is approximately three to four square miles and situated at an altitude of between 7,800 and 11,000 feet above sea level. The glacier is confined to the steep north slope of Mount Hector. The length of the glacier between the highest point of the névé area and the tongue is approximately $1\frac{1}{2}$ miles. The glacier flows north-eastward down the mountain-side into the valley of

Molar Creek, a tributary of the Bow River.

Near the Hector Glacier, massive beds of Cambrian limestones and quartzites dip steeply towards the north-east, forming part of the eastern limb of the Bow River anticline. Weathering and erosion of the strata formed numerous cliffs on the north slope of Mt. Hector, consequently the glacier is split into several tongues and is highly crevassed. The eastern tongue is a hanging glacier, which formerly supplied a glacier in the valley below. Unsorted glacial deposits, forming numerous moraines, are located near a remnant of the glacier at the cliff-foot. Study of the recession and deposits of the Hector Glacier was concentrated near the western tongue.

3. Peyto Glacier

The Peyto is the western-most of the three glaciers and forms the northern tongue of a large ice-sheet located along the Continental Divide (Figure 1.1). The total area of the ice-sheet is approximately forty square miles and generally lies at 9,000 feet above sea level (Meek, 1948). The Peyto Glacier flows north-north-eastward in a deep valley between mountain peaks over 9,000 feet high. The glacier is largely free of crevasses for most of its length.

The geology near the glacier is dominated by an eroded anticline composed of beds of Cambrian and Pre-Cambrian limestones and quartzites. The beds are part of the western limits of a large anticline which is eroded and forms the valley of the Mistaya River. The strata are of varying resistance to erosion and bedrock ridges cross the valley at several points. At present the ice tongue occupies a gorge in one of the ridges.

Recession Pattern and History of Observation

The following section will describe the recession record of each glacier, including the evidence of recession and the history of observation. After the estimates of relatively long-term recession have been described, recent frontal measurements of the Drummond and Peyto Glaciers will be discussed in a spparate section.

1. Drummond Glacier

a. Photographic Record[1]

Although fur traders and others are known to have been active in the Canadian Rocky Mountains prior to 1800, little reference is made to early use of the Red Deer Valley. The valley seems to have been used very infrequently as a communication route, probably because the Bow River Valley, in close proximity to the south, provided much better access to and through the mountains. One of the first recorded trips by a white man up the valley is that of George M. Dawson in 1884. He took many photos including two excellent shots of the Drummond Glacier from a point about two miles south of the ice near the junction of the Drummond Creek and the main Red Deer River (Figure 2.1). The quality of the photographs is good and it is possible to plot the position of the eastern lobe of the ice with considerable accuracy.

In the early twentieth century, increased interest in glaciers

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[1]Many different sources of old photographs have been found by members of the Red Deer Project. In each case, acknowledgment of the source and finder, other than the writer, is noted underneath. A substantial part of the material on the Drummond Glacier appeared in Nelson, Ashwell and Brunger (1966) in much the same form as in this thesis. This paper developed from an early draft of the present chapter.

Figure 2.1

Drummond Glacier : 1884. Note the extent of the eastern tongue of ice on the right of the picture. Photo by G.M . Dawson. Source, Geological Survey of Canada. Finder, Roger Byrne.[1]

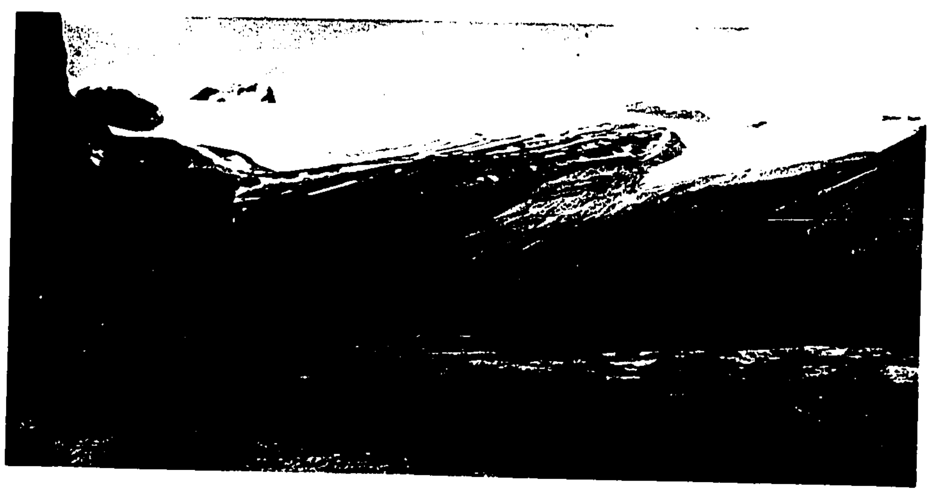

Figure 2.2

Drummond Glacier : 1906
Photo by A. O. Wheeler. Source, Topographical Survey of Canada. Finder, J. G. Nelson.[1]

1. This photograph appears in Nelson,Ashwell and Brunger(1966).

accompanied the development of the Banff area as a tourist resort. Mountaineers began to note the positions of glaciers. The Canadian Alpine Club, founded in 1907 by A. O. Wheeler, had glacier observation as one of its objectives. Members of the club usually visited and made records of the most accessible areas. Consequently, the Red Deer Valley seems to have been infrequently reached by climbers, and no records exist of the Drummond Glacier.

In the period 1902-1906, Wheeler surveyed much of the area of the eastern Rockies and took numerous photographic panoramas from mountain peaks (Thomson, 1966, p. 56). These include several photographs of the Drummond Glacier, which permit very precise estimation of its position. One of the photos (Figure 2.2) was taken from a point near Dawson's 1884 viewpoint and these two shots can be closely compared.

The next record of the Drummond Glacier that has been discovered is a photo of the ice from a mountain located several miles to the south. The photograph was taken by M. P. Bridgland, who was surveying in the area of the foothills and front ranges in the period 1917-1920. The detail in the photograph is not good, largely because of the distance from the glacier.

The photographs so far described are derived from government-sponsored surveys. The surveyors travelled the area for purposes of mapping or research and were undoubtedly among the first white people in the upper Red Deer Valley. It is difficult to estimate the number of other travellers in the area. A number of mountaineers and packers were in the Red Deer Valley during the early part of the century but their interest was apparently mainly non-scientific, and few of them returned with photographs.

In 1930, Mr. Leonard Leacock travelled into the Red Deer Valley and photographed the Drummond ice from Dawson's viewpoint (Figure 2.3). A further photograph was taken in 1939 by Colin Wyatt, from a more distant viewpoint on the southern side of the Red Deer Valley, about five miles away from the ice (Figure 2.4). Both these photographs give a good view of the glacier tongue and enable an accurate estimation to be made of its position. Wyatt's photograph can be compared with another taken from a similar position by J. Gardner in 1963. The later photograph shows considerable recession from the 1939 position (Figure 2.5).

For the period 1939-1962, no photographs of the Drummond Glacier are known, except for the aerial photographs taken by federal and Alberta government agencies on September 3, 1951 and July 31, 1962 (Figure 2.6). The provincial photos, by the Department of Lands and Forests (No. 160-5114X, 2426-49 and No. 160-5113X, 2426-15), provide a very clear picture of the glacier and environs and have been used as the base for mapping. Since 1962, a large number of photographs of the Drummond Glacier have been taken by personnel involved in Red Deer valley studies, Figure 2.7 is one example. Figure 2.8 shows six positions of the ice-margin which have been plotted using all the previous photographic evidence. The symbols for estimated and tentative ice-margin are intended to suggest relative difficulty in plotting. The data of recession derived from these records and mapped in Figure 2.8 are shown in Table 2.1.

Figure 2.3

Drummond Glacier, 1930.
Photo by L. Leacock. Source, Glenbow Foundation Library.[1]

1. This photograph appears in Nelson, Ashwell and Brunger(1966).

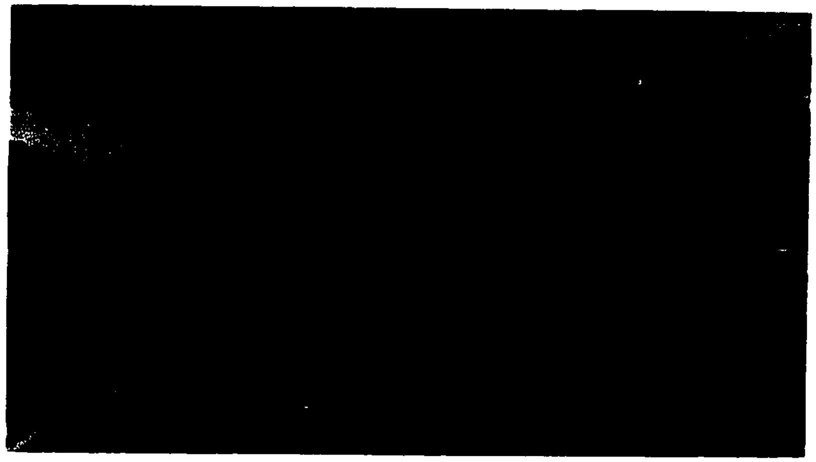

Figure 2.4

Drummond Glacier, 1939
Photo by Colin Wyatt. Source, The Call of the Mountains. London, 1965. Finder, R.King.

Figure 2.5

Drummond Glacier, 1963
Photo by James Gardner

Figure 2.6

Drummond Glacier, 1952..
(Parts of air-photographs No. 160-5114X, 2426-49 and No. 160-5113X, 2426-15, by kind permission of Alberta Provincial Government, Dept. of Lands and Forests).

Figure 2.7

Drummond Glacier, 1964.
Photo by Marvin Sundstrom.[1]

1. This photograph appears in Nelson, Ashwell and Brunger(1966).

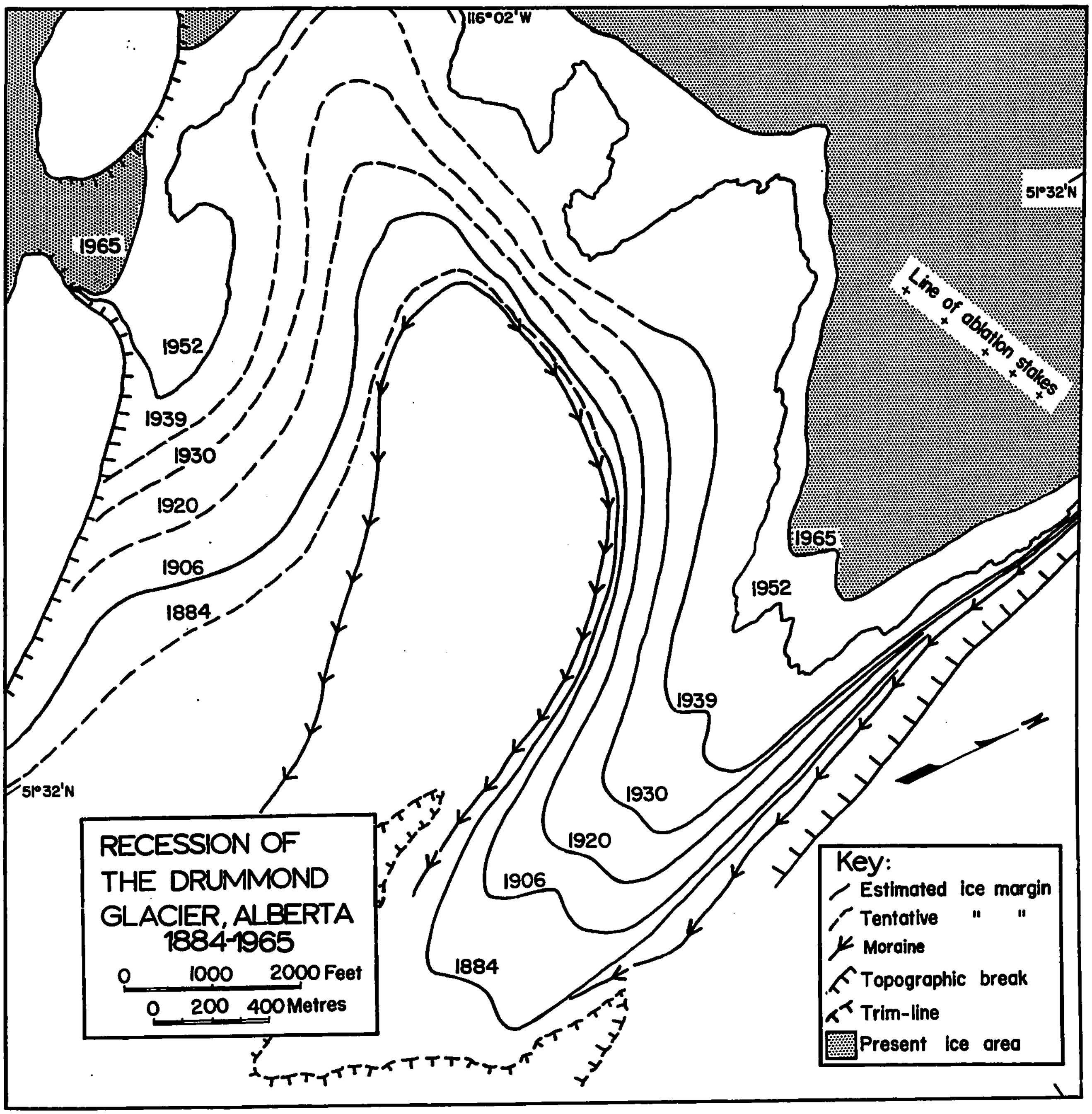

Figure 2.8 [1]

1. This map appears in Nelson, Ashwell and Brunger(1966).

Table 2.1

Recession of Drummond Glacier, 1884-1965

Frontal Recession in Feet (and Metres)

Time Period	Total Amount	Annual Amount
1884-1906	1080 (330)	49 (15.0)
1906-1920	850 (260)	61 (18.6)
1920-1930	850 (260)	85 (26.0)
1930-1939	1115 (340)	124 (37.9)
1939-1952	1115 (340)	86 (26.2)
1952-1965	1062 (325)	82 (25.0)

During the period from 1884-1965, the Drummond has receded at varying rates, increasing through about the first fifty years of the period to a maximum average annual recession in the 1930-1939 period. Since 1939, the rate of recession has decreased.

b. Recession Estimates Based on Dendrochronological and Carbon 14 Evidence

Tree-ring samples have been collected from Engelmann Spruce located at several points in the Drummond Valley. Three trees near the forest trim-line[1] and within half a mile of the prominent moraine surrounding the present ice, were over 300 years old. This date represents a minimum estimate of the length of time since the glacier extended beyond the trim-line.

Study of areas shown to be covered by ice in Dawson's photo of

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[1]Heusser defined the 'trim-line' as "the boundary between terrain bearing either mature or youthful vegetation and that denuded or bearing relatively younger vegetation and formed as a consequence of increase and subsequent decrease of a glacier." (Heusser, 1956, p. 274).

1884, and since deglaciated, reveals little or no tree-growth as yet. An eighty-year period without regrowth is relatively long (Bray and Struik, 1963; Lawrence, 1950), although it may be partly explained by the high altitude. If such a regrowth period applied to the Engelmann Spruce forest in the surrounding trim-line, the date indicates a period of at least 380 years since the ice penetrated the lateral moraine containing the present ice-field.

C_{14} dates have been obtained for two samples recovered about fifteen miles and two and one-half miles from the Drummond Glacier respectively. The first date was from a small amount of charcoal recovered from a till-like deposit located on the north side of the Red Deer River valley near Scotch Camp. The result, which was greater than 33,000 years, is quite out of line with dates which are available for nearby areas. The second date was obtained from a sample of wood and organic debris located about nine feet from the surface of a large mudflow on the east side of the Drummond Valley. Several layers of wood and organic debris, buried by former mudflows, were exposed during digging of a cross-section along the stream bank. The C_{14} date, for the lowest of these was 2930 $\pm$ 150 years. B.P., a minimum date for deglaciation inasmuch as an unknown amount of mass-wastage, and perhaps other debris underlies the sample horizon.

2. Hector Glacier

a. Photographic Record

The Hector is situated within 2½ miles of the Bow Valley which has been a major routeway for travel since the white man first penetrated the area. The glacier itself, however, is not easily accessible.

The first photographs of the Hector Glacier were those taken by federal government surveyors who visited the area for the purposes of mapping. The earliest record to come to light is a photograph (Figure 2.9), which is believed to be dated 1886, although the precise date is uncertain. It was taken by an employee of the Topographical Survey of Canada who may have been working under J. J. McArthur, the surveyor responsible for mapping the route of the C.P.R. line through the Rockies. According to Thompson (1966) this survey was carried out in the two years 1886 and 1887. The photograph of the Hector Glacier shows the ice margin fairly well although the northern-most tongue of ice is obscured. The 1886 shot can be compared with another taken in August 1965 from approximately the same viewpoint (Figure 2.10) which indicates the glacier has receded considerably in the 79 year period since the date of the first photograph.

In 1904, A. O. Wheeler took two photographs of the Hector from the peak of Mt. Molar, a viewpoint about three miles away to the north-east (Figure 2.11). The shots give an excellent view of the ice margin and permit accurate estimation of its terminal position. It is difficult to judge the amount of recession that occurred on the Hector Glacier in the 18 year period between 1886 and 1904, as the earlier photograph is poor in detail compared to that of 1904. Wheeler took another photograph of the Hector Glacier in 1906. The viewpoint in this case was from the area of the upper Pipestone River valley and at a much greater distance than the 1904 photograph. Unfortunately no estimate of ice recession can be gained from comparison of these two photographs.

The next record of the Hector ice is a photograph taken by M. P. Bridgland who surveyed the area of western Alberta during the period 1917-1920. The poor quality of the photograph permits only a

Figure 2.9

Hector Glacier, ca. 1886
Photo by anonymous. Source Appalachia, Vol. 8, No. 1, 1896, p. 1

Figure 2.10

Hector Glacier, 1965.

