THE UNIVERSITY OF CALGARY

LATE-WISCONSIN ICE IN THE MORLEY FLATS AREA OF THE BOW VALLEY AND ADJACENT AREAS OF THE KANANASKIS VALLEY, ALBERTA

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

July 1971.

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies for acceptance, a thesis entitled "Late Wisconsin Ice in the Morley Flats area of the Bow Valley and adjacent areas of the Kananaskis Valley, Alberta," submitted by Michael J. C. Walker in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The Morley Flats area of the Bow Valley and the lower ten miles of the Kananaskis Valley, approximately 45 miles west of Calgary, were studied to determine Late-Wisconsin ice movement in this portion of the Rocky Mountain Front Ranges. In particular, attention was directed towards establishing the areal extent of Bow and Kananaskis ice, and the possibility that the two valley glaciers had converged on the undulating plain of the Morley Flats.

Detailed field work was complemented by analysis of samples in the laboratory, and the results suggest the following sequence of events. With the onset of the Classical Wisconsin, Bow Valley ice crossed the Morley Flats area as a large piedmont lobe and deposited thick layers of buff-grey till. A number of longitudinal ridges which occur on the Flats are interpreted as drumlins which are thought to have formed by a process of accretion during this glacial phase. Rutter (1965) tentatively correlated this advance of Bow Valley ice with the Early Pinedale Stade recognised by Richmond (1965) in the northern U.S.A.

Analysis of deposits in the Kananaskis Valley indicates that the lower ten miles of the valley were occupied by Bow ice at this period, the ice being of the order of 2500-3000 feet in thickness. No evidence could be found for the former presence of Kananaskis ice in the study area.

Wasting and thinning of the ice produced a lake in the lower Kananaskis Valley which was dammed by Bow ice occupying the Morley Flats

to the north. Progressive lowering of the ice barrier led to the formation of a series of channels and spillways, allowing water impounded in the valley to escape initially eastwards into the Elbow River drainage system and finally northwards into the valley of the Bow River. It is suggested that the post-glacial course of the Kananaskis River occupies the lowest of these channels.

ACKNOWLEDGEMENTS

The writer is deeply indebted to Dr. S. A. Harris for his guidance and encouragement during the preparation of this thesis. Thanks are also due to Professor J. P. Crowley, Department of Geography, for his valuable suggestions, and for his assistance with the statistical analysis. The writer would also like to thank Dr. N. W. Rutter, Geological Survey of Canada, whose advice and comments were much appreciated.

Special thanks are extended to the staff of the Environmental Sciences Centre at Kananaskis for their hospitality during the 1970 field season. In particular, the co-operation of Mrs. E. Chaykowski, Mr. G. Kittleson and Dr. S. Telang is gratefully acknowledged.

Mr. B. Ciccone and Mr. K. Drabinsky assisted with the laboratory analysis, while Mr. N. Babey and Mr. H. Liphuysen, Technicians in the Department of Geography, carried out the photographic work for the thesis. The writer is especially grateful to Geophoto Services of Calgary for permission to reproduce Figure 6, and to Mrs. Susan Day for her competent typing of the final draft of the thesis.

Finally, my thanks to my wife, Liz, for her assistance in compiling the maps, and for her patience during the time spent in the completion of this study.

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CHAPTER I

INTRODUCTION

The behaviour of former mountain glaciers has long intrigued students of natural science, and the last 20 years has seen a marked increase in the amount of research into this complex phenomenon. Thus far however, studies have been concentrated in the major arterial valleys and few detailed reports are available on the behaviour of former tributary valley glaciers. The purpose of this study is to investigate the relationship between ice movement in the Morley Flats area of the Bow Valley and adjacent areas of the Kananaskis Valley in order to establish a meaningful sequence of events for the late-Quaternary period in this portion of the Rocky Mountain Front Ranges of Canada.

This particular area was selected for two main reasons. As the Kananaskis Valley forms one of the larger tributaries in the Bow River system (Figure 1), it was felt that evidence for former glacial activity would be abundant and that a distinction would therefore be possible between material originating in the Kananaskis Valley and deposits from the Bow Valley glacier. Secondly, access to the study area was relatively good and was complemented by excellent air-photo coverage. The presence of adequate surficial material coupled with good access to key localities are considered to be essential prerequisites if a project of this nature is to be successfully carried through.