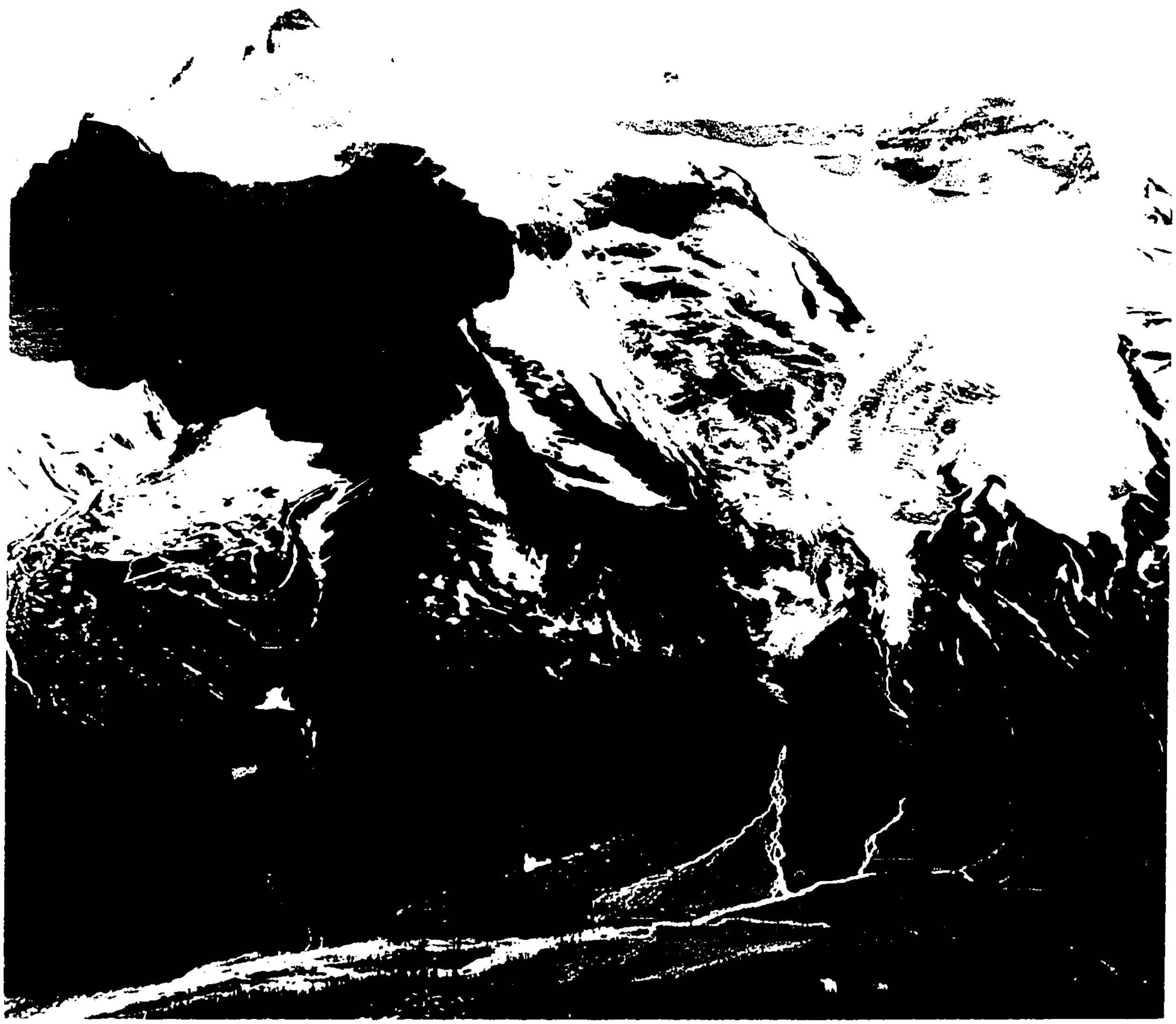

Figure 2.11

Hector Glacier, 1904
Photo by A. O. Wheeler. Source, Topographical Survey of Canada.

rough estimate of the ice terminus. As a result, there is no accurate record of the Hector Glacier position available for the whole period 1904 to 1938.

In 1938, a large mass of ice broke away from the Hector Glacier and slid into the Molar Creek valley. The Topographical Survey of Canada has 18 photographs of the ice-slide and one of these (Figure 2.12) permits fairly accurate mapping of the glacier margin. The slide has apparently affected both the vegetation and the glacial deposits of the Molar Creek valley into which it slid. Evidence for this assumption will be dealt with in the appropriate section.

The only known records of the Hector Glacier for the period 1938-1962, are the aerial photographs taken by federal and Alberta government agencies. Provincial photos (No. 160-5113X, 2426-11 and No. 160-5114X, 2426-44), dated July 31, 1952, have been used as the base for mapping retreat stages (Figure 2.13). In 1965 the writer took a large number of photographs of the ice and surrounding area and these permit accurate mapping of the present ice margin (Figure 2.14 is one example).

Figure 2.15 shows a map of the successive retreat positions of the Hector Glacier. Six positions of the ice margin are drawn on the map although the 1886 and 1919 positions are tentative, as indicated by the broken line symbol. Estimates of the amounts and rates of recession are expressed in Table 2.2.

Table 2.2

Recession of the Hector Glacier, 1904-1965

	Frontal Recession in Feet (and Metres)			
Time Period	Total Amount		Annual Amount	
1904-1938	1148	(380)	32.7	(10.3)
1938-1952	491	(150)	35.0	(10.7)
1952-1965	228	(70)	17.5	(5.4)

Figure 2.12

Hector Glacier, 1938
Note that the ice from the slide fills the Molar Creek valley below the glacier. "X" on the left of the photograph marks the position of the source of the slide and was used in estimating the position of the glacier margin. Source, Topographical Survey of Canada. Finder, Robert Scace.

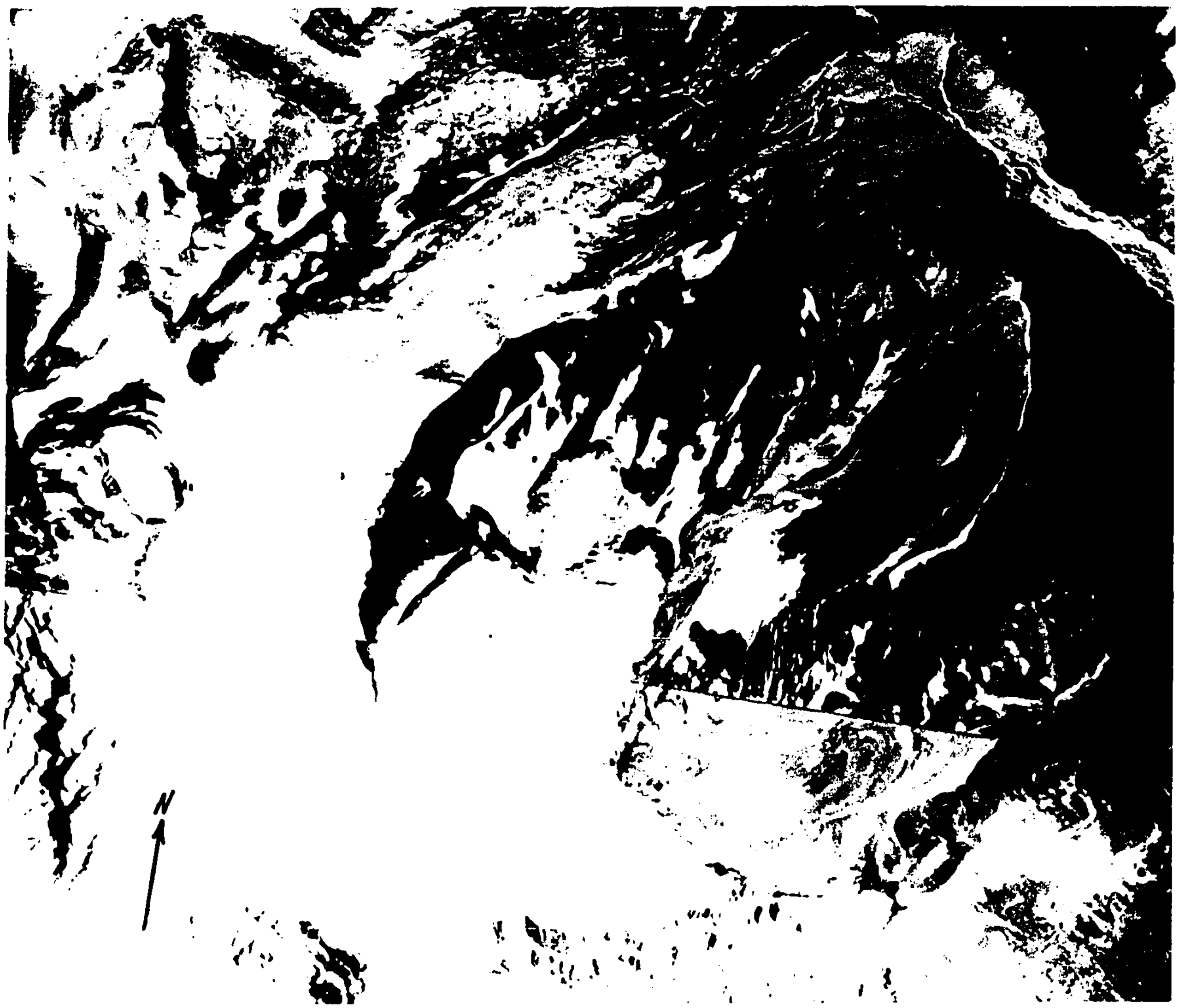

Figure 2.13

Hector Glacier, 1952
(Parts of air-photographs No. 160-5113X, 2426-11 and No. 160-5114X, 2426-44, by kind permission of Alberta Provincial Government, Department of Lands and Forests).

Figure 2.14

Hector Glacier, 1965
Note, dark area of "dead" ice between top of cliff and white glacier ice, in background.

b. Recession estimates based on dendrochronological evidence.

A clearly defined trim-line is located in the forest of the Molar Creek valley to the north of the present ice (Figure 2.15).

The absence of fire-charred trees, the deposits of unsorted glacial debris, and the position of the area in relation to the apparent direction of movement of the ice, suggest that the Hector Glacier was responsible for clearing the forest and creating the trim-line. The trim-line is clearly shown in the photograph taken in 1965, from the southern side of the valley (Figure 2.16). The trim-line is distinct and numerous broken dead trees are situated along it (Figure 2.17). Table 3 contains data from tree-bores near the western trim-line.

Table 2.3

Tree-bore Data From Trees Near the Trim-line of Hector Glacier

No.	Age	Diameter b.h. (inches)	Details of Site
1	91	24	western trim-line
2	100	10	30 feet from western trim-line
3	143	16	western trim-line
4	290	16	60 feet from eastern trim-line

The date of 290 years gives a minimum time period since the ice advanced beyond the eastern trim-line.

The ice-slide of 1938 may have destroyed very little vegetation in the Molar Creek valley. Photographs (Figures 2.18 and 2.19) suggest that the slide barely reached the present trim-line. Few broken trees are located along the edge of the slide debris and vegetation may merely have been covered by the slide. Trees, shown in the 1904 photograph

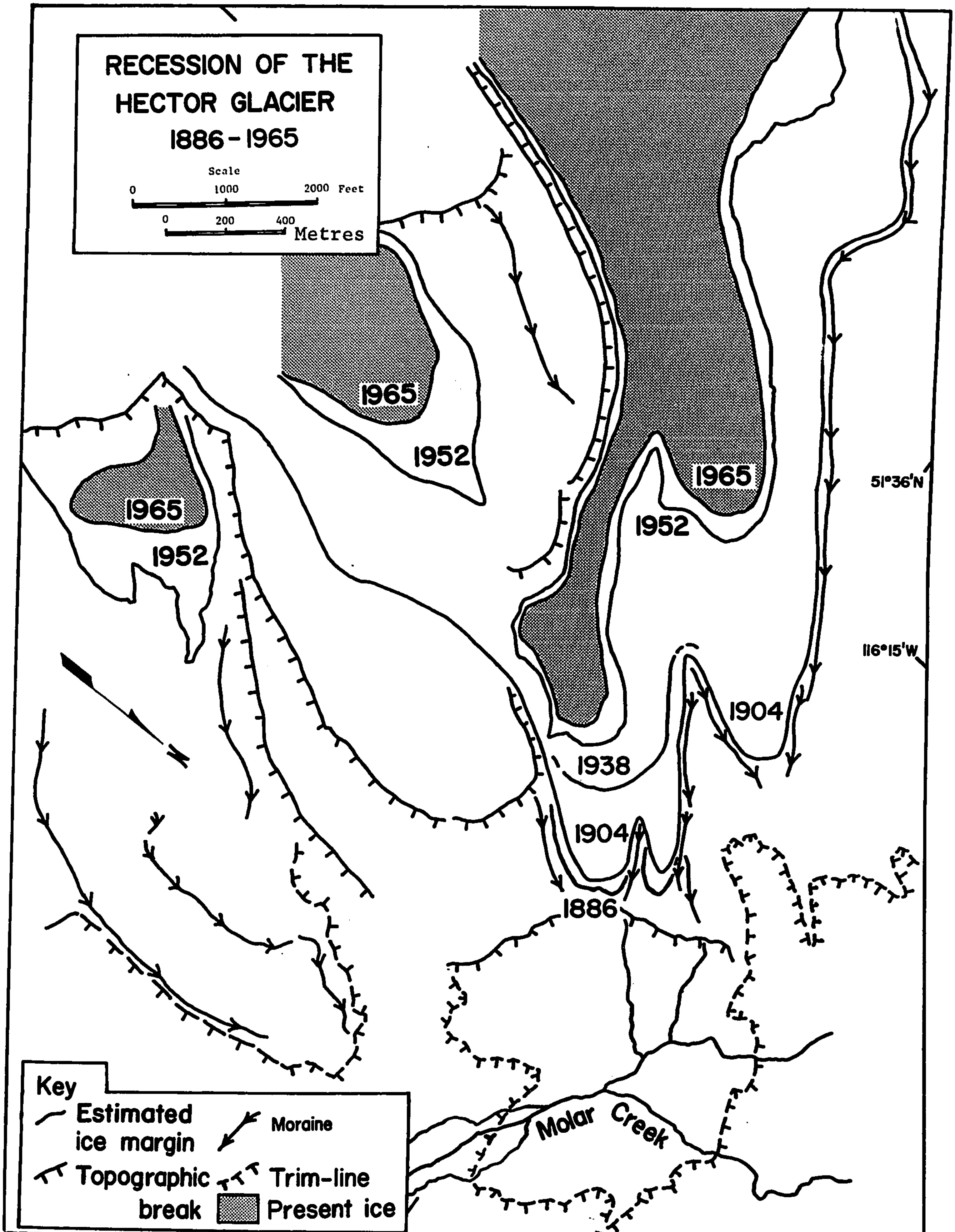
RECESSION OF THE
HECTOR GLACIER
1886-1965
Scale
0
1000
2000 Feet
0
200
400
Metres
1965
1952
1965
1952
1965
1952
1938
1904
1904
1886
51°36'N
116°15'W
Molar Creek
Key
Estimated ice margin
Moraine
Topographic break
Trim-line
Present ice

Figure 2.15

Figure 2.16

Molar Creek valley, showing trim-line below Hector Glacier.

Figure 2.17

Dead trees on the trim-line of the Hector Glacier in the Molar Creek valley.

Figure 2.18

Ice from the Hector Glacier slide, 1938. Note, absence of dead trees along ice margin.

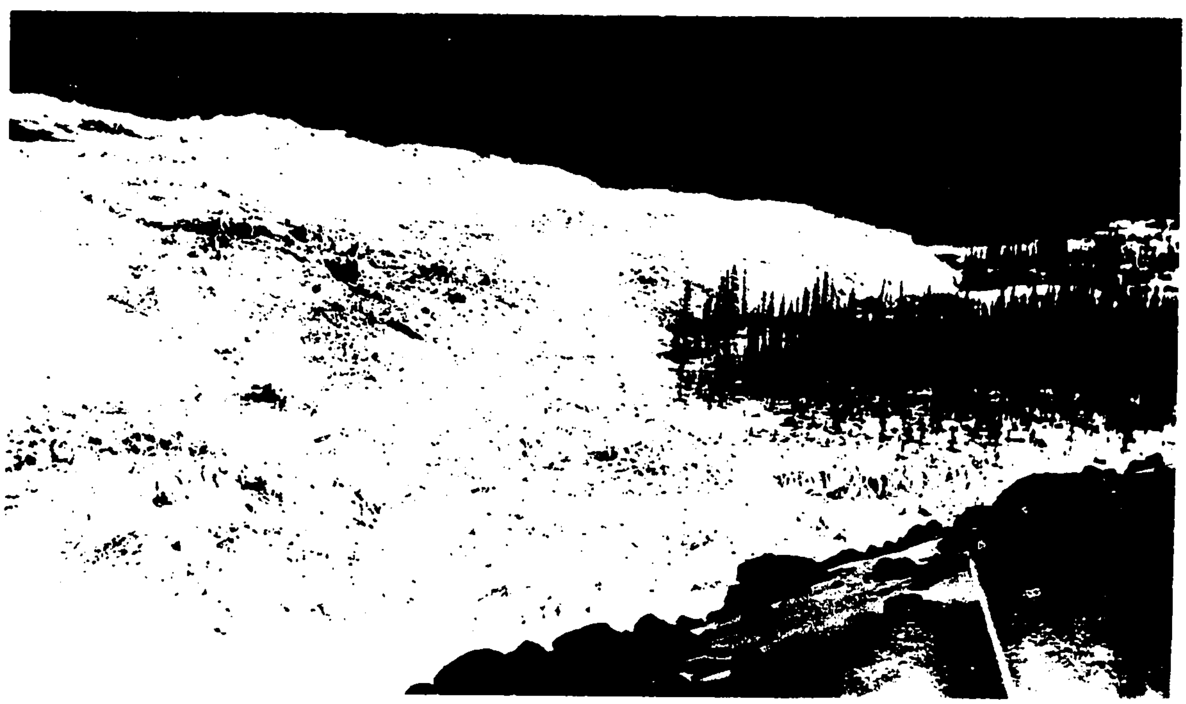

Figure 2.19

Ice from the Hector Glacier slide, 1938. Source of both photos, Topographical Survey of Canada. Finder, Robert Scace.