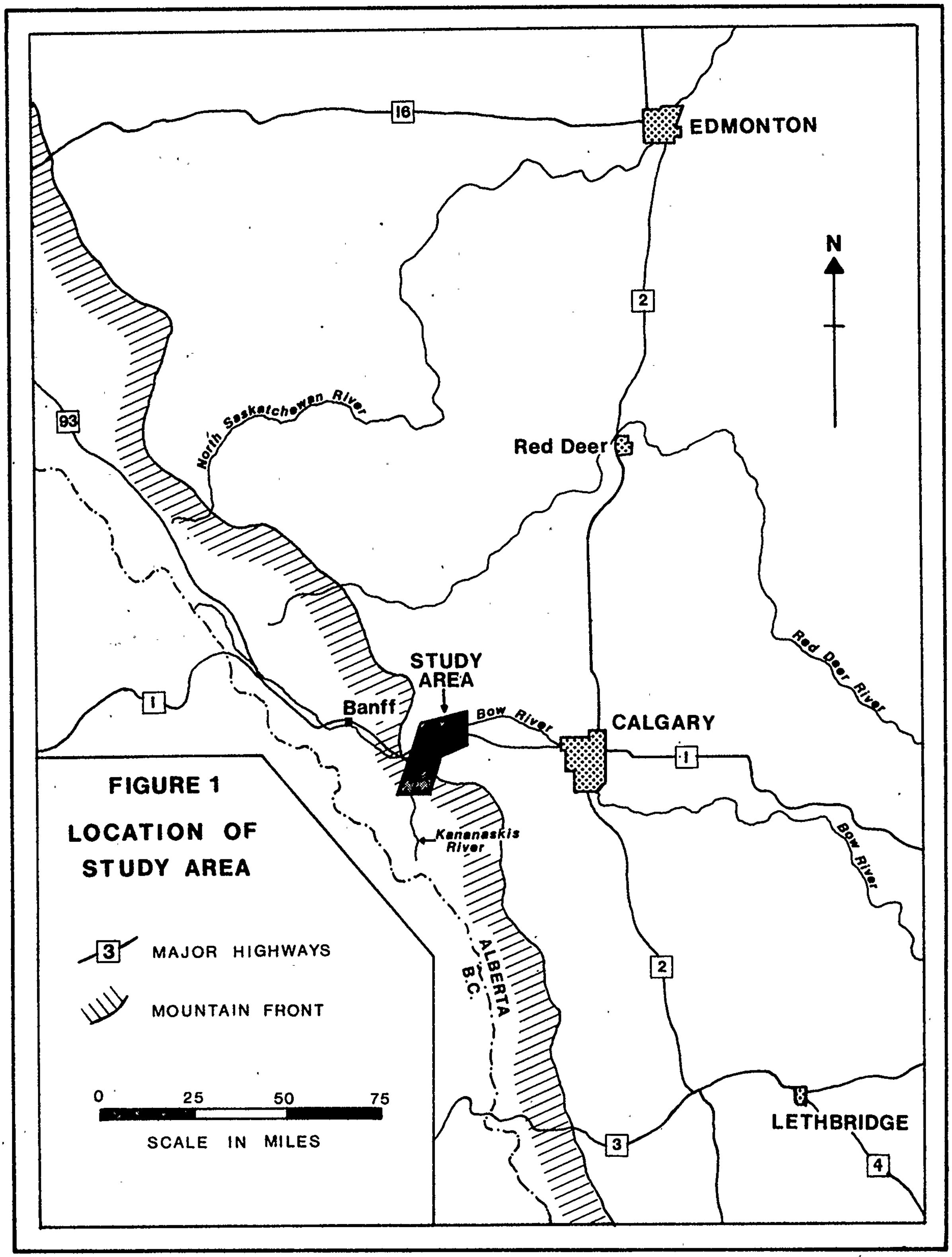


FIGURE 1

LOCATION OF STUDY AREA

Previous Literature

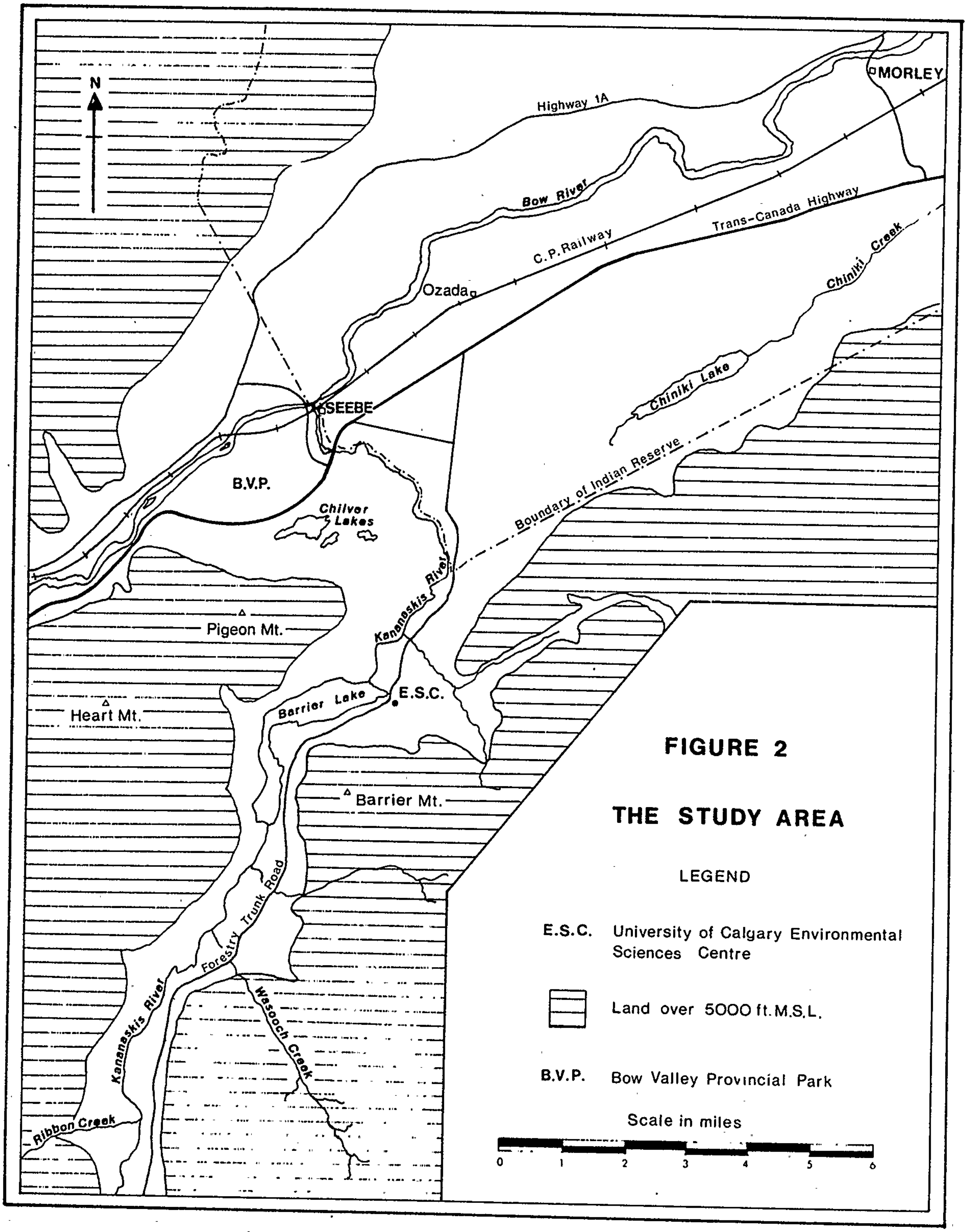
This review of previous literature has been divided into two sections. The first deals with reports which detail the glacial history of the Bow Valley while the second section is concerned with research previously undertaken within the bounds of the present study area. This body of literature is felt to be of particular importance in formulating the framework for the investigation.

The earliest reports on this area of the Front Ranges stem from the work of Dr. J. Hector who was the geologist with the Palliser expedition of the 1850's. Despite the superficial nature of the reconnaissance, Hector (1861) did record the presence of erratics which he attributed to ice-rafting.

The first detailed surveys were carried out by G. M. Dawson and R. G. McConnell. In a series of papers (1875-1895), Dawson reported on many aspects of the structural and surficial geology of Western Canada. He was the first observer to make reference to the former presence of ice in the Bow Valley noting in 1885 that:

> "The rocks at this point (4½ miles S.W. of Seebe) have been heavily grooved and striated by the great glacier which evidently at one time debouched by the Bow Valley into the foothills region."
>
> (Dawson, 1885, p. 53)

Although a two-till sequence had been discovered in the Calgary area by McConnell (1895), Nichols (1931) was the first geologist to offer definite proof for more than one ice advance down the Bow Valley. Near Ozada on the Morley Flats (Figure 2) he located a river section where a marked break occurred between two deposits of boulder-clay. He suggested that:


N
MORLEY
Highway 1A
Bow River
Trans-Canada Highway
C.P. Railway
Chiniki Creek
Ozada
Chiniki Lake
SEEBE
B.V.P.
Chilver Lakes
Boundary of Indian Reserve
Kananaskis River
Pigeon Mt.
Barrier Lake
E.S.C.
Heart Mt.
Barrier Mt.
Forestry Trunk Road
Wasootch Creek
Ribbon Creek
FIGURE 2
THE STUDY AREA
LEGEND
E.S.C. University of Calgary Environmental Sciences Centre
Land over 5000 ft. M.S.L.
B.V.P. Bow Valley Provincial Park
Scale in miles
0 1 2 3 4 5 6

> "This occurrence of a break in the boulder clay in conjunction with the interpretation of McConnell's number two clay near Calgary suggests that there are two stages of Cordilleran Glaciation evidenced in the Bow Valley."
>
> (Nichols, 1931, p. 57-8)

The earliest attempt to solve the glacial history of a valley in the Bow area was made by Jennings (1951). Although he presented a detailed report on the glacial geomorphology of the Sunwapta Pass to the north of Bow Lake (Figure 3), he found a chronology impossible as all evidence for previous glacial activity had been removed by the last ice advance through the area.

Tharin (1960) worked on the glacial sequence in the Calgary area and suggested that although two western ice advances are recorded in the Calgary region, only the earlier advance extended as far as the present site of the city.

The most comprehensive study so far carried out in the Bow Valley was the one undertaken by Rutter (1965, 1966a, 1966b, 1971). Working east from Eisenhower Junction (some 35 miles northwest of Banff) down to the Morley Flats, he found evidence for four periods of glacial activity. These he termed the Pre-Bow advance, the Bow advance, the Canmore advance and the Eisenhower Junction advance. A black-blocky till observed in a river section near Morley and later discovered in a borehole in the Canmore area (Figure 3) provided the evidence for the Pre-Bow glacier. The stratigraphic position of the till suggests that this is the earliest advance recorded in the valley although the areal extent is unknown. Thick deposits of till which blanket the lower Bow Valley area are thought to have resulted from the main Bow advance which probably reached the

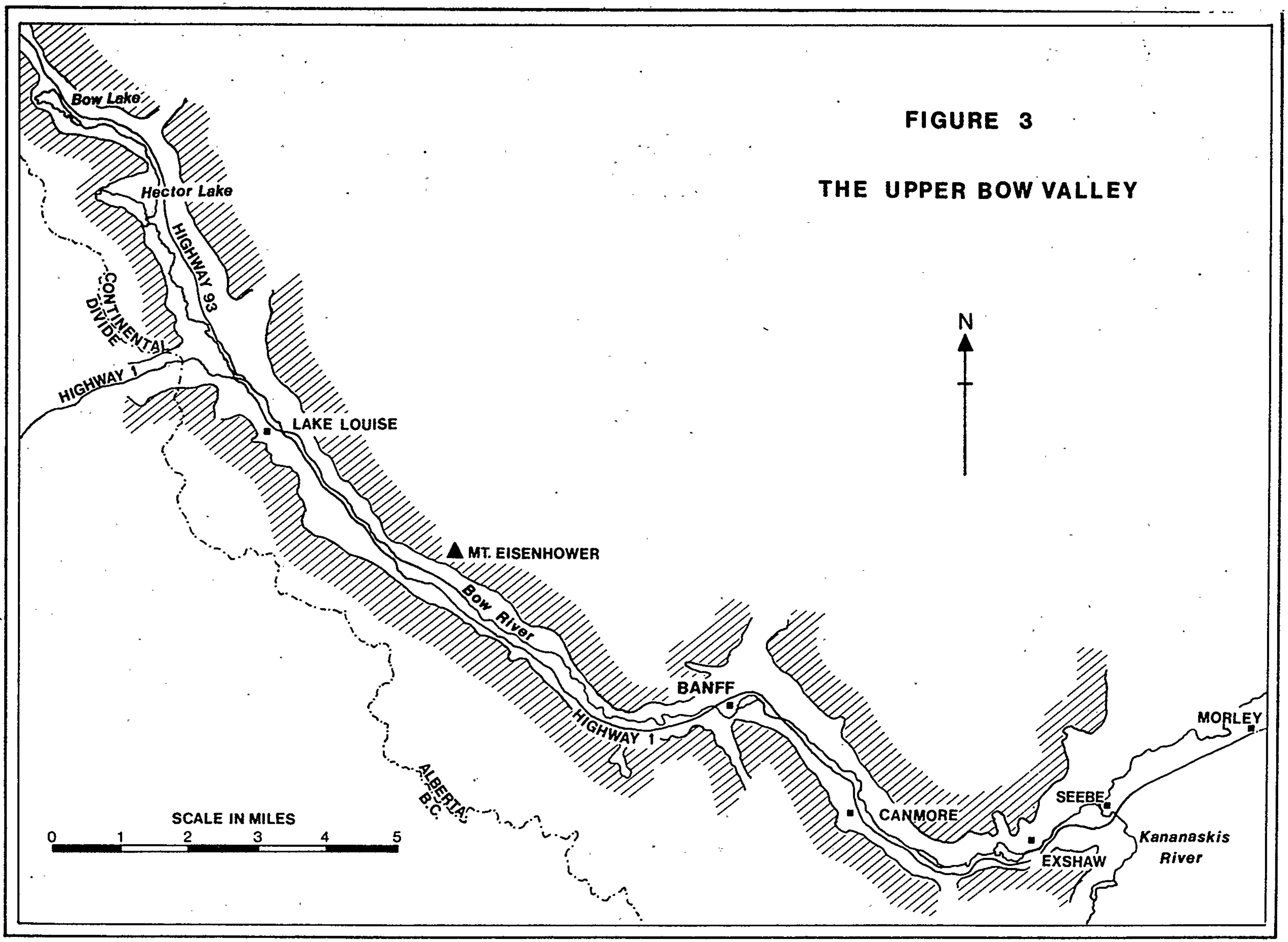


FIGURE 3

THE UPPER BOW VALLEY

TABLE 1. CORRELATION CHART OF THE BANFF AREA, ALBERTA, AND THE ROCKY MOUNTAINS OF THE NORTHERN U.S.A. (after Rutter, 1965).

Banff area, Alberta.	Approximate age B.P.	Rocky Mountains (after Richmond).		
Nineteenth Century advance Upper cirque? Recent advances Middle? (Forested moraines etc.)	800 900	Neoglaciation	Gannett Peak Stade	
			Interstade	
			Temple Lake Stade	
	4,000			
Altithermal Interval (Ash layer 6020±90 yrs B.P.)		Altithermal Interval		
	6,500			
?Eisenhower Junction Readvance (Min. 9330±170 yrs.) Eisenhower Junction advance		Pinedale	Late Stade	
	10,000		Interstade	
	12,000			
Bow Valley Readvance (now termed Canmore advance - see Rutter, 1971).			Middle Stade	
			Interstade	
Bow Valley advance		Glaciation	Early Stade	
	25,000			
		Interglaciation		
	32,000			
Pre-Bow Valley advance or advances	45,000	Bull Lake	Late	2nd episode
				Nonglacial interval
			Stade	1st episode
			Nonglacial interval	
		Glaciation	Early Stade	

Calgary area. The fluvio-glacial complex near Exshaw marks the limit of the Canmore advance while the moraine near Mt. Eisenhower (Figure 3) was deposited by the last glacier moving down the Bow Valley towards the Banff area. This was termed the Eisenhower Junction advance by Rutter (1965). He further suggests (1965, p. 72) that ice advances in the Bow Valley can be tentatively correlated with the sequence of events recognised by Richmond (1965) for the northern Rocky Mountains of the U.S.A. (Table 1). Thus, the Pre-Bow advance is assigned to Bull Lake age and the three later advances of the Bow glacier to Early, Middle and Late Pinedale stades respectively. These correlations were made before a Pinedale IV stade was recognised and thus far no evidence has been put forward for a Pinedale IV ice advance in the Bow Valley.

Studies in the Athabasca Valley have revealed that in that area of the Front Ranges, late-Quaternary ice crossed the Continental Divide from the interior ranges of British Columbia (Roed, Mountjoy and Rutter, 1967). In the Bow, however, the lack of exotic material in the till led Rutter to conclude that all the glaciers which formerly advanced through the area originated near Bow Summit to the east of the Continental Divide. Ice heights in the Banff area based on lateral breaks in slope and the presence of erratics on the mountain sides, are estimated at 1600-2600 feet for the Bow advance and 750 feet for the Canmore advance. However, in spite of the depth of ice in the Bow Valley, no reference is made to the occurrence of glacial diffluence having taken place across low divides between major and tributary valleys in the Bow area.

Previous literature from the present study area which has a direct bearing on the problem outlined above is restricted to three papers. Dawson (1885) was the first research worker to make reference to the former presence of Kananaskis ice on the Morley Flats of the Bow Valley. He noted that:

> "The hilly tract intervening between Chiniki Lake and the Bow evidently owes its character to the morainic accumulation of glaciers which formerly debouched from the Bow and Kananaskis Valleys."
>
> (Dawson, 1885, p. 57)

Beach (1943) supported Dawson's hypothesis in postulating that:

> ". . . glaciers extending from the mountain front along Bow and Kananaskis Valleys coalesced to the east of Seebe and filled the lower Bow Valley at least as far as Morley."
>
> (Beach, 1943, p. 49)

Between Seebe and Morley settlement (Figure 2) a group of longitudinal ridges oriented parallel or sub-parallel to the course of the Bow River have been discussed in a number of papers. They have been variously interpreted as moraines (Dawson, 1885), drumlins (McConnell, 1895; Tharin, 1960), and crevasse fillings (Nelson, 1963). The latter paper is considered to be of particular importance as the author invoked the presence of Kananaskis ice on the Morley Flats in order to explain the development of the landforms. He suggested that the ridges originated from the lowering of material into splaying crevasses which formed as the Kananaskis glacier spread out from the constricted valley onto the wide undulating plain of the Morley Flats.

This review of previous literature provides the basis for the development of a working hypothesis which will be tested in the course of this study. It has been pointed out above that ice from the Kananaskis Valley probably moved northward onto the Morley Flats in the late-Quaternary period. This view is consistent with the work of Rutter in the Banff area and Richmond in the northwest U.S.A. as,

(1) Richmond noted (1965, p. 224) that in the Front Ranges of Montana, moraines of early and middle stades of the Pinedale lie in large piedmont lobes near the mountain front. Rutter (1965, p. 73) observed that in the Banff area, glaciers of both the Bow Valley advance and Canmore advance flowed out beyond the Front Ranges forming piedmont lobes. Hence, it would be logical to assume that Kananaskis ice would follow the same pattern.

(2) If the curve for the average altitude of late-Pleistocene and Recent moraines derived by Richmond is extended to the Banff area, then end moraines of the Pinedale advances would be expected to occur at 4000, 4600 and 4800 feet respectively (Rutter, 1965, p. 73). In the Bow Valley Rutter suggested that the main Bow advance terminated below 4000 feet and the Canmore advance at approximately 4200 feet.