(Figure 2.11), must have been destroyed by the ice, as no trees are growing in the same locality today, twenty-seven years after.

3. Peyto Glacier

a. Photographic Record

The Peyto Glacier is situated at the head of the Mistaya River, a tributary of the North Saskatchewan River. The present Banff-Jasper Highway crosses the Bow Summit Pass on a route that has been important since the first explorations by white men. The number of observations of the Peyto Glacier is large, owing to its accessibility, and as a result a very accurate retreat pattern has been established.

The first accurate record of the Peyto Glacier is a photograph taken by W.D. Wilcox from a point near Bow Summit in 1897 (Figure 2.20). The tongue of the glacier is shown very clearly and its position can be accurately plotted.

In 1907, the Canadian Alpine Journal published a map (Scale, 1:50,000) based on a photo survey of the Peyto Glacier. Location of features and contour lines does not correspond to the 1952 Government map on the same scale. The position of the glacier margin is not considered accurate. An improved map, also based on a photographic survey, was published by the Interprovincial Boundary Commission Survey in 1917, at a scale of 1:62,500. The position of the glacier margin is considered to be reasonably accurate on this map.

The next known record of the glacier's position is dated as 1933 when Thorington photographed the ice on July 17. It was rephotographed twelve days later by Dickson and Vandenburg, who recorded 18.5 feet recession since Thorington's visit (Wheeler, 1933, p. 175 and 181). In 1936, Kingman re-photographed the terminus from his 1933 photo station. (McCoubrey, 1937, p. 113).

Figure 2.20

Peyto Glacier, 1897
Photo by W. D. Wilcox. Source, Geographical Journal, V. 13, 1899, p. 358-375.

In 1945, the Dominion Water and Power Bureau began a program of glacial termini measurements in the Gordillera of Alberta and B.C., including the Peyto Glacier. The measurements of recession from this source provide an accurate record of the glacier until the present. In this study selected positions of the Peyto Glacier have been plotted (Figure 2.21), although for only three dates since 1933. The 1917 position of the ice was estimated from the federal government map, the 1952 position from the provincial air photograph (160-5115X, 2426-112, Figure 2.22) and the 1965 position from photographs taken by the writer, of which Figure 2.23 is an example.

The recession data were combined for the purposes of this study and an average rate was found for the periods 1939-1952 and 1952-1965. The rates for these periods are almost identical on the Peyto Glacier, whereas during similar periods, the Drummond Glacier experienced a slight decrease in the rate of recession.

The data issued by the Dominion Water and Power Bureau for the period 1945-1958 have been revised, owing to a change to an improved method of calculating recession on the irregularly shaped tongue of the Peyto. Recession data for the glacier is expressed in Table 2.4.

Table 2.4

Recession of the Peyto Glacier, 1897-1965

Time Period	Frontal Recession in Feet (and Mètres) Total Amount		Annual Amount	
1897-1917	379	(115)	19	(5.7)
1917-1933	838	(255)	23	(7.0)
1933-1936	237	(69)	79	(23.0)
1936-1939	345	(90)	115	(30.0)
1939-1952	1498	(440)	134	(39.0)
1952-1965	1514	(445)	116	(34.1)

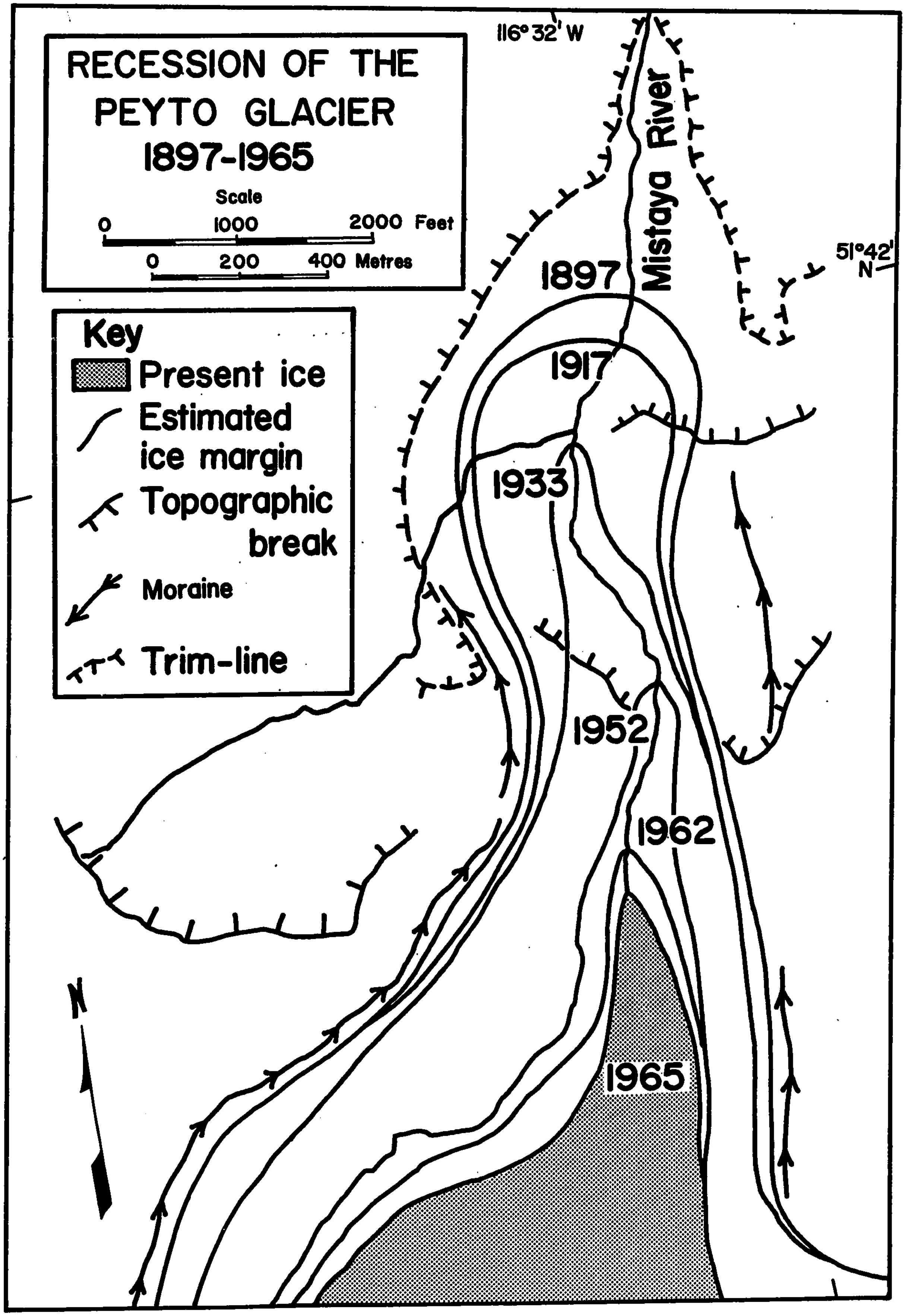
RECESSION OF THE
PEYTO GLACIER
1897-1965
Scale
0
1000
2000 Feet
0
200
400 Metres
Key
Present ice
Estimated
ice margin
Topographic
break
Moraine
Trim-line
116°32' W
51°42' N
Mistaya River
1897
1917
1933
1952
1962
1965
N

Figure 2.21

Figure 2.22

Peyto Glacier, 1952
(Part of air photograph No. 160-5116X, 2426-112 by kind permission of the Alberta Provincial Government, Dept. of Lands and Forests).

Figure 2.23

Peyto Glacier, 1965

The data of annual recession rate of Table 2.4 show that the Peyto Glacier has receded at an ever increasing rate up to the 1939-1952 period, since 1952 the recession rate has decreased.

In 1965, the Geographical Branch initiated a series of mass-balance studies on selected glaciers in western Canada (Østrem, 1965). The Peyto was one of the glaciers selected for study and in 1965, observations were made throughout the melt-season. The program of study did not include frontal recession measurements however, but the results obtained revealed that the glacier was almost in a state of equilibrium.

b. Recession estimates based on dendrochronological evidence

A clearly marked trim-line can be seen in spruce forest below the Peyto Glacier. Borings taken in trees on both east and west sides of the trim-line yielded ages of 247 and 190 years respectively. The glacier has therefore not advanced beyond the trim-line for a period of at least 247 years. This meagre dendrochronological evidence is verified by work done by Heusser (1956). He reconstructed the recession of a number of glaciers in the Canadian Rockies on the basis of age and amount of vegetation close to the ice termini. Heusser found evidence near the Peyto Glacier, to suggest an eighteenth and nineteenth century advance of the ice and he dated the trim-line forest as over three centuries in age.

Heusser found seven moraines near Peyto Glacier which are best developed on the west side of the valley (Figure 2.24). He dated spruce trees growing on all seven of the moraines and added a 12-year ecesis interval to the ages of the trees in order to date the year of formation of the moraines. Although he gave no reason for choosing a 12-year time period, Heusser felt sufficiently confident to give precise dates for the formation of the moraines.

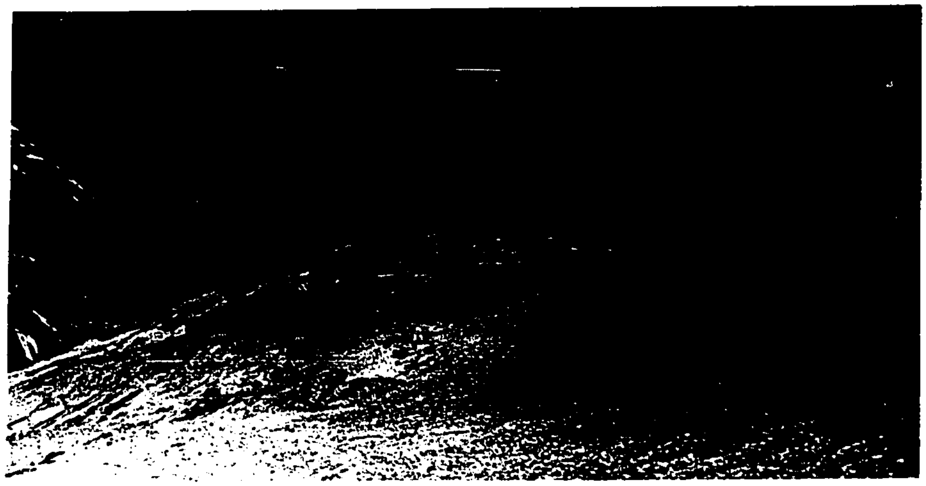

Figure 2.24

Small moraines (on left) in valley below Peyto Glacier.

Figure 2.25

Small moraine (#5 and #6, Appendix 1) below Peyto Glacier.

Such a period may be too short for establishment of forest vegetation. Areas near Peyto Glacier that have been ice-free for periods greater than 50-60 years, as shown in the 1897 photograph, are still devoid of vegetation. In addition, work in other areas indicates that a larger ecesis period may be more accurate. Near the Drummond Glacier, no forest vegetation has become established for a period of 80 years. Near the Hector Glacier, no forest vegetation has become established since 1938, a period of 27 years. Near to Yoho Glacier, in the Rockies of British Columbia, Bray and Struik drew the following conclusion from studying tree-growth patterns.

> Ecesis periods for six moraine surfaces range from 20 to 43 years with a median of 26 and a mean of 28. These results are similar to the findings of Mathers (1951) and Harrison (1956) and are divergent from those of Heusser (1956) of 10 years (?), lawrence (1958) of 5 years, Sigafoos and Hendricks (1961) of 5 years and Palmer and Miller (1961) of one year.
> (Bray and Struik, 1963, p. 1255-1256)

In 1965, the seven moraines found by Heusser were clearly visible although only limited vegetation, mainly small plants, grew on them. Photographs (Figures 2.25 and 2.26) show several of these small moraines on the west side of the valley. The surfaces are devoid of live vegetation or evidence of dead trees. Heusser's dates for formation of recessional moraines could not be checked in 1965 owing to the absence of any evidence of the trees he studied in 1953.[1]

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[1]Personal communication from C.J. Heusser, Dec. 20, 1965--"You might note that trees were found in association with the moraines under discussion. Of course, my work was done 12 years ago, and it is possible that we studied the only trees there and none has come in since then. But it would be hard to imagine that new seedlings had not established themselves in the interim." The failure of vegetation to make any headway at re-establishment since 1953, suggests that plant colonization conditions, possibly related mainly to climate or water supply, have deteriorated. Verification of this suggestion requires further study, however. Appendix 1 contains Heusser's field-map of the moraines near the Peyto Glacier.

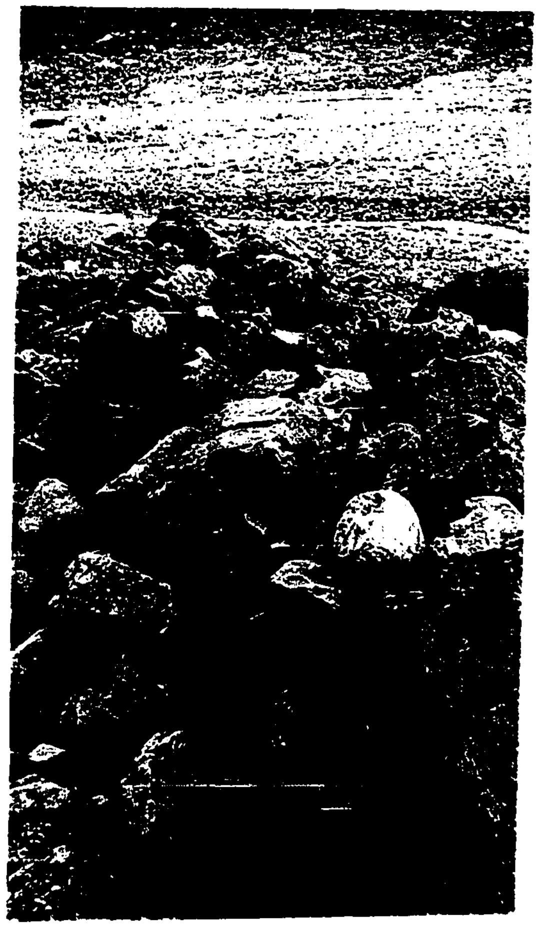


Figure 2.26

Small moraine (#7 in Appendix 1) below Peyto Glacier.

Comparison of Data From the Three Glaciers

If the recession data in Tables 2.1, 2.2 and 2.4 are compared, certain generalizations can be made for the recession patterns of the Drummond, Hector and Peyto Glaciers. The glaciers have all exhibited continuous recession in the period of record although the annual average recession has varied considerably. The pattern of recession has been similar on the Drummond and the Peyto Glaciers for almost the whole period; an increasing rate of recession until the 1930-1940 period was followed by a decrease to the present.

The Hector Glacier has had a decreasing rate of recession since 1938 (Table 2.2) and data prior to 1938 are so sparse that it is difficult to draw any concrete conclusions regarding its recession pattern.

The period 1904 to 1938 was one of marked variation in rates of recession in the Drummond Glacier and so the annual rate of 32.7 feet, for Hector should be regarded as a crude average. The figure is smaller than that for the succeeding period 1938-1952, when the Hector Glacier receded at an estimated 35.0 feet annually. However, it is possible that the first rate of 32.7 feet is a poor representation of the whole of 1904-1938 period. This is particularly the case if the recession rate of the Hector varied as much as that of the Drummond. The annual rate of recession for the 1930-1938 period may have greatly exceeded the estimated annual rate of 35.0 feet, for the following period, 1938-1952. If such were the case, the recession pattern as a whole would resemble that of the Drummond with the greatest recession in the 1930-1940 period.

There are a number of long-term records from other glaciers in the nearby area. Among the best known are those by Field and Heusser (1954), whose data are considerable and are derived from dating of moraines by botanical and other techniques, from photographs, and more recently from direct measurement of recession. Only records from the Saskatchewan and Freshfield Glaciers are discussed in this study, primarily because the time periods for which recession data are available for these two glaciers makes them most suitable for long-term comparison with the record of recession for the Drummond, Hector and Peyto Glaciers.

The data for the Saskatchewan and Freshfield Glaciers are compiled in Table 2.5. The retreat patterns of the glaciers in this study are generally similar to those recorded for the Saskatchewan and Freshfield Glaciers.

This similarity in pattern is not readily apparent for the Saskatchewan Glacier as the period 1924-1948 shows an average annual recession of 108 feet, whereas the period 1948-1964 shows a higher figure of 126 feet. However, the earlier period includes about six years of records (1924-1930) in which the rates of recession were probably closer to the average of 50 feet for the period, 1912-1924, than the average of 108 feet. In other words, the average annual rate of recession of the Saskatchewan Glacier is considered to have been appreciably higher during the period 1930-1939 than it was during the pre-1930 and post-1939 periods.

Table 2.5

Recession of Saskatchewan and Freshfield Glaciers

Time Period	Frontal Recession in Feet (and Metres) Total Amount		Annual Amount	
	Saskatchewan Glacier			
1893-1912	400	(122)	21	(6.5)
1912-1924	600	(184)*	50	(15.3)
1924-1948	2600	(80)	108	(32.5)
1948-1964	2026	(69)	126	(38.5)
	Freshfield Glacier			
1869-1902	1050	(321)	32	(9.8)
1902-1930	1508	(463)	54	(16.5)
1930-1953	2817	(862)	123	(37.5)
1952-1954	150	(46)	75	(23.0)

*Taken from Field (1949) using maximum recession figure.

The actual amounts of frontal recession vary considerably between the Drummond, Hector and Peyto Glaciers. The differences in recession may be due to several factors, such as altitude, amount of supra-glacial deposits, depth of ice, minor climate differences and aspect, i.e., direction in which the ice is flowing. The Drummond and Hector Glaciers are similar in the first four of these characteristics but differ with regard to aspect. This may explain why the Drummond Glacier, which flows south-east and is thus more exposed to insolation, has receded further than the north-east facing Hector. Similarly, the Peyto has receded much further than the other two glaciers, possibly as a result of its relatively low altitude. In addition, the Peyto Glacier has receded rapidly in certain recent years because of sudden collapse of the tongue in the confining gorge below the ice.[1]

Recent Measures of Glacier Recession and Vertical Ablation

Having discussed the relatively long-term pattern of recession for the three glaciers, this section deals with recent measurements of recession on the Drummond and Peyto Glaciers only.