Thus if end moraines for Kananaskis ice occur at the same altitude, at least one ice advance should be recorded on the Morley Flats and evidence for two advances should be present in the lower Kananaskis Valley. This assumes, however, that catchment area, regional slope and tilting are unimportant for this time period in the study area.

If Kananaskis ice did move out of the Kananaskis Valley onto the Morley Flats in the late-Quaternary period, then answers must be sought to the following questions:

(a) Did Kananaskis ice meet ice moving eastwards down the Bow Valley in the Morley Flats area?

(b) If so, then what was the nature of the interaction of the two ice masses?

(c) What was the areal extent of the Kananaskis glacier?

None of the research previously carried out in the study area offered a solution to these problems and indeed statements on former ice movement tended to lack foundation. This, it is felt, was due to shortcomings inherent in previous research techniques. As both Dawson and Beach were geologists whose primary concern was with the structure of the region, the surficial geology of the Morley Flats was discussed in very general terms. Nelson analysed the landforms on the Flats but his discussion of ice flow appears to be based more on speculation than upon field evidence. In each of these cases, detailed sampling of surficial material was never undertaken and therefore a meaningful comparison of the glacial deposits across the area was impossible. Field techniques were largely qualitative and such methods as fabric analysis for determining the direction of ice flow were never employed. Laboratory analysis to complement field observations was carried out by Nelson, but no attempt was made to use these results to differentiate material derived from the Kananaskis Valley from that originating in the Bow Valley.

In order to fulfil the aims of the study as stated above, the following points are considered to be important in formulating a framework for the project:

(a) If viable results are to be obtained, then a programme of intensive field sampling is essential. The methods employed must be uniform both spatially and temporally.

(b) Conclusions must be based on fieldwork which is supported by analysis of samples in the laboratory.

(c) The genesis of the landforms occurring on the Morley Flats must be established in order that their relationship to former ice masses may be determined.

(d) The deglacial sequence must be analysed as it is felt that this may be of value in an understanding of the glacial history of the area.

CHAPTER II

THE STUDY AREA

INTRODUCTION

The study area lies approximately 45 miles west of Calgary where the northward-flowing Kananaskis River joins the Bow River on the undulating plain known as the Morley Flats (Figure 2, Plates 1 and 2). The region of approximately 150 square miles lies between latitudes 50°55' and 51°10' north, and longitudes 114°50' and 115°07' west, and is covered by the 1:50,000 topographic sheets 82 0/2 W. (1939), 82 0/3 E. (1959) and 82 J/14 E. (1954) for Morley, Canmore and Evans Thomas Creek respectively. The area encompasses the lower 12 miles of the Kananaskis Valley from Ribbon Creek in the south to the Morley Flats in the north. The study area on the Flats is bounded in the north by Highway 1A, while the highland to the south of Lake Chiniki forms the southern margin. The eastern boundary lies two miles to the east of Morley settlement and the western margin is delimited by the steep mountain front to the west of the Bow Valley Provincial Park.

CLIMATE, SOILS AND VEGETATION

The climate of the region is essentially continental and is characterised by warm summers and relatively cold winters with intermittent Chinook winds. The warmest month is July with a mean maximum of 55.7°F being recorded at the Field Station in the Lower Kananaskis Valley.

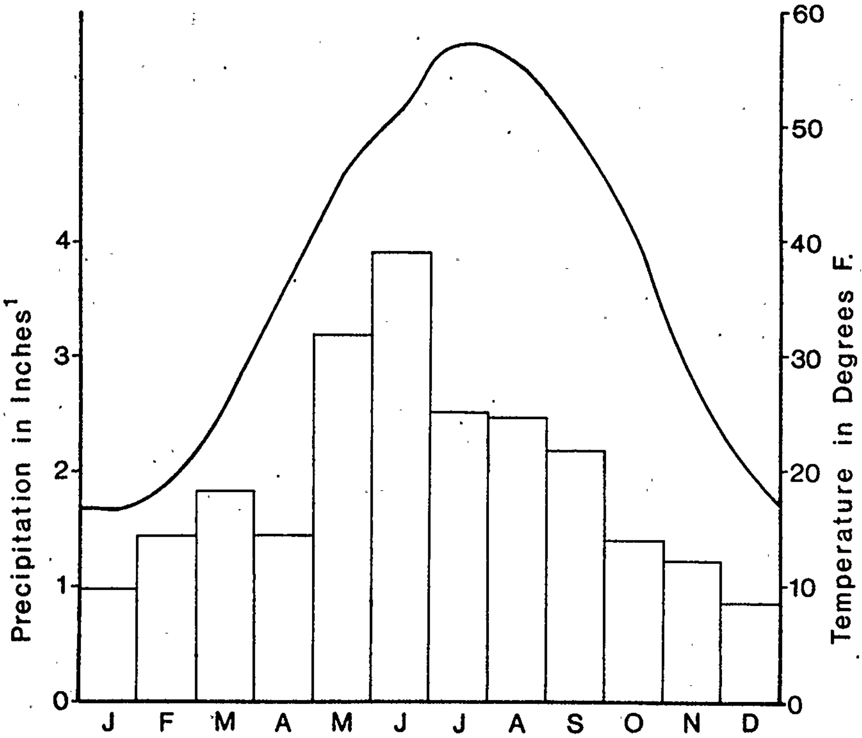
Mean January temperatures in the lower valley average 16.7°F. Maximum precipitation falls in the three summer months of May, June and July and the annual total ranges from 23.45 inches at the Field Centre (Figure 4) to 45 inches on the higher slopes (Kirby and Ogilvie, 1969). The average frost-free period is approximately 58 days extending from about mid-June to the third week in August (Duffy and England, 1967; Kirby and Ogilvie, 1969).

There is no apparent relationship between soils and parent material, for on the gravel deposits of the Morley Flats, Black Chernozems, Grey Wooded soils (Wyatt et al., 1943) and Podzols are all well developed. In the Kananaskis Valley, podzolisation is the dominant soil-forming process despite the calcareous nature of the underlying bedrock (Crossley, 1951). However, isolated patches of Chernozemic soil are found on the fine sands north of the Environmental Sciences Centre and Brown Forest soils occur on lacustrine material around Barrier Lake.

The distribution of natural vegetation in the study area is a result of a number of interrelated environmental variables. Elevation, and aspect, soils, climate and edaphic factors combine to produce a variety of vegetation types. In general terms, the area lies across the transition zone between the parkland vegetation of the Prairies and the alpine vegetation on the crests of the Front Ranges. Hence on the Morley Flats, coarse grasses form the dominant ground cover with occasional groves of Douglas fir, limber pine and lodgepole pine on the coarser gravels, and stands of poplar, willow and white birch along the rivers (Ogilvie, R. T., personal communication, 1971). In the Kananaskis Valley the dominant species are Douglas fir, lodgepole pine, white spruce and

FIGURE 4

CLIMATIC DATA FOR THE KANANASKIS FOREST EXPERIMENTAL STATION 1941—50



Total Annual Precipitation = 23·45 ins.[1]

[1] Precipitation includes snowfall in water equivalent.

Source: Climatic Data Sheet, Canadian Weather Service.

trembling aspen on the lower slopes. At higher elevations Englemann spruce and alpine fir occur (Duffy and England, 1967).

GEOLOGY

Regional Structure

The following description is abstracted from the paper by Crockford (1956, p. 72) in the Alberta Society of Petroleum Geologists' Guidebook to the Bow Valley.

The foothills and mountains of S.W. Alberta are part of a vast anticlinorum which has its apex at the British Columbia-Alberta border. Erosion has reduced the arch to a series of parallel and sub-parallel fault ridges which trend in a general N.W.-S.E. direction along the strike of the beds. The strata are progressively older westward, and only on the eastern margins of the Front Ranges are Mesozoic rocks exposed. The more competent strata of thickly-bedded Paleozoic limestones and dolomites form the most prominent ridges while rocks of Mesozoic age, being composed mainly of shale, sandstone and conglomerates, are less competent and occupy the topographically low areas. The Mesozoic strata are, in most cases, intricately folded, faulted and crushed.