1. Drummond Glacier

In recent years the recession of the Drummond Glacier has been measured from both frontal stakes and vertical stakes sunk into the ice. The lateral retreat of the glacier was first measured in 1962 and the next year frontal recession was measured along a line of five stakes. This line has been the basis for subsequent observations. The data for frontal recession are expressed in Table 2.6.

Table 2.6

Recent Frontal Recession of Drummond Glacier

Time Period	Average Annual Recession in Feet (and Metres)	
July 6, 1962 - August 3, 1963	68	(20.8)
July 23, 1963 - July 15, 1964	51	(17.0)
July 15, 1964 - July 14, 1965	27	(7.3)
July 14, 1965 - July 21, 1966	35.3	(10.8)

The vertical ablation of the glacier was first measured in 1963. On a line across the glacier approximately half a mile from the tongue, ten stakes were inserted to depths of about ten feet, and an aluminum tube, consisting of ten-foot sections and intended for ice-movement

[1]Personal communication with Mr. Campbell, Water Resources Branch, Federal Department of Northern Affairs and National Resources, Calgary, July, 1966.

studies, was also inserted into the glacier. These stakes, which required re-setting in 1964, four being inserted to depths of about thirty feet, have provided ablation measurements since 1963 and have been measured as often as practicable in each field season. Although a check was not possible during the summer of 1965, the resurveying in 1964 indicated glacial movement of about twenty-five feet during the period from early August, 1963, to early July, 1964. The results of ablation measurements on the stakes are expressed in Table 2.7.

Table 2.7

Vertical Ablation of Drummond Glacier

Time Period	Amounts of Ablation Inches	(cm.)
August 7, 1963-July 16, 1964	79	(200)
July 16, 1964-July 26, 1965	40	(101)
July 26, 1965-July 21, 1966	63	(160)

The 1962-1963 measurements were not very useful since the recession was measured at only one stake and overlaps part of the following recession period. The measurements for the 1963-1964, 1964-1965 and 1965-1966 periods were more reliable, being the average for five stakes located approximately parallel to the southern edge of the Drummond Glacier. The recession for 1963-1964 was considerably greater than that for the next year 1964-1965. However, the rate has increased significantly in 1965-1966 when 35.3 feet (10.8 metres) of recession were recorded. All the recent measurements from frontal stakes were smaller than the average rate of recession of 82 feet, estimated by the use of photos for the period 1952-1965 (Table 2.1).

The ablation for the latest melt-season, 1965-1966, shows a great increase over the previous year. In fact, the overall vertical measurements reflect the pattern of frontal recession; in this important sense the two sets of measurements reinforce one another.

Recent measurements are not available for the Hector Glacier because it was included in the Red Deer Project for the first time in 1965. For the Peyto Glacier, recent surveys by the Federal Water Resources Branch indicate a decrease in the annual recession rate from 1956 to 1962, from 255 feet (75 metres) to 80 feet (23.5 metres) a year.

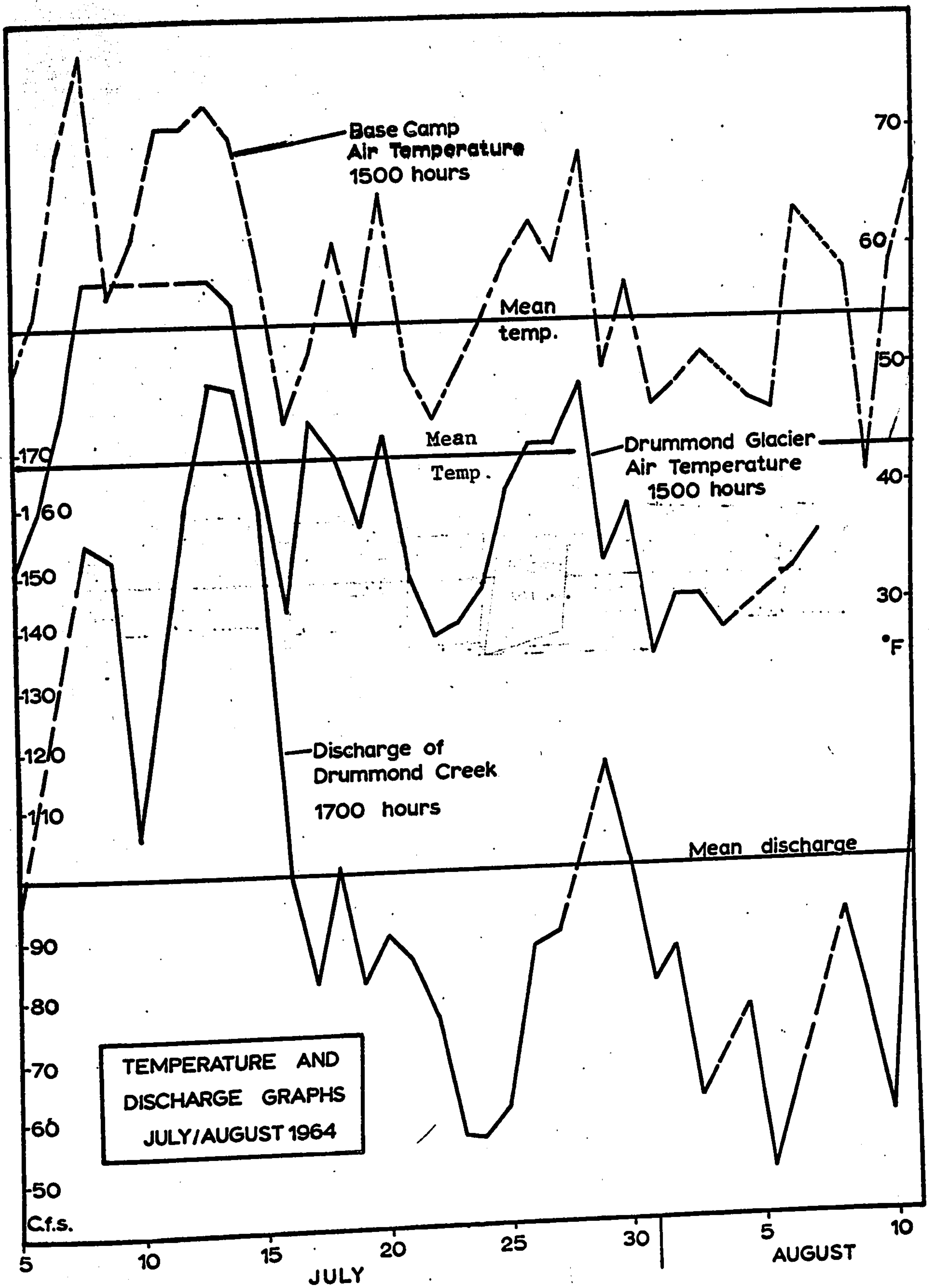
In addition to measurements on the Peyto Glacier, the Water Resources Branch, formerly the Water and Power Bureau, has surveyed the tongues of several other glaciers in the eastern Rockies since 1945. Unfortunately, only two of these surveys were continued until 1964 but these provide relatively precise data on the recession of the Saskatchewan and Athabasca Glaciers. The average rate of annual retreat on the Saskatchewan in the period 1960-1962 was 133 feet (41 metres), and in 1962-1964, 88 feet (27 metres). The Athabasca Glacier advanced 1.5 feet (0.46 metres) in 1960-1962, and in 1962-1964 receded at an annual rate of 56 feet (17 metres). In summary, the Drummond Glacier seems to be similar to the Saskatchewan and the Athabasca Glaciers in that the rate of recession has decreased in very recent years, the Athabasca actually advancing for one short period.

Correlation of Glacier Recession with Climate

During July and August, 1964, air temperature measurements were made in the valley below the Drummond Glacier and on the eastern tongue of the glacier itself, as part of the climatological programme of the Red Deer project. The temperatures were recorded with mercury thermometers and thermographs in screens set four feet above the ground and glacier surface. During the same period of 1964, discharge was measured in the Drummond Creek, approximately two miles from the glacier and just above the junction of the creek with the main Red Deer River. At this point the creek was predominantly glacial meltwater although a supply of other water formed a small and virtually constant portion of the discharge. Discharge was measured twice a day, at 800 and 1700 hours, using a Gurley current meter.

Data of air-temperature and stream-discharge show a strong positive correlation when plotted graphically (Figure 2.27). The two-hour time interval between the air-temperature measurements at 1500 hours, and discharge measurements at 1700 hours, may approximately equal the time taken for the stream at the point of measurement to register the effects of air-temperature on the rate of melting of the ice, two miles upstream. The correlation suggests increased melting is the direct result of higher air-temperatures.

This conclusion is relevant to a recent study of glacier fluctuation by Millett (1965), who investigated recession records for twenty-two glaciers in Prince William Sound, Alaska. Although only one of many such studies, Millett's work is of interest to this thesis because of his exhaustive attempts to correlate recession data with environmental factors such as climate and physiography. Millett first attempted to correlate glacier fluctuation with climatic conditions because he assumed climate was "the element that at first glance might be expected to hold the principal key to glacial behavior." (Millett, 1965, p. 241).



Base Camp
Air Temperature
1500 hours
Mean
temp.
Mean
Temp.
Drummond Glacier
Air Temperature
1500 hours
Discharge of
Drummond Creek
1700 hours
Mean discharge
TEMPERATURE AND
DISCHARGE GRAPHS
JULY/AUGUST 1964
170
160
150
140
130
120
110
90
80
70
60
50
C.f.s.
70
60
50
40
30
°F
5
10
15
20
25
30
JULY
5
10
AUGUST

Figure 2.27

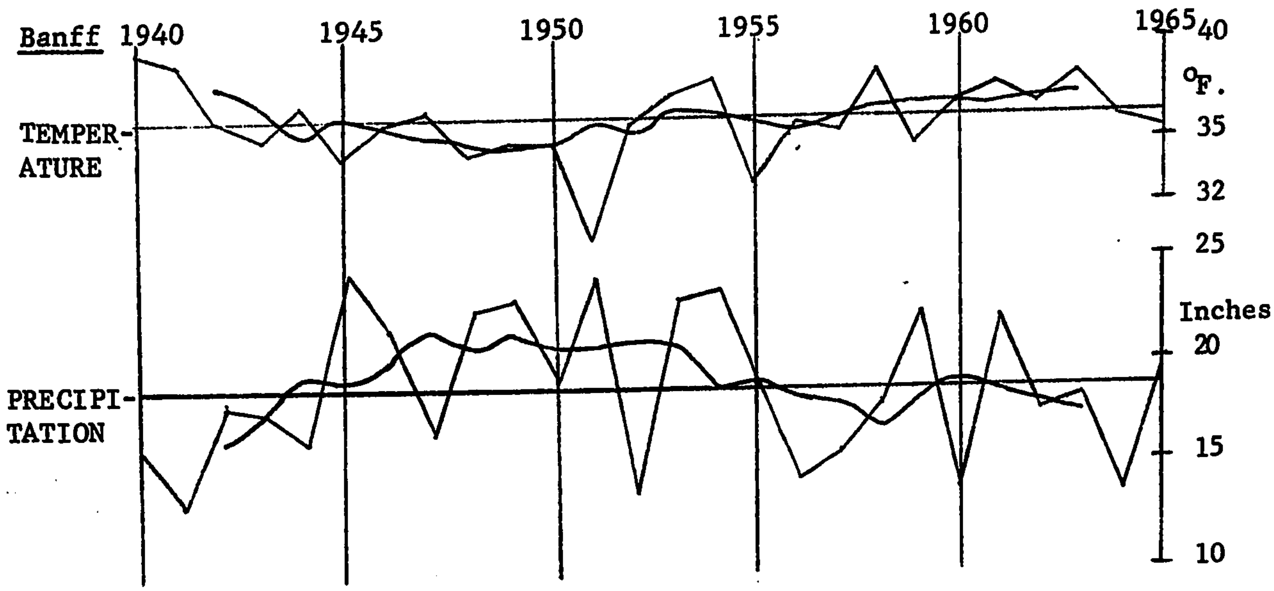
Millett assumed that favourable climatic conditions, i.e., increased precipitation with below normal temperatures, would result in glacial growth. The opposite effect, glacial recession, would result from decreased precipitation and above normal temperatures.

Millett used 10-year means of temperature and precipitation to show climate trends for two stations near the glaciers, but found little positive correlation with glacier fluctuations. He maintained that the time-lag in terminus response to climatic change, which was different for each glacier, was the main reason for the lack of correlation in his data.

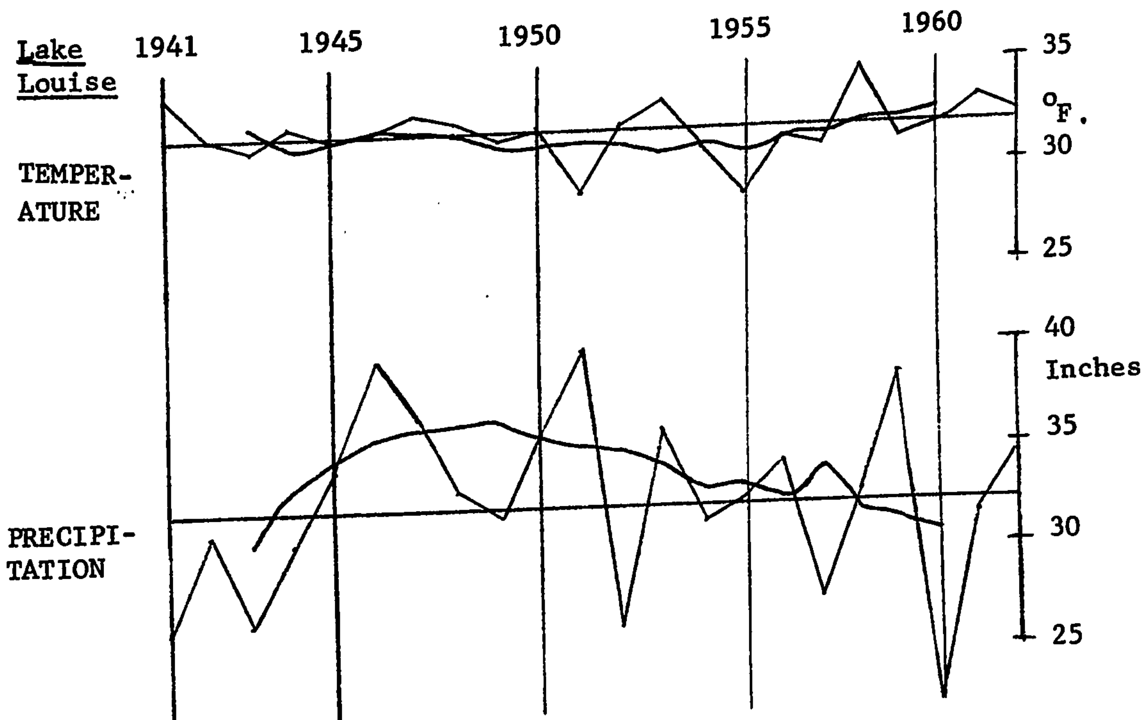
The factor of time-lag may be introduced more significantly into this study where five-year means of temperature and precipitation are used to show climatic trends for two stations, Banff and Lake Louise (Figure 2.28). Data are available only for the period since 1940 and only part of the glacier recession record can be considered for correlation. During the period 1940-1952, decreasing temperatures and increasing precipitation should have caused a glacial advance, or at least a reduction in recession rate. During the subsequent period, 1952-1965, increasing temperatures and decreasing precipitation should have caused increased glacial recession. The data of glacial recession are not as detailed as the climatic data and close correlation is impossible. However, the reduction in recession rate noted on the Drummond, Hector and Peyto Glaciers for the period 1952-1965 appears to be the response to the climatic conditions during the period 1940-1952. In this case the time-lag involved is approximately 10-15 years. The climatic conditions of the subsequent period 1952-1965, may cause increased glacial recession after a time-lag of a similar length. The 1965-1966 increase

Figure 2.28

AVERAGE ANNUAL TEMPERATURE AND ANNUAL PRECIPITATION
DATA FROM THE ROCKY MOUNTAIN STATIONS OF BANFF AND LAKE LOUISE



Key; Horizontal line - Mean for whole period.
Angular line - Actual annual data.
Curved line - Five-year running mean.



SOURCE OF DATA: Canada Department of Transport;
Meteorological Branch. 'Monthly Record'.

in recession on the Drummond Glacier is evidence that such a trend may have started.

The data of glacier recession in this study show a crude positive correlation with climatic records for the area if a time-lag of 10-15 years is assumed in terminus response to climate. This assumption is supported partly by Collier (1957) who concluded that about 20 years time-lag occurred in terminus response to climate in the eastern Rockies.

CHAPTER III

MAPPING AND DISTRIBUTION OF DEPOSITS

The deposits near the three glaciers were mapped on a preliminary basis from enlargements of Alberta Government air-photographs (Figures 2.6, 13 and 22) and mapping was completed by field-investigation (Figures 3.5, 3.12 and 3.16). In 1964, Marvin Sundstrom did much of the mapping of deposits near the eastern tongue of the Drummond Glacier. The writer completed the task and extended the investigation to the other glaciers in 1965.

In selecting a mapping classification for deposits both genetic and descriptive types were considered. However, many commonly-used terms in geomorphology having a genetic basis are so defined that they cannot be confidently used for field-mapping. Sitwell, who protested at the currency of certain geomorphological terms, commented on his study of two prominent workers as follows:

> Both writers use genetic classification but are quite happy to use them descriptively, cheerfully labelling activities which they admit are not understood for the sake of having a complete picture of the processes at work in nature.
> (Sitwell, 1962, p. 47)

The terms used in mapping deposits in this study are both descriptive and genetic. In the field,deposits were distinguished on the basis of texture, structure, form and field relationships. The terms used in mapping were not made purely descriptive because they became too general to be meaningful, as with the category "unsorted deposits." The characteristics of form and field relations were used in conjunction with texture and structure as a basis for distinguishing the genesis of deposits. As a result the term "unsorted deposit" was divided into the categories of "unsorted glacial deposit" and "unsorted mass-wastage deposit." The term "unsorted glacial deposit" was preferred to that of "till" because it did not prejudice interpretation of the mode of origin of these deposits to the same degree as "till." However the validity of certain descriptive-genetic terms was found to be questionable after mapping and interpretation had been completed. This problem will be dealt with further in the conclusion to this chapter.

Deposits and associated surface features were mapped under six categories: (1) Bedrock, (2) Vegetated area, (3) Unsorted mass-wastage deposit, (4) Unsorted glacial deposit, (5) Water-worked deposit, and (6) Thin unsorted glacial deposit.

1. Bedrock was mapped in areas where superficial deposits including the products of mass-wastage were virtually absent.

2. Vegetated areas are located entirely beyond the limit of recent glaciation because little vegetation has invaded recently deglaciated areas. The vegetation changes from forest to lichens and mosses at higher altitudes, generally nearer the glacier. One area of smaller plant species near the Drummond Glacier was termed the "driftless area" (Brunger, Nelson and Ashwell, 1965) and merits detailed description.

The driftless area is free of glacial deposits despite its proximity to the Drummond Glacier and the fact that the glacial deposits almost completely surround it. The limestone bedrock that characterizes much of the driftless area displays virtually no sign of the polishing or plucking observed widely in nearby recently-glaciated areas; rather, the surface of the driftless area is marked by angular debris and by low vegetation (Figure 3.1). The driftless area appears to have been ice-free during the recent glacial maximum, although its proximity to the ice and the presence of a reddish-coloured limestone

Figure 3.1

Soil-Creep Terracettes Formed on a Vegetated Slope in the Driftless Area

Figure 3.2

Unsorted Glacial Deposits near Drummond Glacier boulder quite unlike the underlying grey limestone, and therefore a possible erratic, suggest the area may have been formerly glaciated. The area merits further research into aspects of its geomorphic and biotic development.

3. Unsorted mass-wastage deposit. A category of deposit that consists of a heterogeneous mixture of angular rock fragments apparently formed as a result of material moving downslope under the influence of gravity. The finer material in such deposits may be the product of weathering of the mass-wastage deposit itself, or material deposited by small streams flowing over and through the deposits (Figure 3.2).

4. Unsorted glacial deposit. This deposit is very similar to "unsorted mass-wastage deposit" in texture and structure, being a heterogeneous mixture of angular rock fragments. This material has been in contact with the glacier and was distinguished from mass-wastage material on the basis of form, e.g. moraine, and field relations, as such deposits occur entirely within the area of recent glaciation. The limit of recent glaciation is usually marked by a moraine or trim-line. The early photographs show the glaciers near their maximum extent covering most of the recently glaciated area, including the unsorted glacial deposits.

5. Thin unsorted glacial deposit forms a discontinuous veneer over much of the area near the glaciers (Figure 3.3). The material is heterogeneous and non-sorted; in some cases it is merely widely scattered boulders upon a bedrock surface.

6. Water-worked deposit is relatively well-sorted with regard to grain-size and pebbles are usually well-rounded. This material is frequently imbricated, indicating that pebbles and boulders were moved by stream-action (Fahnestock, 1963, p. A56).

Figure 3.3

Thin unsorted glacial deposits near Drummond Glacier

Figure 3.4

Melt-water channels near Drummond Glacier

In addition to the six categories of deposit, three types of topographic features were mapped near the glaciers.

1. Moraine. This feature is a ridge-like accumulation of unsorted glacial debris and includes the features of "lateral, recessional and terminal moraines" as defined by Flint (1957).[1]

2. Bedrock Cliff. This is an abrupt topographic break in bedrock which is usually undergoing weathering and erosion and may have unsorted mass-wastage deposits at its base.

3. Melt-water channel has a varying width and depth, and was considered to have been eroded by glacial melt-water into glacial deposits or bedrock. Such a channel may have a curved plan, similar to that of the present ice-margin, and may have been eroded by a stream flowing along the former ice-margin. Several channels are being actively eroded by melt-water streams near the Drummond Glacier (Figure 3.4), although most of the channels are dry at present.

The deposits mapped near the glaciers will now be described in order to provide a basis for comparison between the different areas and to emphasize significant features of their distribution. Description will be followed by interpretation of deposits as to their origin.

Description of Deposits Near the Glaciers

1. Drummond Glacier

Unsorted glacial deposits (Figure 3.5) predominate near the

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[1] Flint defined these features in the following way: "A terminal moraine is an end moraine built along the downstream or terminal margin of a glacier lobe occupying a valley. A lateral moraine is an end moraine built along the lateral margin of any glacier lobe occupying a valley. Ideally a lateral moraine grades into a terminal moraine." (Flint, 1957, p. 131) The terms lateral and terminal moraine, as used by Flint, are imprecise. Flint used, in addition, the term "end moraine," which included both lateral and terminal moraine in its definition.

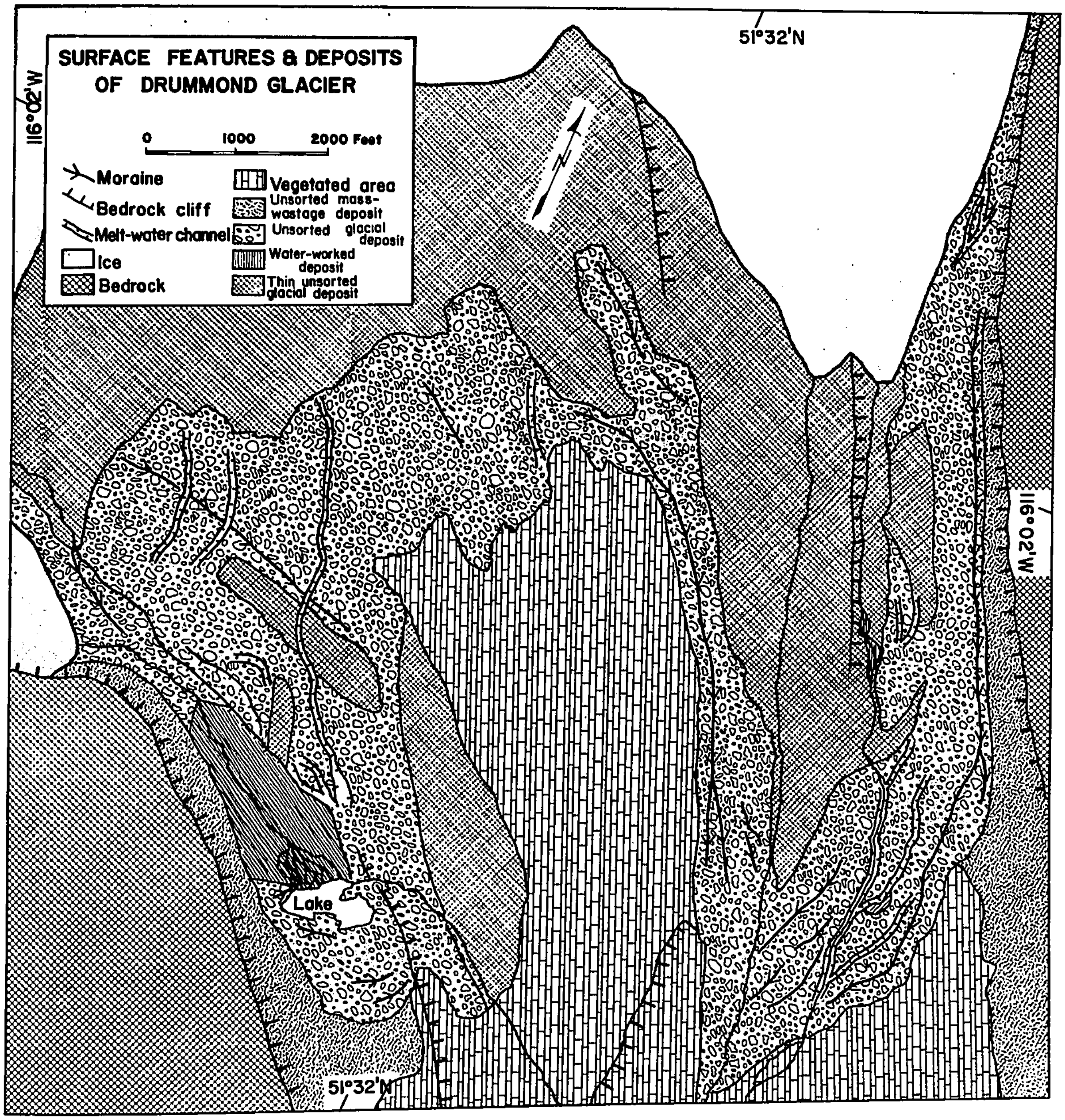

SURFACE FEATURES & DEPOSITS
OF DRUMMOND GLACIER
0
1000
2000 Feet
Moraine
Bedrock cliff
Melt-water channel
Ice
Bedrock
Vegetated area
Unsorted mass-wastage deposit
Unsorted glacial deposit
Water-worked deposit
Thin unsorted glacial deposit
51°32'N
116°02'W
116°02'W
51°32'N
Lake

Figure 3.5

glaciers. In general these deposits appear to have been formed during the maximum extent of the ice in recent times. Comparison of the recession and deposit maps for the Drummond Glacier shows that very little unsorted glacial deposit has been laid down by the receding glacier since about 1906. Unsorted glacial deposits form a large moraine near the eastern tongue of the ice and smaller, less continuous moraines are formed in other areas.

Much of the area near the Drummond Glacier is formed of bedrock mantled by thin,unsorted glacial deposits, although near the western tongue both unsorted glacial deposits and water-worked deposits are found. The western tongue of the Drummond Glacier consists of steeply-sloping ice descending a cliff. A mass of stagnant ice is located at the foot of the cliff on the inside edge of a broad bench (Figure 3.6).

The stagnant ice is covered by a thin mantle of debris derived by mass-wastage from the cliff above. Several large, angular boulders are included in the debris along the margin of the stagnant ice (Figure 3.7). Near this margin, and approximately parallel to it are several discontinuous lines or "zones",of large boulders (Figure 3.8 and 3.9). The rocks forming these lines, or "zones", bear no evidence of glacial or fluvial transport in the form of rounding or striations; the rock lines are therefore considered to have formed by mass-wastage processes similar to those operating on the stagnant ice at present, and to mark former positions of the ice-margin. The process involved in the deposition of these boulders will be referred to again in the section on interpretation of deposits.

Water-worked deposits only occur extensively near the western

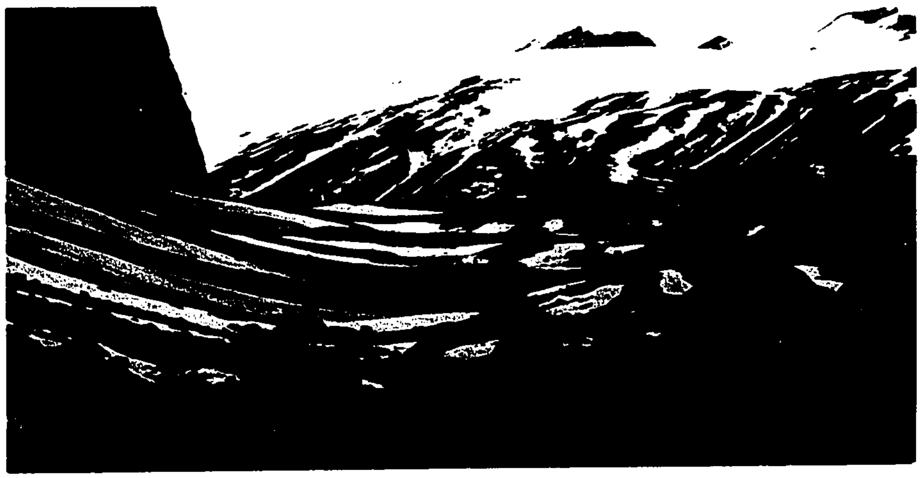


Figure 3.6

Bench Below Cliff Near the Western Tongue of Drummond Glacier

Figure 3.7

Unsorted Mass-wastage Deposits on top of and Bordering Stagnant Ice on the Inside of the Bench (Fig. 3.6) Near Western Tongue of Drummond Glacier

Figure 3.8

Lines, or 'Zones' of Boulders Resulting from Mass-wastage Action over Stagnant ice on Bench Near Western Tongue of Drummond Glacier.

Figure 3.9

Line or 'Zone' of Boulders on Bench Near Western Tongue of Drummond Glacier tongue of the Drummond Glacier (Figure 3.10). However, extensive gravel flats of water-worked deposits occur in the valley approximately two miles from the Drummond Glacier. Measurements of bank erosion, utilizing fixed stake lines (Figure 3.11), and pebble transport, utilizing painted boulders of variable sizes, have been made in the stream on the gravel flats as part of the Red Deer project. During a 6-8 week period in 1963, the maximum bank erosion recorded was 0.9 feet, in 1964, 4.6 feet and in 1965, 12.7 feet, suggesting that the stream is changing its course fairly rapidly. A comparison of Dawson's 1884 photograph with that of 1964 reveals that the gravel flats in the foreground are much wider in the later view. The stream has migrated across the valley and eroded the material underlying the grassed slope in the right foreground of the 1884 photograph. The stream thus appears to have migrated across the gravel flats at least once during the last 80 years.

Bank erosion and pebble transport measurements indicate that material is being both transported downstream and across the flats as the stream migrates from side to side. These observations show that contemporary processes are of importance in re-working glacial material to form present-day fluvial deposits.

2. Hector Glacier

Unsorted glacial deposits are located (Figure 3.12) near the limit of recent glaciation and form large moraines near the glacier. Comparison of the recession and deposit maps indicate that most of the unsorted glacial deposits were formed during the maximum advance of the glacier and the receding ice has deposited little material since about 1904.

Unsorted glacial deposits occur in the Molar Creek valley,

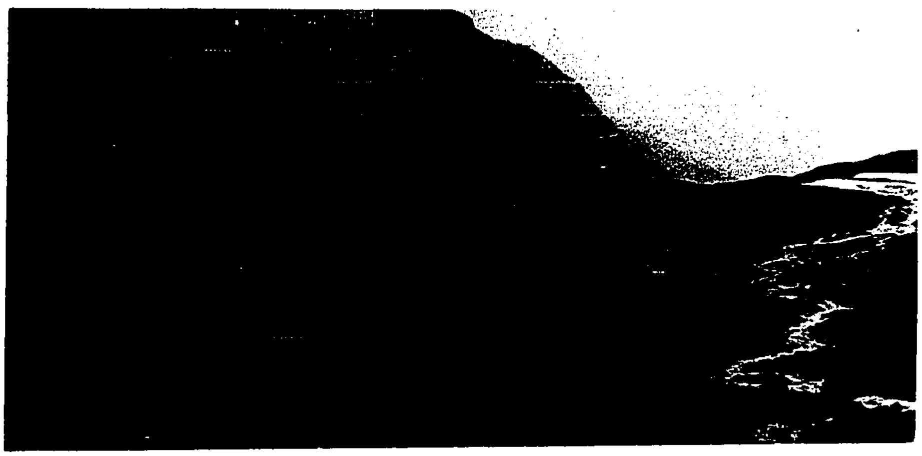


Figure 3.10

Stream-eroded Unsorted Glacial Deposits (left and foreground) and Water-worked Deposits (right) Near the Western Tongue of Drummond Glacier.