The study area is underlain by both rock types (Table II). To the east of the mountain front, the low-lying area of the Morley Flats rests on great thicknesses of sandstone, shale and pebble conglomerates of Upper Cretaceous age (Figure 5) with the beds dipping gently westwards (Beach, 1943). The lower Kananaskis Valley is cut into highly folded and faulted limestones and dolomites of Devonian and Cambrian age, with the dominant structural trend N 30^{o}W (Figure 6). Paleozoic outcrops are continuous throughout the lower Kananaskis Valley except in the area around Ribbon Creek (Figure 2) where strata of lower Mesozoic age are exposed at the surface.

Bedrock Geology

The bedrock geology of the Morley Flats portion of the study area is covered by the Morley Map sheet (Beach, 1943). The author encountered some difficulty in obtaining details of the geology of the lower Kananaskis Valley as maps covering that area are still in preparation (Ollerenshaw, personal communication, 1971). However, a geological map based on air-photo interpretation was obtained from the Geophoto Company in Calgary and is reproduced in Figure 6. Additional information was derived from Alberta Society of Petroleum Geologists' Field Conference Guide Book for the Bow Valley (1956). The following description is based on the above sources.

Strata of Cambrian age are restricted to the area near the mouth of the Kananaskis Valley around Barrier Lake. The outcrop is lithologically uniform and consists of buff weathered, hard, light greyarenaceous dolomite interspersed with bands of fine-grained black limestone. Bands of pale green shale also occur.

Great thicknesses of Devonian strata outcrop in the Kananaskis Valley, although the beds have been considerably disturbed by folding and faulting. The Fairholme Formation consists of massive to thinly bedded, black, fine-grained limestone and dolomite with massive beds of light grey, coarse-grained dolomite at the base and top. The Palliser Formation is composed of massive beds of mottled, dark grey, fine-grained

TABLE 11. TABLE OF GEOLOGIC FORMATIONS IN THE STUDY AREA.

System	Series	Formation	Character
Cretaceous	Upper Cretaceous	Belly River	Sandstone, shale, conglomerate and coal seams.
		Wapiabi	Sandy shale and sandstone
		Cardium	Quartzite sandstone and sandy shale.
		Blackstone	Shale and sandstone.
	Lower Cretaceous	Blairmore	Sandstone, shale, conglomerate and arkose.
	Unconformity		
		Kootenay	Sandstone, carbonaceous shale and coal seams.
	Unconformity		
Jurassic		Fernie	Shale, sandy shale and limestone.
	Unconformity		
Triassic		Spray River	Sandstone, shale, dolomite and limestone
	Unconformity		
Permian		Rocky Mtn.	Limestone and dolomite.
	Unconformity		
Carboniferous	Mississip-ian	Banff	Limestone and shale
Devonian		Palliser	Limestone and dolomite
		Fairholme	Limestone and dolomite
	Unconformity		
Cambrian			Limestone and dolomite.

(modified after Beach, 1943)