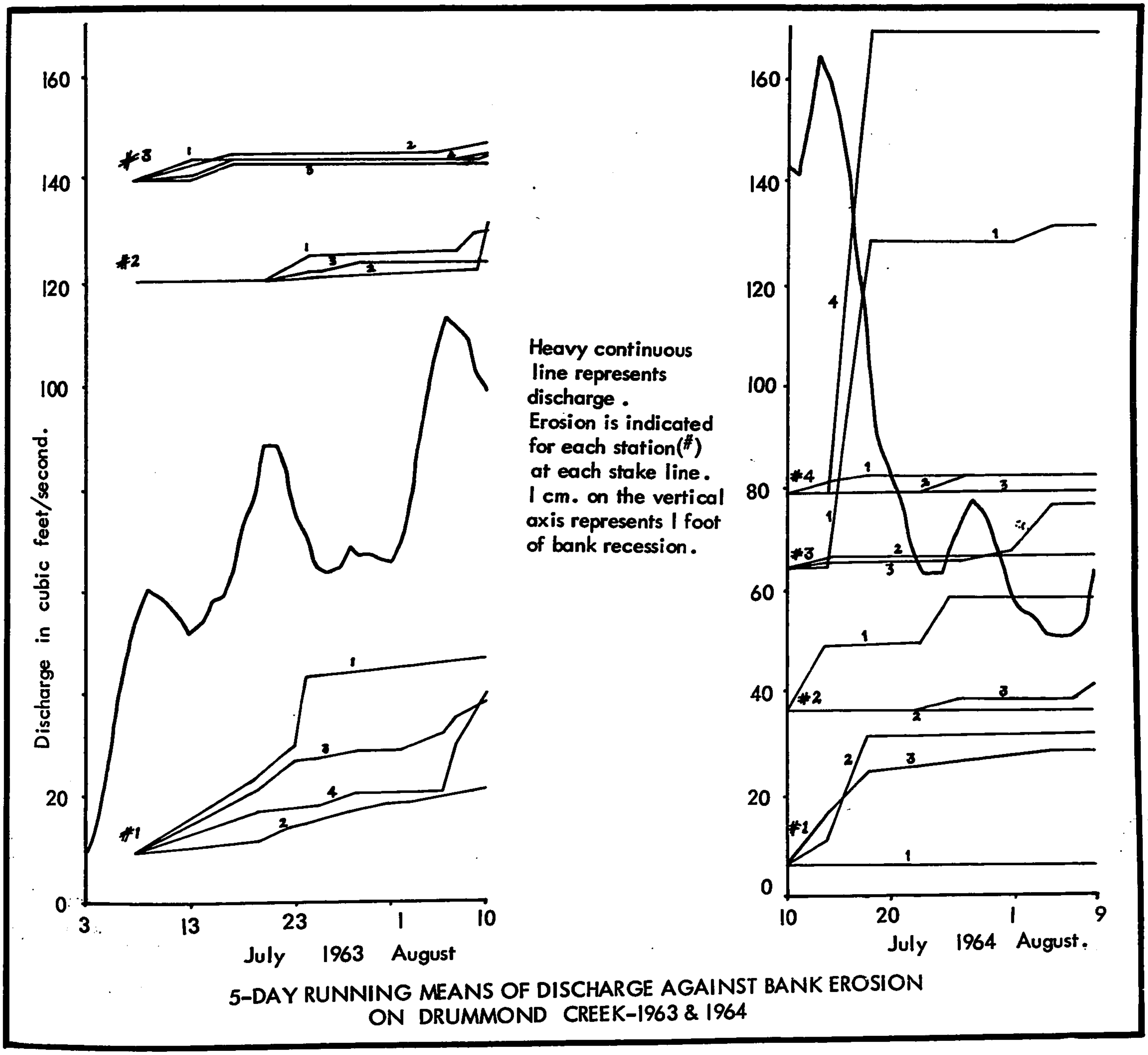

Discharge in cubic feet/second.
160
140
120
100
80
60
40
20
0
#3
#2
#1
#4
3
13
23
1
10
July 1963 August
10
20
1
9
July 1964 August.
Heavy continuous line represents discharge.
Erosion is indicated for each station(#) at each stake line.
1 cm. on the vertical axis represents 1 foot of bank recession.
5-DAY RUNNING MEANS OF DISCHARGE AGAINST BANK EROSION ON DRUMMOND CREEK-1963 & 1964

Figure 3.11

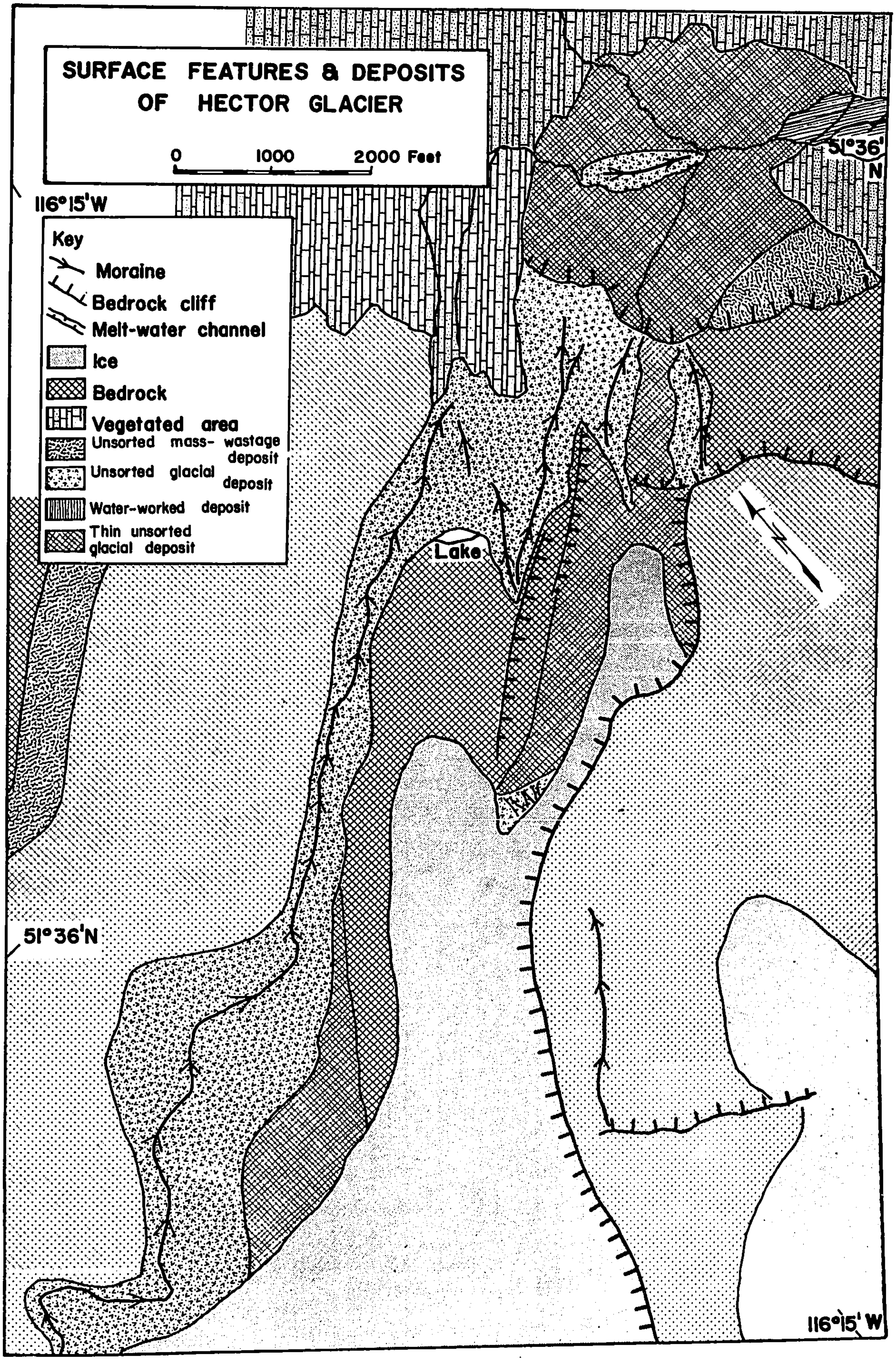

SURFACE FEATURES & DEPOSITS
OF HECTOR GLACIER
0
1000
2000 Feet
116°15'W
51°36'N
116°15'W
51°36' N
Key
Moraine
Bedrock cliff
Melt-water channel
Ice
Bedrock
Vegetated area
Unsorted mass- wastage deposit
Unsorted glacial deposit
Water-worked deposit
Thin unsorted glacial deposit
Lake

Figure 3.12

northeast of the Hector Glacier. The northern part of these deposits is relatively thin (Figure 3.13) although their depth increases towards the ice. A single small moraine is located on the south side of Molar Creek, in the center of the area of unsorted glacial deposits (Figure 3.14). The edge of the deposits is marked by a trim-line with no evidence of a moraine like that found nearer the Hector Glacier. The orientation of the moraines found near the ice, in a general north-east to south-west direction, suggests that the Hector Glacier advanced north-eastwards over a 150-feet high cliff (Figure 3.15) into the Molar Creek valley. Unsorted debris piled against the cliff resulted from either deposition by the glacier or mass-wastage. Subsequently the glacier appears to have advanced into the former forest, clearing it and creating a trim-line at the position of maximum advance.

The ice-slide, which occurred in 1938 on the Hector Glacier, descended into the Molar Creek valley (Figure 2.18). Comparison of the 1904, 1938 and 1965 photographs indicates that the slide remained within the area bounded by the forest trim-line. The ice-slide appears to have had little effect on the topography of the valley although the small moraine near Molar Creek may have been lowered by it.

Extensive gravel flats occur at the downstream end of the area of unsorted glacial deposits in the Molar Creek valley. The gravel flats, which were mapped as water-worked deposits,have a maximum width of 200 feet and are braided for most of their length.

3. Peyto Glacier

Unsorted glacial deposits are located near the limit of recent glaciation (Figure 3.16), and these form large moraines on both eastern and western sides of the ice. In addition, seven small moraines which

Figure 3.13

Northern Part of Thin Unsorted Glacial Deposits in Molar Creek Valley

Figure 3.14

Low Moraine Near Molar Creek on Unsorted Glacial Deposits

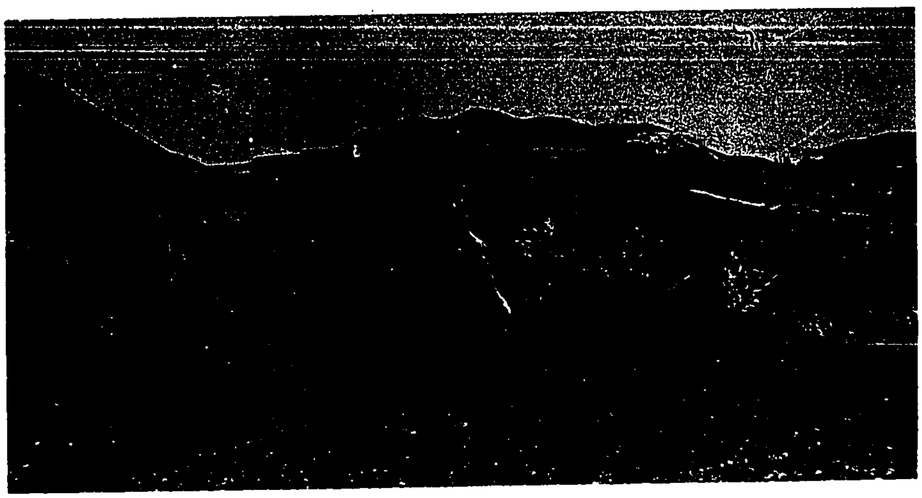


Figure 3.15

Cliff on the North Side of Molar Creek valley below Hector Glacier, showing unsorted glacial deposits banked up against it.

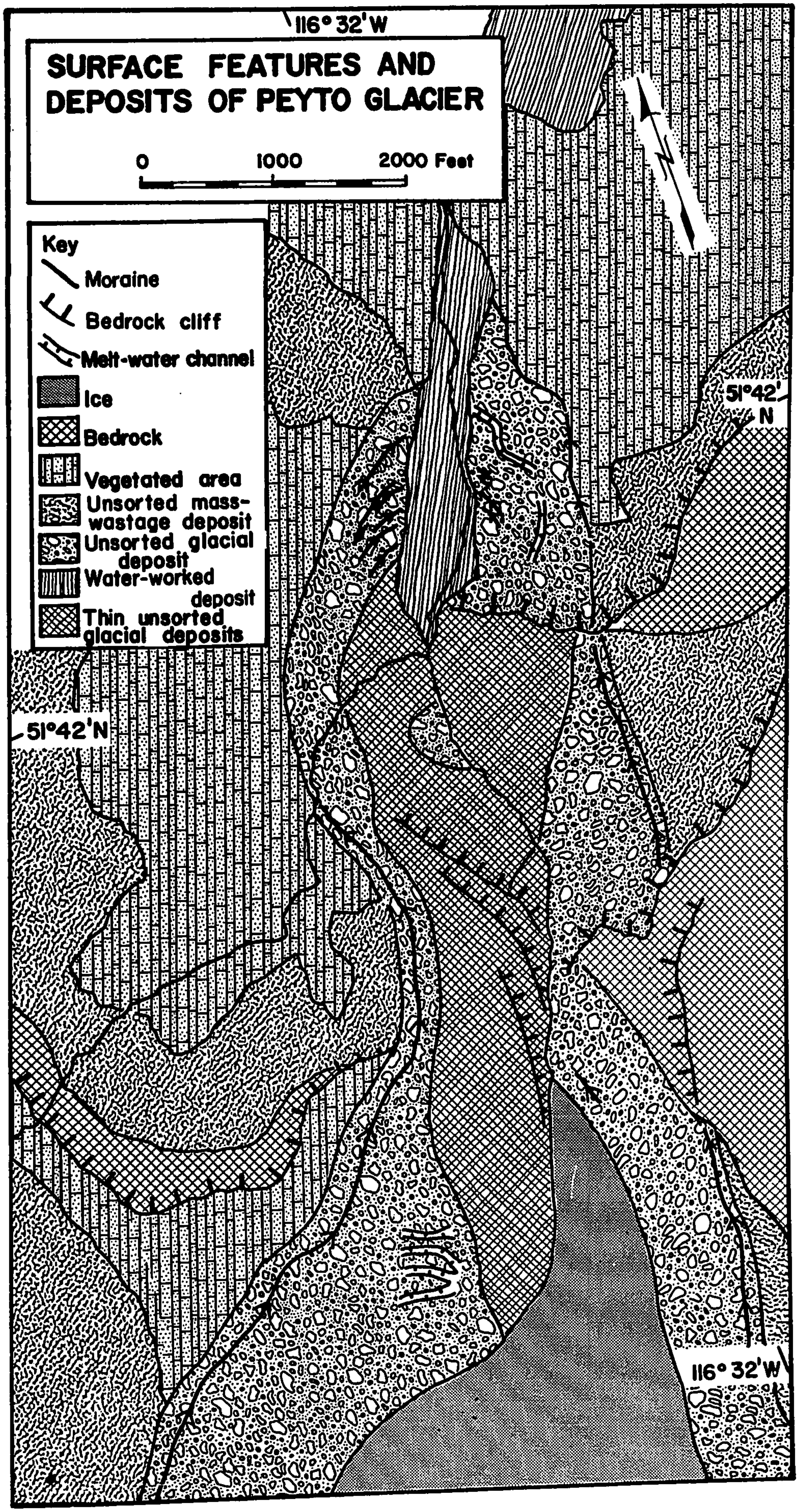

116° 32'W
SURFACE FEATURES AND DEPOSITS OF PEYTO GLACIER
0
1000
2000 Feet
Key
Moraine
Bedrock cliff
Melt-water channel
Ice
Bedrock
Vegetated area
Unsorted mass-wastage deposit
Unsorted glacial deposit
Water-worked deposit
Thin unsorted glacial deposits
51°42'N
51°42' N
116° 32'W

Figure 3.16

were mapped by Heusser (1956) are located approximately 7000-8000 feet from the glacier (Figure 2.24 and Appendix 1). Nearer the Peyto Glacier, unsorted deposits form a thin veneer on the bedrock surface. On the eastern side of the glacier large masses of ice underlie the thin unsorted deposits (Figure 3.17 and 3.18).

In the northern part of the recently-glaciated area, extensive water-worked deposits form gravel flats. The main stream appears to be migrating from side to side and eroding unsorted glacial deposits as it does so.

Interpretation of Deposits Around the Glaciers

The main period of deposition by each of the three glaciers appears to have coincided with the maximum advance of the ice-sheets in recent times. The glaciers have been receding for the past 80 years, at least, and little deposition has occurred in this period. The pattern and distribution of deposits is roughly similar near all three glaciers.

Unsorted glacial deposits

These deposits form large moraines near all three glaciers and, in addition, form generally level, undulating or stream-dissected topography. Large moraines rarely completely encircle the glacier tongue but rather tend to occur laterally. In the case of the Hector and Peyto Glaciers, moraines are discontinuous and in the valley furthest from the glacier, a trim-line marks the limit of glacial advance. The slopes surrounding the trim-line are forested and free from extensive deposits of unsorted mass-wastage origin. The absence of such rock debris may also reflect the lack of a supply of material moving down onto the ice, thus accounting for the absence of large moraines and extensive unsorted glacial deposits in these areas.

Figure 3.17

Unsorted Debris Overlying Ice on the East side of Peyto Glacier with a Karst-like Sink-hole in the ice.

Figure 3.18

Unsorted Deposits on the Tongue of the Peyto Glacier.

This idea is further supported by the evidence from the Drummond Glacier area, where large moraines almost completely encircle the ice. The Drummond Glacier did not advance into an area with forested slopes and did not form a trim-line. In addition, large unsorted mass-wastage deposits at the base of the cliff on the east side of the Drummond Glacier, may have easily been removed by the advancing ice and re-deposited elsewhere.

The problem of the origin of the moraines and the unsorted glacial deposits forming them may be explained in several ways. The source of the debris may have been either bedrock or unsorted mass-wastage deposit eroded by the glacier, the debris then being transported by the ice from its source to its present position over a varying distance. Mass-wastage seems to be a definite source of supply in the case of moraines such as those on the eastern side of the Drummond and Hector Glaciers, located adjacent to cliffs actively undergoing mass-wastage. Here mass-wastage deposits appear to have been merely piled upon or against the glacier, presumably with a minimum of pushing of debris by the glacier.

A more serious problem exists in the explanation of moraines such as those to the west of the Drummond and Hector Glaciers, which are located far from cliffs or mass-wastage deposits. Furthermore, no deposits cover the ice to suggest transport of mass-wastage deposits across the glacier surface. Erosion of both bedrock and mass-wastage deposits by ice and transport of debris by the glacier over a considerable distance seem to be important in explaining these deposits.

The use of fabric measurement is a possible means of identifying the transporting and depositing agency. Results of fabric studies will be related to the origin of the moraines and unsorted glacial deposits, in general, in the next chapter.

One other point in connection with moraines concerns several ridges of unsorted material in the valley below the Drummond Glacier noted in a preliminary report of the Red Deer project as follows:

> At two locations the stream channel is restricted to small gorges which cut through bedrock and rolling irregular ridges that are believed to be old recessional moraines.
> (Gardner, Nelson & Ashwell, 1963, p. 139)

However, these ridges actually may not have formed through pauses in ice retreat and so mark former end positions of the ice margin as the term recessional moraine implies. Rather they may have formed in a similar way to the lines or "zones" of debris below the cliff near the western tongue of the Drummond Glacier, which was described earlier in this chapter. They appear to have formed when the entire lower portion of the cliff was covered by ice, so that mass-wastage onto and over the ice carried debris well out into the Drummond Valley.

Thin unsorted glacial deposits

These deposits are generally found in areas nearest the three glaciers, between the ice and unsorted glacial deposits. Such deposits appear to have been derived largely from the wastage of the glacier and are evidence of the small load carried by the ice.

Water-worked deposits

These may be either;

1. transported from the glacier itself by melt streams,
2. unsorted glacial or mass-wastage deposits which have been sorted and re-deposited by streams,

or, 3. formed by a combination of the two processes.

The small amount of debris in the glaciers has already been noted and very little material is carried from the ice. As the maps (Figures

3.1, 2 and 3) indicate, relatively little water-worked material has been mapped near the glaciers. That which was observed can be correlated with steep banks and other signs of erosion in nearby unsorted deposits. These observations and other studies in unsorted deposits near water-worked material in the lower Drummond Valley all suggest that the water-worked deposits are largely the result of the second hypothesis stated above.

Final Remarks on Terminology

At the outset, the problem of selecting terminology conducive to interpreting, rather than prejudicing, the origin of deposits was briefly discussed. Despite these precautions, the terminology used in this thesis presents some difficulties.

The term "unsorted glacial deposits" was used because it depended upon both descriptive and genetic characteristics and was considered to be an improvement over a widely-accepted, genetic term such as "till," in interpreting deposits for their mode of origin. The term "unsorted glacial deposit" has proved to be far from ideal, however, as the material it describes may owe very little to the glacier in its formation. Most of these deposits appear to be largely mass-wastage debris that may have come to rest against the ice. The glacier may have been no more than a platform for most of the deposits. On the other hand, the moraines of unsorted glacial material situated far from mass-wastage slopes appear to have been transported some distance by ice. Thus the unsorted glacial deposits vary from area to area in the degree to which they have been affected by the ice. The term "unsorted glacial deposits" is a generalization that presumably may be improved upon as processes of glacial deposition are better understood.

CHAPTER IV

FABRIC ANALYSIS OF GLACIAL DEPOSITS

Fabric studies have been used increasingly in recent years as a means for interpreting the character of depositional forces. Potter and Pettijohn (1963) have made a comprehensive review of the field of fabric analysis. Johansson (1965) has collected the results of many fabric studies and has discussed methods of fabric interpretation as they reveal the processes involved in formation of the deposit.

Potter and Pettijohn maintain that the fabric of a sedimentary deposit refers to the spatial arrangement and orientation of fabric elements. These workers describe fabric elements as spheres, discs or rods, even though the actual shapes of most elements only approximate those three forms. Although preferred orientation cannot be measured in a perfectly spherical pebble, they include such pebbles because of the possible importance of packing arrangements. The most commonly used fabric elements are the so-called disc-and rod-like pebbles. The orientation and dip of these pebble types is found by measuring the azimuth and angle of slope of the 'a', or long axis, of the pebble. By measuring the orientation and dip of constituent pebbles, or smaller particles, in a deposit, preferred direction may be discovered in the deposit. Potter and Pettijohn attribute preferred direction of orientation and dip in sedimentary deposits to such factors as gravity and current flow, either in water, air or ice.

In his survey of fabric study, Johansson concluded that in general relatively little of value had been derived from a large number of studies. For example, in his study of fabric research in moraine deposits he concluded:

> The survey of the literature shows that the particle orientation in moraines is affected by a great many factors. The dynamics are more difficult to explain, for example, in running water. In spite of the many investigations the fabric conditions cannot yet be regarded as having been definitely clarified.
> (Johansson, 1965, p. 28-29).

Method of Fabric Measurement

The field technique used for measuring fabric was relatively simple, compared to that of other workers, e.g. Wadell (1936), Krumbein and Pettijohn (1938), Krumbein (1939) and Harrison (1957). The technique is similar to that used by Andrews (1963) in that its objective is to measure orientation and dip of only the long axis of individual pebbles.

The actual measurement sites in glacial debris were chosen on a purposive basis, based on factors such as ease of access and texture of material. For example, moraine deposits were often very steep and sites could not be selected for this reason. Similarly, very unconsolidated sandy material was impossible to measure because any removal of pebbles from the face caused the collapse of a large amount of material. Fabric in such deposits was easily affected by gravity and measurements could not be relied on to reflect the original depositional agent.

The site was cleared to a depth of approximately one foot from the surface over the area of a three-foot square. The depth of excavation was small when compared to that used by other workers, e.g. Andrews (1963) used 40 inches depth as he was concerned as to the possible effect on the fabric of freeze-thaw in the active layer. However, Andrews himself suggested that the effect of the active layer was negligible because of the location of the pits, which were all below the crest of the ridge and away from steep slopes.

In this study the depth of excavation was less, and the pebbles measured may be in the active zone as regards freeze-thaw action. However, the material was usually very consolidated and showed little evidence of periglacial disturbance by freeze-thaw action. In certain cases the sites were on steep lateral moraines but they were only chosen where the material was very compact. The consolidated character of the deposits in these cases suggested that periglacial action was minimal. On looser deposits, evidence of mass-wastage movement was noticed. For example, a mud-flow occurred on the lower slope of the eastern lateral moraine of the Drummond Glacier in 1964. Loose deposits, such as these, were strictly avoided when selecting sites for fabric measurement.

A compass placed next to the site was the guide for measuring the orientation of the long-axes of pebbles. A circular card, with diameters, was used to measure the orientation and dip of long-axes. The card was orientated with its north-pointing diameter parallel to that direction on the compass and it was then held under a long nail to give the orientation of the pebble long-axis, accurate to within about five degrees either way. Such a degree of accuracy was acceptable to Holmes (1941), Harrison (1957) and Andrews (1963). By turning the card through 90 degrees into the vertical plane, the angle of dip of the long-axis was measured with a comparable degree of accuracy.

Fifty pebbles and cobbles were selected at each site, from the size range of 16 to 128 mm., measured along the 'b' axis of the pebble. Smaller pebbles were considered too difficult to orient, larger ones may possess an orientation and dip unrelated to the fabric of the deposit. Elongated pebbles were selected because these are believed to best reflect the direction of flow of the depositional agent.

In addition to measuring fabric, texture and structure of deposits was measured by noting size and roundness of fifty randomly-selected pebbles. Roundness (r) was measured on the basis of the sharpest corner of the individual pebble, as proposed by Wadell (Krumbein and Pettijohn, 1938, p. 298).

Description of Fabric in Glacial Deposits

The data relating to orientation and dip of pebbles in the study were originally plotted by the widely-accepted method of using polar stereographic projection nets (Hoppe, 1952; Harrison, 1957; Andrews, 1963). However, difficulty was experienced using this method when relating the data on the projection nets to their field positions. As a result, the fabric data were expressed by means of rose-diagrams on a map of the area of study (Figures 4.1, 2 and 3). Degree of dip was a factor not well understood and consequently ignored, while orientation and dip direction were stressed.

The rose-diagram takes the form of a circle, which is divided into 18 twenty-degree sectors; sector boundaries are, for example, 357½ - 17½, 17½ - 37½, etc. degrees east of north, with corresponding mid-points of 7½ and 27½ degrees. The frequency of occurrence of orientation and dip of pebble long-axis in each of the 18 sectors, is shown on the rose-diagram by a bar, of length proportional to occurrence. The radius of the circle is equal to five occurrences. The rose-diagrams are related to the site of the fabric count on the map.

Interpretation of the rose-diagrams is facilitated by considering individual topographic features. Where several fabric sites have been sampled, for example, in a moraine, the diagram should be studied for preference of fabric orientation with relation to the orientation of the moraine. Preference of orientation at a particular site is represented by longer bars on the rose-diagrams.

When considering the fabric in relation to the hypothetical origin of the deposit, the dominant forces that are likely to have acted are considered. In the case of unsorted glacial deposits, the direction of ice-movement and approximate orientation of any former ice-front are important factors. In the case of water-worked deposits, or even unsorted glacial deposits that have been eroded by streams, the direction of water-flow must be considered. In either case the additional factor of gravity cannot be ignored. The sites in the moraines, the largest group of fabric sites near all the glaciers, will be considered first.

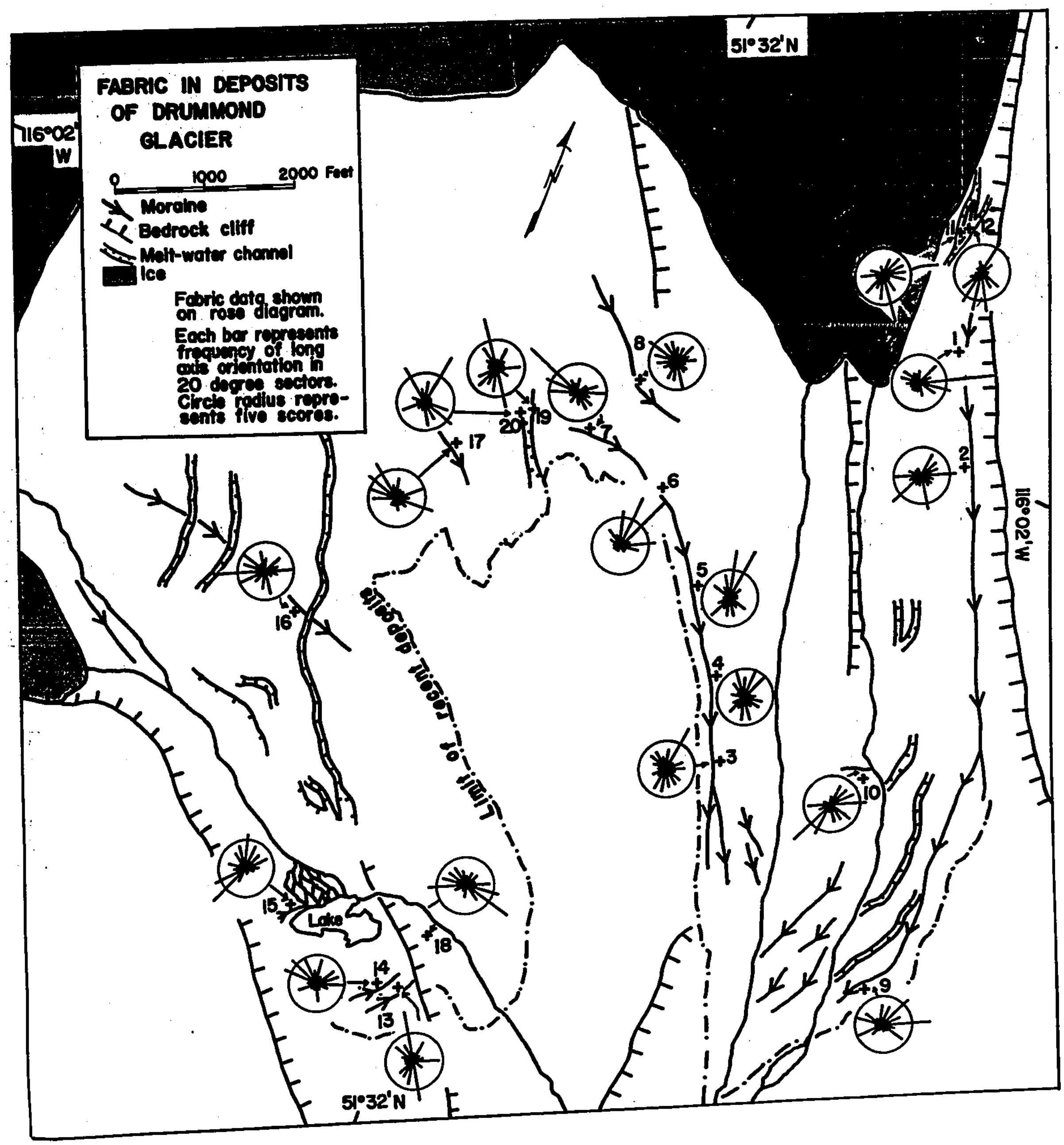
Description of Fabric in Glacial Deposits

1. Drummond Glacier

Of the 20 sites sampled in the vicinity of the Drummond Glacier 15 were in unsorted glacial deposits, forming moraines, and the remainder were in stream-eroded unsorted glacial deposits (Figure 4.1).

Moraines

In the area around the eastern tongue the fabrics do not display similar degrees of preference. This applies particularly to the eastern moraine although only two counts were taken. In the western moraine, fabrics display considerably greater accordance of preferred orientation than on the eastern side. The direction of preferred orientation is at an angle to that of the moraine, the angle varying between about 20° and 40°. The orientation may have been approximately at right angles to the former ice-flow. Generally, preferred dip in fabrics #3-7 is up-valley



FABRIC IN DEPOSITS OF DRUMMOND GLACIER
0 1000 2000 Feet
Moraine
Bedrock cliff
Melt-water channel
Ice
Fabric data shown on rose diagram.
Each bar represents frequency of long axis orientation in 20 degree sectors.
Circle radius represents five scores.
116°02' W
51°32'N
116°02'W
Limit of recent deposits
Lake

Figure 4.1

The other fabrics taken in lateral moraines, #9, 10, 13, 14, 15, 16, 17, display varying degrees of preferred orientation.

<u>Other unsorted deposits</u>

The five fabrics in this category were taken from stream-eroded deposits. Sites #11, 12, 19, and 20 display fabrics having preferred orientation approximately parallel to the direction of former ice-advance. Site #18 is probably mass-wasted material because its fabric has a down-slope preference.

2. Hector Glacier

Eighteen fabric sites were selected from deposits near the Hector Glacier, 17 from moraines and one from unsorted glacial deposits near the ice (Figure 4.2).

<u>Moraines</u>

Nine fabrics from the western lateral moraine showed a similar preferred orientation at an angle of about 40-50 degrees to the direction of the moraine. The direction of preferred orientation appears to be approximately at right-angles to the former ice-flow. Preferred dip direction is generally down-valley.

Five fabrics from smaller moraines north-east of the glacier show two preferred orientations approximately at right-angles. One of the directions is similar to the preferred orientation of fabric in the western moraine. Fabric #11 shows a single direction of preferred orientation similar to that of the western moraine.

In the Molar Creek valley, two fabric sites are situated on the southern proximal side of the low lateral moraine in the centre of the cleared area. No similarity of preference exists in the fabrics although the moraine may have been disturbed by the ice-slide of 1938.

The fabric (#10) in unsorted deposits near the glacier displays

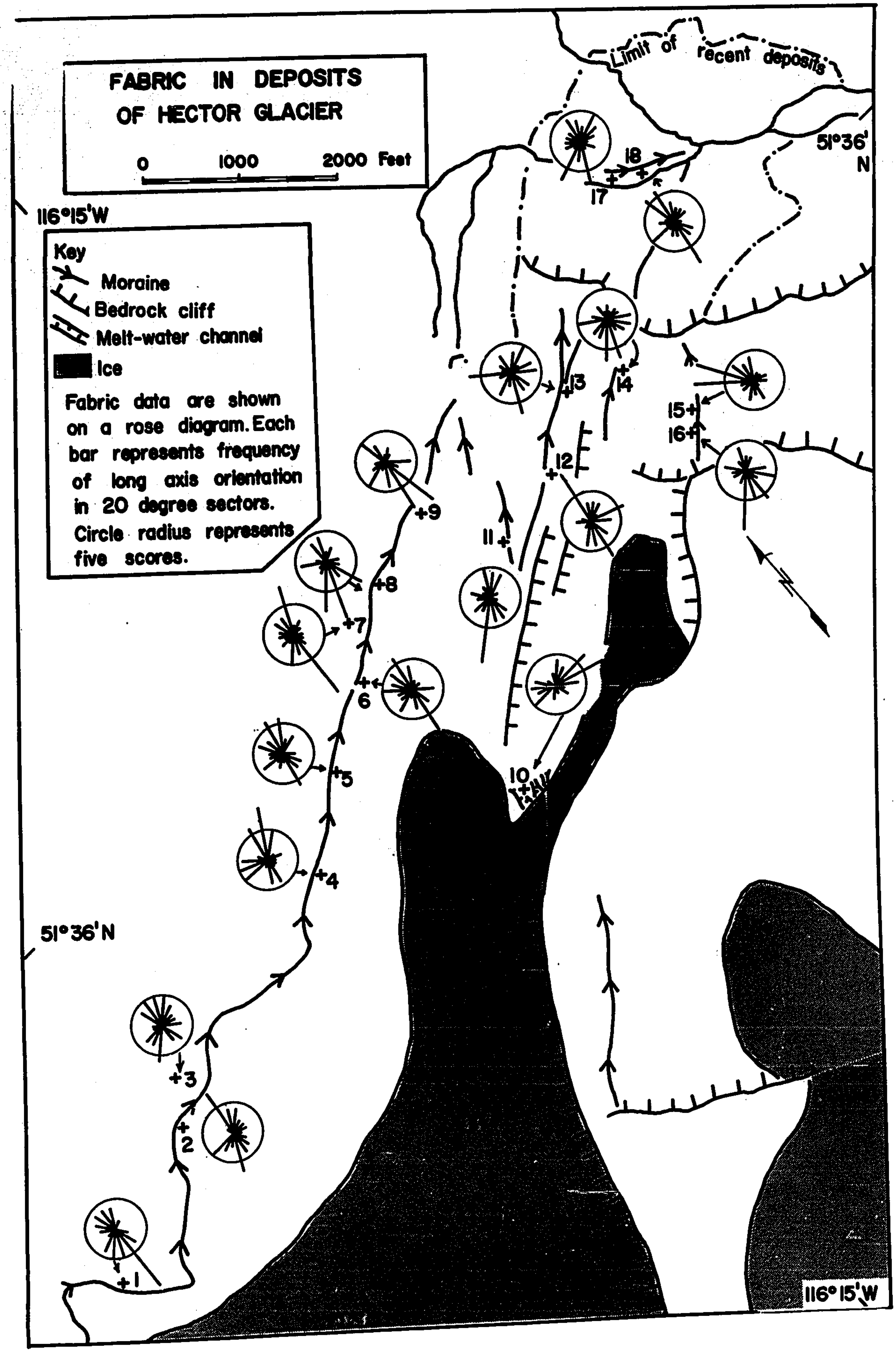

FABRIC IN DEPOSITS
OF HECTOR GLACIER
0 1000 2000 Feet
Key
Moraine
Bedrock cliff
Melt-water channel
Ice
Fabric data are shown on a rose diagram. Each bar represents frequency of long axis orientation in 20 degree sectors. Circle radius represents five scores.
Limit of recent deposits
116°15'W
51°36' N
51°36'N
116°15'W
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Figure 4.2

a preferred orientation approximately parallel to the ice-front in this area and may have resulted from slumping.

3. Peyto Glacier

Seventeen sites are located near the Peyto Glacier, eight in large moraines, six in unsorted glacial deposits and three in water-worked and unsorted glacial deposits (Figure 4.3).