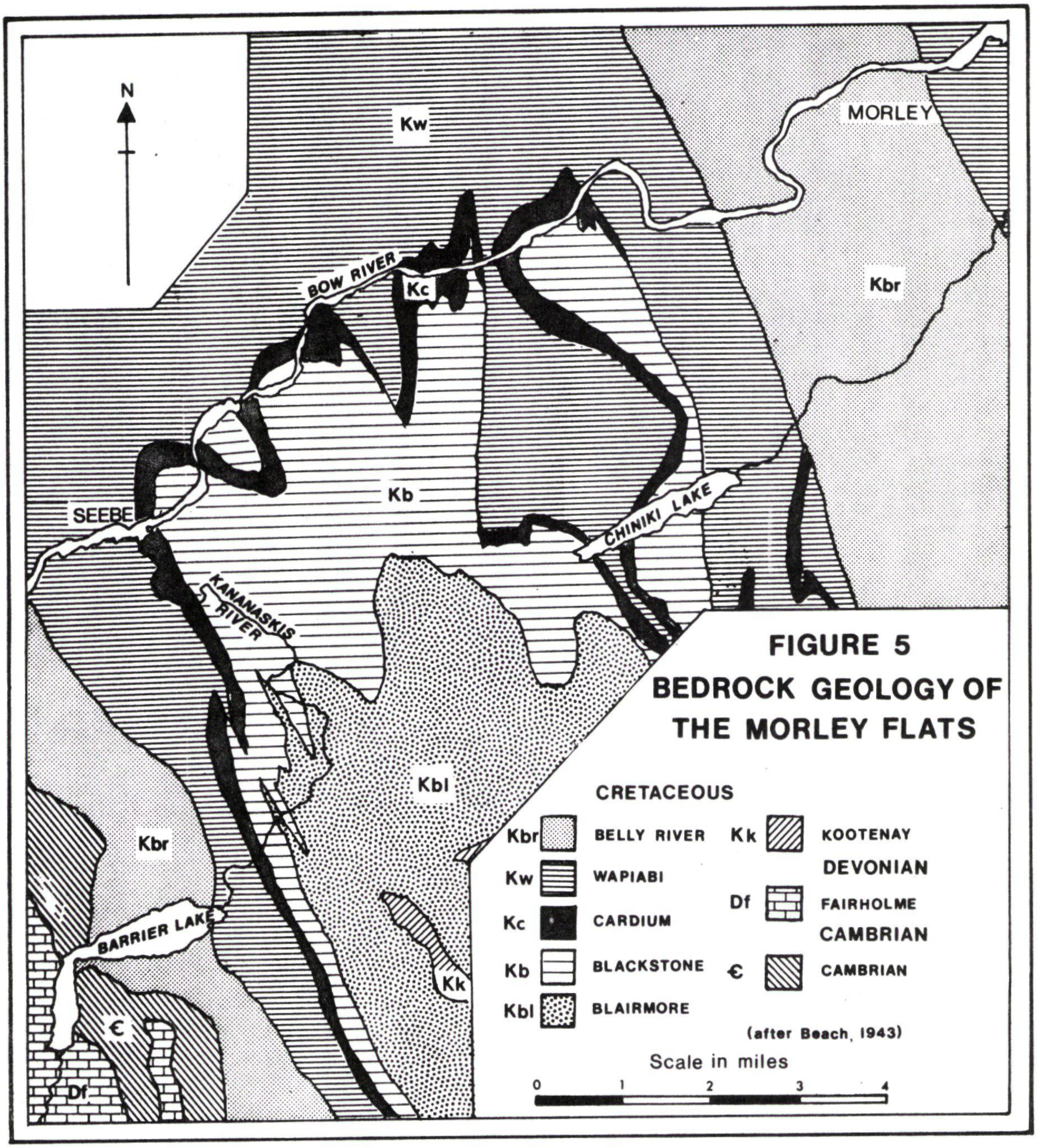


FIGURE 5
BEDROCK GEOLOGY OF THE MORLEY FLATS

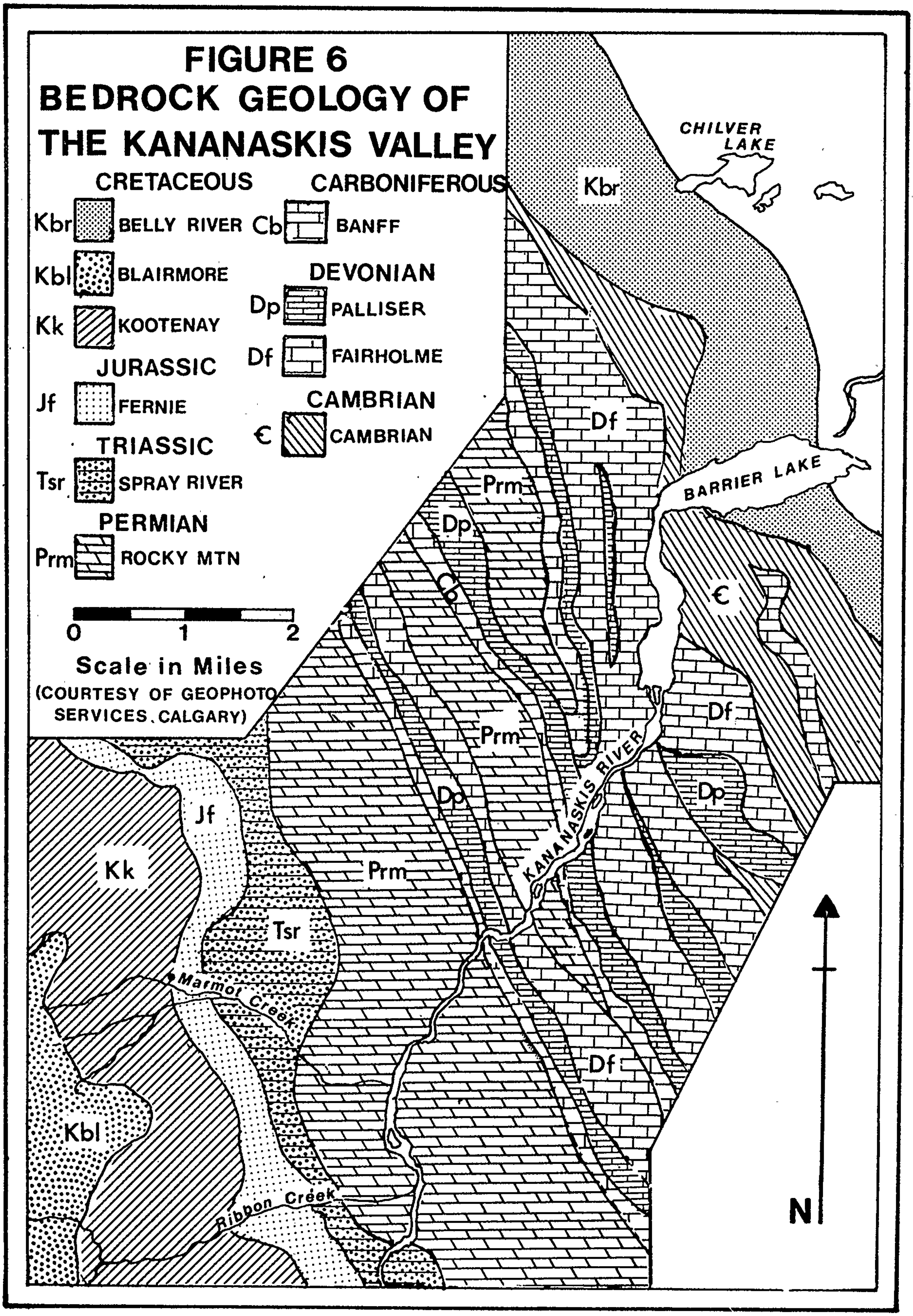


FIGURE 6
BEDROCK GEOLOGY OF THE KANANASKIS VALLEY
CRETACEOUS
Kbr BELLY RIVER
Kbl BLAIRMORE
Kk KOOTENAY
JURASSIC
Jf FERNIE
TRIASSIC
Tsr SPRAY RIVER
PERMIAN
Prm ROCKY MTN
CARBONIFEROUS
Cb BANFF
DEVONIAN
Dp PALLISER
Df FAIRHOLME
CAMBRIAN
€ CAMBRIAN
0 1 2
Scale in Miles
(COURTESY OF GEOPHOTO SERVICES, CALGARY)
CHILVER LAKE
BARRIER LAKE
KANANASKIS RIVER
Marmot Creek
Ribbon Creek
N

dolomite and limestone with thinly bedded black limestone at the top.

The Carboniferous System is represented in the Kananaskis Valley region by the Banff and overlying Rundle Formations. The Banff group consists of thinly-bedded, dark grey argillaceous limestones and calcareous shale grading upwards into black nodular limestone. The overlying Rundle Formation is characterised by massive, light grey, coarse-grained, and dark grey, fine-grained, commonly nodular limestone with beds of arenaceous dolomite, dolomite breccia and cherty limestone in the upper part. In the study area, the Rocky Mountain Group of Permian age is included with the Rundle Formation as the boundary between the two units has yet to be firmly established.

Near the southwestern margins of the study area in the region of Marmot Basin, the Spray River Formation of Triassic age is exposed at the surface. This consists of silty, grey-brown sandstone which is thinly bedded and friable, together with sandy shale, dolomitic shales and argillaceous dolomite and limestone.

The Jurassic is represented in the area by strata of the Fernie Formation which outcrops in the Marmot Creek area of the Kananaskis Valley. The beds consist of black, nodular shales and minor dark limestones overlain by brown, sandy shales with ironstone nodules.

The oldest member of the Lower Cretaceous series in the study area is the Kootenay Formation which outcrops in one locality to the north of Ribbon Creek. It is composed of dark grey and black shales interbedded with fine-grained silty sandstones, dark-grey, coarse-grained sandstones, conglomerate beds and coal seams. The Kootenay Formation is overlain by strata of the Blairmore Group which appears at the surface in Marmot Basin and also forms the high ground to the south of Chiniki Lake. The Formation consists of green, grey and black shales interbedded with fine-grained silty sandstones, coarse sandstones, limestone nodules and massive conglomerates near the base.

Four stratigraphic units of Upper Cretaceous age outcrop in the Morley Flats portion of the study area. These are from oldest to youngest, the Blackstone Formation, the Cardium Group, the Wapiabi Series and the Belly River Formation. The Blackstone Formation consists of black, fissile shale with a few thin beds of sandstone, while the Cardium Group is composed of rusty weathering quartzite sandstone with pebble conglomerate, interbedded with rusty, sandy shale. Nodular sandy shale and dark, platy shale with minor thin sandstone beds characterise the Wapiabi Series and the Belly River Formation consists of green-grey, cross-bedded sandstones interbedded with greenish shales.

All the formations outcropping in the study area have contributed to the surficial material as will be evident when the lithology of the tills is examined.

PHYSIOGRAPHY

The Morley Flats consist of a broad, rolling plain encompassing an area of almost 150 square miles with an average elevation of 4000 feet. The area is masked by thick deposits of outwash gravel and coarse sands which overlie considerable thicknesses of till. Extensive downcutting through the surficial deposits has resulted in the formation of a complex series of terraces which are best developed along the Bow River near Morley, but can be traced southward into the valley of the

Kananaskis. To the south of the Bow River between Seebe and Morley a series of longitudinal ridges trending N.E.-S.W. stand out above the surrounding plain and constitute a distinct morphological unit. These features will be discussed in more detail in Chapter IV. A low ridge with a maximum elevation of 4800 feet separates the Morley Flats proper from the valley occupied by Chiniki Lake and the underfit stream of Chiniki Creek. Deposits of till and lacustrine material are found to the west of Chiniki Lake while to the east the valley is filled with hummocky ground moraine. Overall, the influence of bedrock structure on the landscape is minimal and only in the area to the east of Seebe is bedrock exposed at the surface. There, an outcrop of relatively resistant Cardium Formation is responsible for the topographic high of Seebe ridge.

The Kananaskis Valley offers a distinct contrast to the low-lying area of the Morley Flats. A combination of the marked differences in resistance to erosion offered by the various lithological units, and of the extensive folding and faulting that are the results of massive upheaval has influenced the nature of the topography. The valley itself is hemmed in by upthrust ridges of rock displaying a variety of gradual and precipitous slopes, with raw unweathered ridges and outcrops. The peaks rise to 8500 feet in the study area and only in the area around Marmot Basin is there any change in the rugged, angular scenery. There, an outcrop of less resistant Mesozoic strata is reflected in a wide, gently-sloping valley separated from the Bow Valley to the north by a low col. The significance of this through valley will be discussed below. Glacial activity has left an indelible impression on the landscape and degraded cirques are prominent features on the mountain sides. Truncated spurs, arretes, cols and large areas of ice-scoured bedrock further testify to the power of glacial erosion.

As downslope movement of material occurs at a considerable rate (Harris, 1971), there are few areas in the valley where undisturbed glacial material can be found. Deposits of ground moraine are common around the Environmental Sciences Centre but elsewhere colluvium and mud flow deposits comprise the majority of the surficial material. Outwash gravels and recent alluvium are widespread on the valley floor while around Barrier Lake there are extensive deposits of fine sands and lacustrine material. These latter sediments are felt to be particularly important as they are indicative of the former presence of a large lake. This phenomenon will be discussed at length in Chapter VI.

CHAPTER III

METHODS USED

INTRODUCTION

This chapter deals with the field and laboratory methods used in the pursuit of the study objectives outlined above. The summer months of 1970 were spent in the field and the laboratory programme was completed in the spring of 1971.

FIELD METHODS

Extensive use was made of air photographs (scale 1:16,700 and 1:31,860) throughout the field season. Several flight lines cross the study area and these were examined before field work was begun in order to obtain an overall picture of the region. As the 1:50,000 maps of the area were on too small a scale, overlay maps were derived from the photographs and these were then used to record field observations. Permission to sample on the Stony Indian Reserve which occupies a substantial proportion of the Morley Flats (Figure 2) was denied, and hence air photographs were the only method by which the geomorphic features of this part of the study area could be determined. The dense vegetation cover in the lower Kananaskis Valley also impeded the tracing of surface features on the ground so in this area as well, air photographs proved to be an important interpretive tool.

The sampling technique was determined by the conditions prevailing in the study area and no attempt was made to devise a random sampling design. In the lower Kananaskis Valley, all available sections were examined and it was felt that no benefit could be derived from an alternative method, due to the nature of the terrain, the dense vegetation cover and the equipment available. On the Morley Flats, the presence of the Indian Reserve posed a severe problem. However, modifications to the Trans-Canada Highway exposed a number of fresh road-cuts through the ridge country and thus a transect was possible across the area of the Reserve to the south of the Bow River. Elsewhere on the Flats, detailed sampling was possible along Highway 1A, along the road through Morley Village and in the area between the western boundary of the Reserve and the mountain front. In these localities, all road and river sections were sampled (Figure 7).

At each section, the following techniques were employed. The face was first cleared of loose material and vegetation until a "clean" surface was exposed. When sampling the road-cuts on the Morley Flats it was often necessary to remove over 4 feet of material in order that an undisturbed face could be examined. Moreover, the size of the sections in this area were such that 3 or more sampling pits were necessary to determine variations in the underlying material. When the site had been cleared sufficiently, the colour, texture and degree of stoniness were observed and recorded, although this proved to be of no value in the subsequent analysis. The stratigraphic succession was described and a bulk sample of material was removed for analysis in the laboratory.

A fabric analysis was then carried out as recommended by Harris (1969). A two-foot square was described on the face of the section and the

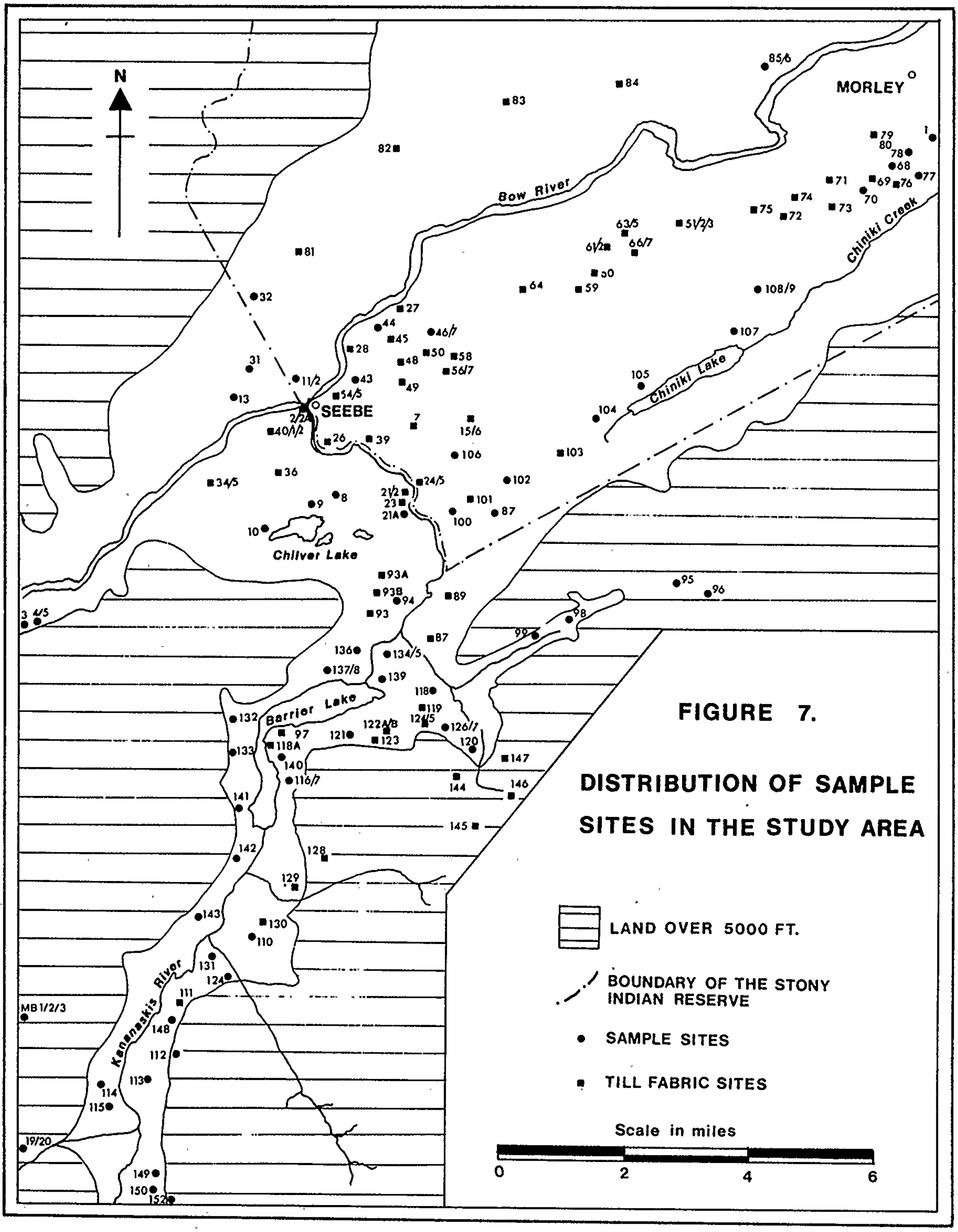


FIGURE 7.

DISTRIBUTION OF SAMPLE SITES IN THE STUDY AREA direction of the long axis of each pebble was measured using a prismatic compass. The readings were recorded in the field and later transferred to a rose diagram using 20 degree class intervals. Discoidal and rounded pebbles were rejected for the purposes of this analysis as it was impossible to determine the preferred orientation of these stones. Upturned pebbles were also rejected owing to the possibility that these had been disturbed by frost heaving.

The problem of sample size for fabric studies has been discussed by several workers. Harrison (1957, p. 279) suggested that a sample size of 25 is sufficient providing that the direction of ice flow is based on data from at least three sites, whereas Krumbein and Pettijohn (1938, p. 218) maintain that at least 100 pebbles should be measured. Harris (1968, p. 24) however, showed that there was no significant difference between fabrics derived from samples of 50, 100 and 150 for the Parkhill Till near Waterloo, Ontario. Hence a sample size of 50 was considered adequate for the present study.

The Chi-square test was employed to determine the significance of the results (Andrews, 1963). In this method, the number of pebbles which would be in each class if all classes were equally filled are compared with the number of pebbles actually occurring in a given mode. The technique is shown in Appendix E and the results are presented in Appendix A. A total of 60 till fabrics were taken and at 52 sites, a significant orientation was obtained. Of the remaining 8 sites, 3 were interpreted as stagnation deposits, and although the required significance level was not reached at the other 5 sites, the preferred orientation was consistent with that obtained at adjacent sites where the primary mode reached the required level of significance.