Moraines

Four fabrics from the western maraine show no similarity in direction of preferred orientation. The direction varies between that of fabric #1, approximately at right-angles to the moraine, to that of fabric #3, parallel to the moraine. The fabrics from the eastern moraine, have a similar variation in direction of preferred orientation. In this case the fabrics may differ because two of the sites are on the distal, and two of the sites on the proximal side of the moraine.

Unsorted and other deposits

The other fabrics from the Peyto Glacier give no clear impression of orientation. Site #5, 11 and 16 are in small moraines and show preferred orientations approximately at right angles (#5 and 11) and parallel (#16) to the moraine. Fabrics #12, 14, and 15, are in unsorted glacial deposits and, of these, only #14 has a preferred orientation, approximately parallel to the direction of former ice-flow. Three other fabrics are from non-glacial deposits; #10 and 17 are from unsorted mass-wastage deposits and #13 is from water-worked material. No. 13 displays a preferred orientation that corresponds to the direction of stream flow.

Interpretation of Results of Fabric Measurement

Johansson (1965) has summarized the conclusions of many workers engaged in interpreting moraine fabrics from the point of view of

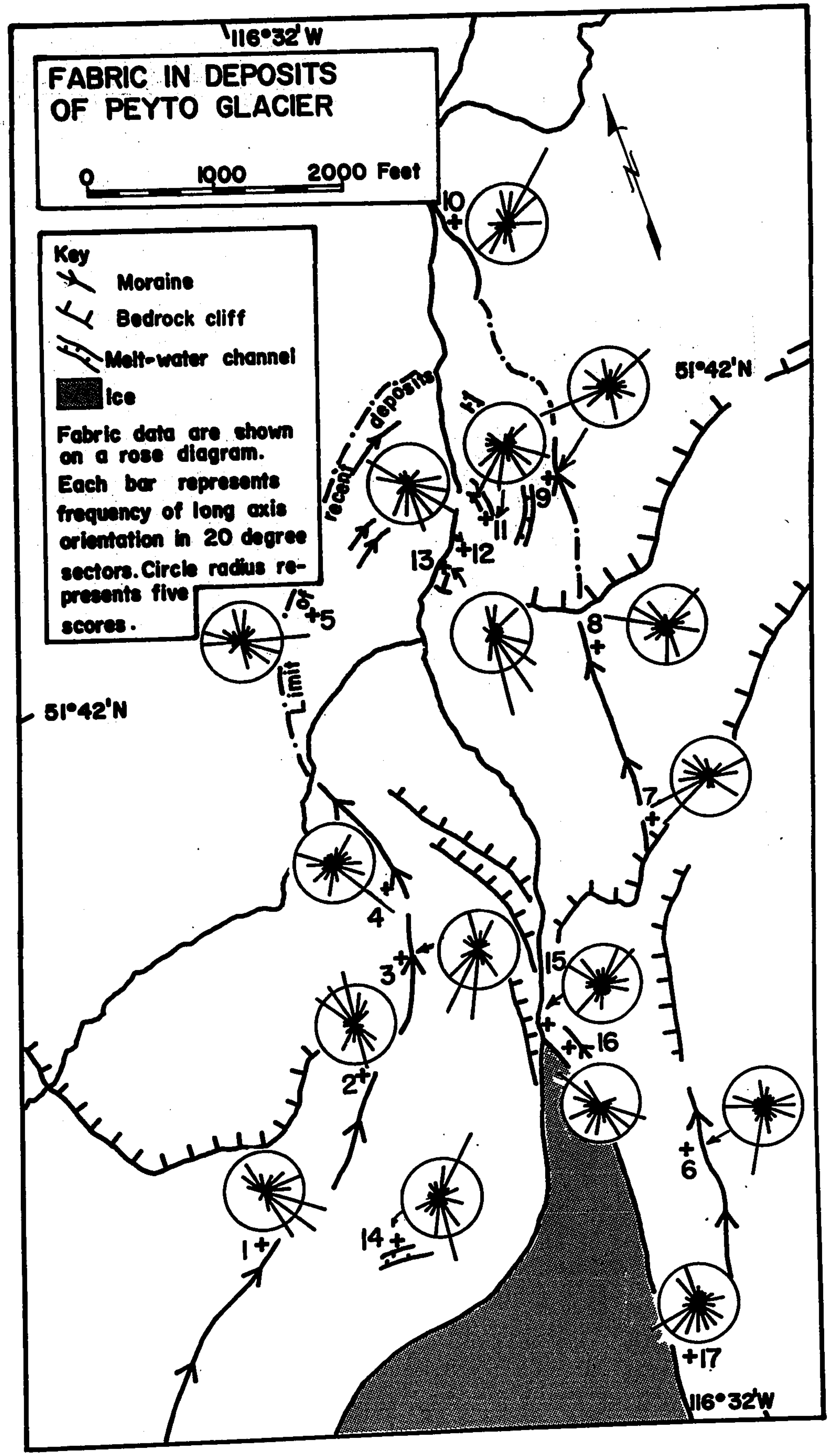

116°32'W
FABRIC IN DEPOSITS
OF PEYTO GLACIER
0
1000
2000 Feet
Key
Moraine
Bedrock cliff
Melt-water channel
Ice
Fabric data are shown on a rose diagram. Each bar represents frequency of long axis orientation in 20 degree sectors. Circle radius represents five scores.
recent deposits
Limit
51°42'N
51°42'N
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
116°32'W

Figure 4.3

depositional process. He states:

> A general rule, however, seems to be that, when particles are immersed in the transporting medium, the internal shearing stress of the moving medium causes parallel adjustment, analogous to particle movements above the bed in running water or within the gravitating mass. As soon as they make a certain contact with the high-friction floor, the resulting orientation tends to be transverse to flow (as in running water). Heavy collisions between particles seem to cause different divergences from the general trajectories, usually producing secondary orientation maxima. (Johansson, 1965, p. 29)

In essence, Johansson is saying fabric and preferred orientation can be used to distinguish among various geomorphic processes involved in the formation of a deposit or land-form. The results of fabric measurement are used here in attempting to understand the principal processes responsible for the deposits forming moraines near the glaciers. The problem of the origin of these moraines and deposits was discussed in Chapter III.

Fabrics from moraines located near or adjacent to sources of mass-wastage debris, such as the eastern moraines of the Drummond and Hector Glacier, generally show no preferred orientation of pebbles. On the other hand, fabrics from moraines located some distance from sources of mass-wastage debris, such as the western moraines of the Drummond and Hector Glaciers, show considerable uniformity in direction of preferred orientation. The preferred direction is generally at right-angles to the former ice-margin, or parallel to the direction of glacier movement.

Interpretation of the fabric data on the basis of Johansson's comments leads to the conclusion that the eastern moraines consist of material largely derived from mass-wastage debris that has been pushed by the ice for a very short distance, hence the random pebble orientation. The western moraines of the Drummond and Hector Glaciers may have been derived from erosion of both mass-wastage debris and bedrock and may have acquired the preferred pebble orientation as a result of transport by the glacier over a considerable distance.

Fabrics in unsorted glacial deposits other than moraines generally have a preferred orientation parallel to the direction of former glacier movement. This orientation may result from transport within the ice, although Andrews (1963) found that:

> A preferred orientation could be produced, however, independent of the ice, and would involve flow within the till, either under pressure or even under gravity. With a flow of this type, the long-axis of the particles would become parallel to the flow and dip into the current.
>
> (Andrews, 1963, p. 110)

With regard to the single fabric measurement from water-worked material, Peyto Glacier #13, it is the conclusion of other workers, as summarized by Potter and Pettijohn (1963) and Johansson (1965), that long-axes of pebbles may be either parallel or perpendicular to the direction of stream flow. The fabric, Peyto Glacier #13, displayed a preferred orientation in the general down-valley direction, presumably indicating the former stream-flow direction. The general conclusion of workers as regards stream deposit fabrics is summarized by Johansson (1965) as follows:

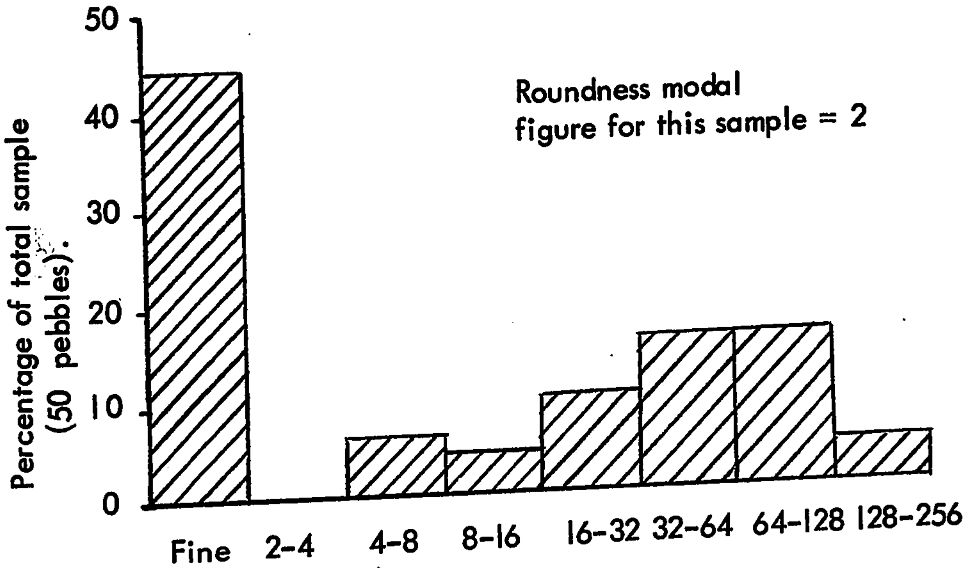
> Pebbles and cobbles are rolled along the bed during low flow in the glacier brook. They are deposited transverse to the direction of flow. The orientation is 90 degrees opposite when the flow gets stronger, so that pebbles leave the bed and are deposited parallel to the direction of flow.
>
> (Johansson, 1965, p. 10)

<u>Interpretation of Texture and Structure of Glacial Deposits</u>

Sample data of pebble counts of size in glacial deposits near the three glaciers are shown in Figure 4.4. Samples were selected because of the general uniformity of the size counts. Size distribution shown

Figure 4.4

Sample data of pebble count in unsorted glacial deposits (Drummond #5).



Size in millimetres measured along the 'b' axis of the pebble.

by means of a histogram shows a general variety of size with a high proportion of fine material. The roundness of material in unsorted glacial deposits is best represented by the modal group which is, generally, 2 or 3. This shows the general angularity of material indicating lack of water-working and short distance of transport.

CHAPTER V

CONCLUSION

The recession data for the three glaciers in this study show that frontal retreat has occurred for the past 70 to 80 years. The pattern of recession for the three glaciers has been similar, the rate increasing in the period 1880-1940, and subsequently decreasing until the present. Recession compares favourably with observations of other glaciers in nearby areas.

The ecesis period for establishment of forest vegetation in deglaciated areas was estimated at 60 to 80 years for all three glaciers. Discharge measurements in summers of 1963 and 1964 for the stream fed by melt-water from Drummond Glacier show a distinct positive correlation with air-temperature near the ice. Recession data for the longer period, 1940-1965, were found to have a low correlation with climate data for nearby stations. A time-lag of about 10 to 15 years seemingly exists for the response of the glacier tongue to climate.

Glacial deposits formed in the last 70 to 80 years near the three glaciers were similar in their distribution. Deposits were mapped on the basis of a descriptive-genetic classification. Widely-accepted, genetic terms, such as "till" and "outwash" initially were rejected in favour of "unsorted glacial deposit" and "mass-wastage deposit," because the purely genetic terms prejudiced interpretation of the origin of deposits.

Today, the glaciers are largely free of debris. Moreover, few unsorted glacial deposits have formed in the last 50 to 60 years. Some unsorted glacial deposits form moraines which were deposited prior to 1880 during the maximum recent advance of the glaciers.

Water-worked deposits are located near all the glaciers, although they appear to be formed by re-working of unsorted glacial and mass-wastage deposits. Unsorted glacial and water-worked deposits both appear to be largely derived from unsorted mass-wastage deposits.

Fabric study suggests that unsorted glacial deposits, forming moraines, close to possible mass-wastage sources have merely been pushed by the ice and relatively little affected by it. Unsorted deposits located some distance away from sources of mass-wastage debris appear to have been transported by the ice which gave a distinctive orientation to the fabric of the deposit. Thus, unsorted glacial deposits may have been formed under varying degrees of influence by the glacier in different areas.

In attempting to relate this study to the glaciation of the main Red Deer Valley and the alpine environment in general, the scale of contemporary and glacial processes should be considered. The deposits and surface features mapped near the glaciers were produced by the recent and relatively minor ice-advance. The size of the glaciers is small compared to the huge ice-sheets that once occupied the mountain valleys, including the Red Deer River valley. The deposits and forms produced during the recent advance may therefore be vastly different to those of a major glaciation.

To illustrate, the main depositional form located near the glaciers is the moraine formed of unsorted glacial deposits. However, in the main valley of the Red Deer River and other nearby mountain valleys, the predominant depositional form is that often referred to as the kame-terrace, a landform consisting of a variety of glacial, glaciofluvial and other deposits. Studies of process and deposits near relatively small contemporary glaciers, therefore, may be less useful to our understanding of the processes and land-forms of former large-scale glaciations than is often imagined.

Some final remarks can be made on the distribution and origin of ice-marginal moraines. Macpherson (1963) noted the paucity of such features in the main valley of the Red Deer River. Moreover, the origin of several small moraines in the valley below the Drummond Glacier has been questioned as a result of an alternative interpretation advanced in this thesis. The so-called recessional moraines located near the Drummond Glacier may be the result primarily of mass-wastage over ice, during glacial recession rather than reflecting a pause or sub-stage in recession. The mode of recession in the main valley thus remains in question. Two alternative hypotheses have been proposed. Macpherson believed that stagnation was widespread throughout the valley of the Red Deer River. This may have been so, however the second alternative is also quite conceivable. In this case the ice may have retreated steadily with no major pauses in recession. The paucity of land-forms characteristic of ice-stagnation and the similarity of the recent ice-recession pattern tends to support this hypothesis.

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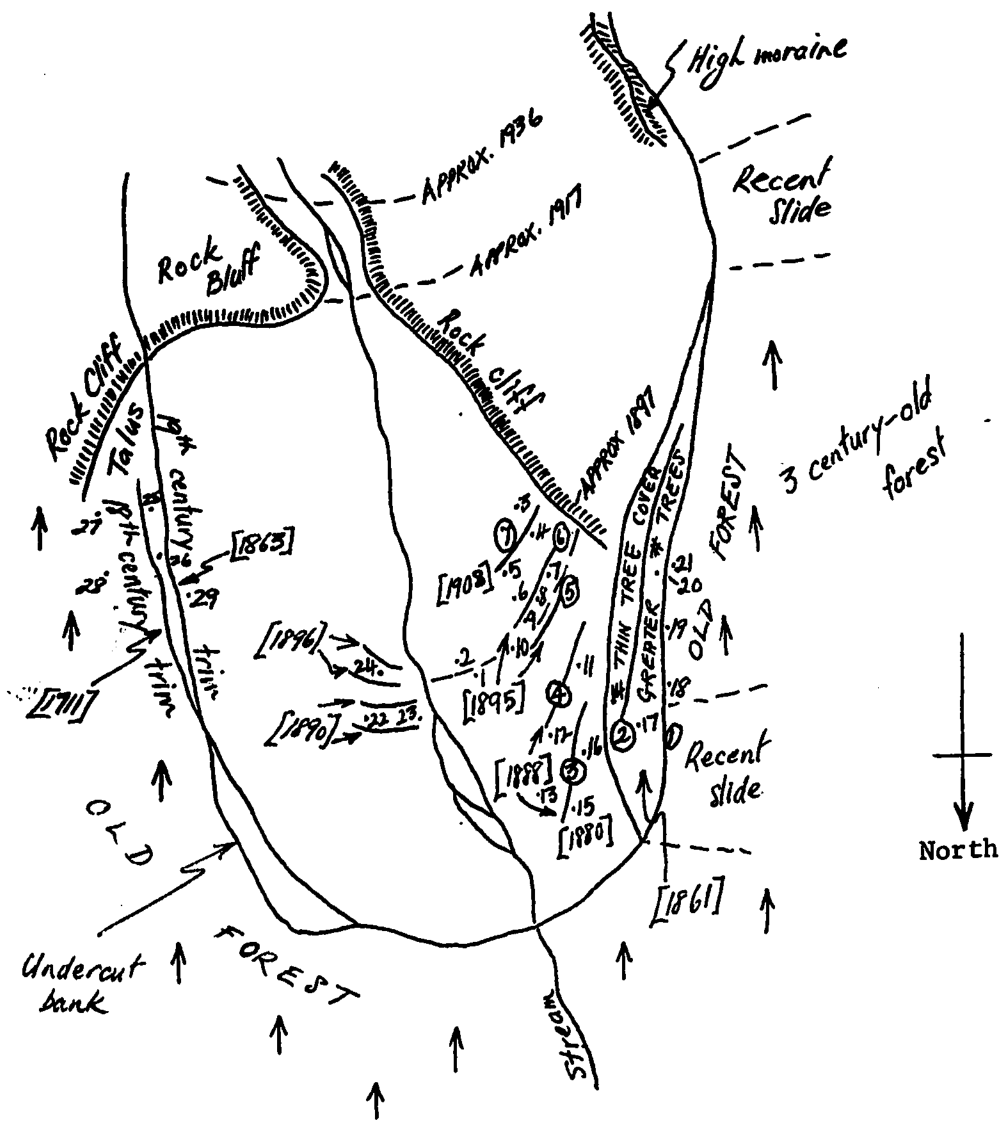
APPENDIX 1.

PEYTO GLACIER BELOW ICE-TONGUE

Sketch map made by C.J.Heusser in 1953. Twenty-nine trees are shown in association with lateral moraines. Each tree was cored and sampled by Heusser. Dates of formation of the moraines are shown in brackets.



KEY

.24 Tree # and location

③ Recessional moraine # and location