Fabric analysis was employed at all till and outwash sites and proved to be a valuable tool in determining the direction of ice flow on the Morley Flats and in the area of the Kananaskis Valley adjacent to the field centre. Despite the widespread occurrence of downslope movement in the Kananaskis Valley proper, cross-slope fabrics were obtained from all but two sites and this was considered to be significant in determining the provenance of till in the valley.

Finally, at each site, pebbles were removed from the original two-foot square and placed in a bag for laboratory identification. Krumbein and Pettijohn (1938, p. 472-474) have noted that at least 300 pebbles are necessary to form a statistically viable sample, which is in agreement with the table of confidence limits (Table III) for counts of different sizes derived by Dryden (1931). However, Rutter (1965, p. 37-9) was satisfied that an unbiased sample could be obtained from a count of 100 pebbles. For the purposes of the present study, it was felt that the difference in pebble lithology between valleys would be slight and thus the larger sample of 300 pebbles was preferred. The size of the pebbles collected ranged from 5-100 mm.

LABORATORY ANALYSIS

The laboratory programme was designed to complement the field observations and to trace the variation in surficial deposits across the study area. In particular, analysis was directed towards differences between tills on the Morley Flats and sediments in the lower Kananaskis Valley in terms of grain size, carbonate content and pebble composition.

TABLE 111. PROBABLE ERROR (%) FOR VARIOUS LEVELS OF PROBABILITY AND NUMBERS OF OBJECTS COUNTED (after Dryden, 1931).

Total objects counted	Level of probability 95%	90%	80%	60%
50	42%	29%	19%	12%
100	30%	20%	14%	8%
150	24%	16%	11%	7%
200	21%	14%	9%	6%
250	19%	13%	8%	5%
300	17%	12%	8%	5%
350	16%	11%	7%	5%
400	15%	10%	7%	5%
450	14%	10%	6%	4%
500	13%	9%	6%	4%

Example: For 300 pebbles of which 30 were dolomite, the percentage of dolomite pebbles at the 95% probability level would be between:

$$\frac{30}{300} \times (100 + 17) = \underline{11.7\%}$$

and,

$$\frac{30}{300} \times (100 - 17) = \underline{8.3\%}$$

If only 100 pebbles were counted of which 10 were dolomite, the percentage of dolomite pebbles at the 95% probability level would be between:

$$\frac{10}{100} \times (100 + 30) = \underline{13.0\%}$$

and,

$$\frac{10}{100} \times (100 - 30) = \underline{7.0\%}$$

Grain size analysis has proved to be a useful technique for distinguishing between tills from different source areas in the foothills zone (Boydell, 1970) although Rutter (1965) encountered some difficulty in attempting to separate different ice advances from the same source area on the basis of this method. However, it was felt that as the bedrock geology of the Bow Valley differs from that of the Kananaskis Valley, then it might be possible to distinguish between tills from the two source areas on the basis of grain-size properties.

Mechanical analysis using the pipette method (Krumbein and Pettijohn, 1938, p. 163-172) was carried out on all samples collected in the field. The pipette method was used since it was considered to be the most accurate (See Harris, 1968). A sample of 20 gms. was used in the laboratory and the organic matter was removed by pre-treatment with a 20% solution of hydrogen peroxide. Sodium hexametaphosphate was used as the dispersing agent. The relative proportions of sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (finer than 0.002 mm) were determined by this method for all till sites in the study area.

In his study of the Banff area, Rutter (1965) pretreated the samples selected for mechanical analysis to remove the carbonate content. A test was carried out on samples from the present study area in order to determine whether there was a significant difference between samples which retained the carbonates and those from which the carbonates had been removed. Five samples were chosen from the Morley Flats and five from the Kananaskis Valley. Both the calcium and magnesium carbonate were removed by the addition of dilute (1 normal) and concentrated (6 normal) hydrochloric acid. In all ten cases, carbonate removal by acid pretreatment resulted in the complete destruction of the clay fraction. This was not unexpected as the clay fraction would be composed of material from the predominantly calcareous bedrock underlying the source areas of former glaciers. However, it was felt that no meaningful results could be obtained from grain-size analysis carried out on samples from which the carbonate content had been removed and therefore in the present study, the results of mechanical analysis were obtained from the original method outlined above.

Calcite and dolomite percentages of the finer fractions of samples from the study area were obtained by the Gasometric Method using the Chittick Apparatus as modified by Dreimanis (1962). The Gasometric Method determines the relative percentages of calcite and dolomite, by measuring the amount of gas released by the reaction between the sample and 20 ccs of concentrated (6 normal) hydrochloric acid. This technique was felt to be particularly important as chemical analysis had proved valuable in similar studies elsewhere (Tharin, 1960; Harris, 1968). Forty samples were selected for analysis by means of random number tables: twenty being tested from the lower Kananaskis Valley and a similar number from the Morley Flats. A sample size of 0.85 gms. of the fraction finer than 0.074 mm. was used in the analysis.

Pebble lithologies have often been used as a means for determining the provenance of till (Gravenor, 1951) and as a means for distinguishing tills from different source areas (Boydell, 1970). As with the mechanical analysis, it was felt that the variations in bedrock geology between the Bow and Kananaskis Valleys may well be reflected in the lithological content of the tills from the two source areas.

The lithology of pebbles obtained from the surficial deposits in the study area were therefore determined in the laboratory. Each of the 300 pebbles was first washed to remove adhering material and then broken open so that a fresh face could be examined. Dilute (1 normal) and concentrated (6 normal) hydrochloric acid were then used to differentiate between Paleozoic limestones and dolomitic rocks and also between the darker carbonate rocks and the black cherts. Quartzites were distinguished from sandstones on the basis of the presence of unaltered grains in the sandstone pebbles. Special emphasis was placed on the pink-banded quartzites which are thought to have originated near Mt. Eisenhower in the upper Bow Valley (Rutter, personal communication, 1971) and are therefore regarded as important source indicators. The pebbles were divided into seven categories - limestone, dolomite, chert, sandstone, quartzite, shale and other. The latter group is composed mainly of iron concretions and metamorphic and granitic pebbles were absent.

The results of these field and laboratory techniques and the significance of the findings will be discussed in the following two chapters.

CHAPTER IV

THE MORLEY FLATS AREA

INTRODUCTION

The study objectives on the Morley Flats were twofold. In the first place, a detailed analysis of the surficial deposits was undertaken in order to determine whether or not ice had moved out of the Kananaskis Valley in late-Quaternary times. If it was found that the Kananaskis glacier did extend onto the Morley Flats, then an attempt would be made to establish the areal extent of the ice mass. Secondly, the study was aimed at determining the origin of the longitudinal ridges on the Flats with a view to relating the features to former ice movements across the region.

INTERPRETATION OF TILLS

On the Morley Flats, the till is generally buff-grey in colour and blocky in character. A wide range of pebble types are present and many display striated or etched surfaces. The maximum thickness of till was difficult to determine, although at most sites examined, over 10 feet was exposed. No attempt was made to distinguish between lodgement till and ablation till, but at some localities it was possible to differentiate between ground moraine and stagnation deposits. It was, however, considered to be of the utmost importance to note the spatial variation of sediments which might indicate differences in tills from source areas in the Kananaskis Valley and those in the Bow.

Fabric Analysis

Although none of the previous workers studying the Bow Valley area had employed fabric analysis, it was felt that this technique would be of particular value in determining the direction of ice-flow across the Flats, and especially in the critical area adjacent to the mouth of the Kananaskis Valley. Two-dimensional fabric analysis was carried out at all till sites and the results are depicted in Figure 8. Although dips of pebbles were not measured accurately, a dominant upvalley plunge was observed throughout the Morley Flats area.

An examination of the fabric data reveals that a marked W.-E. orientation is common throughout the Morley Flats region (Figure 8). Only in the area to the east of Seebe do the fabrics tend to become confused. There, it is suggested that the bedrock high of Seebe ridge acted as a barrier around which ice was initially deflected and over which it later stagnated, producing a more random pebble orientation than occurs elsewhere on the Flats. Evidence of water-washing in the form of gravel bands and sand lenses in the tills near Seebe lends support to this hypothesis.

The most significant point emerging from the fabric data concerns the direction of preferred orientation of pebbles in the area near the mouth of the Kananaskis Valley. If ice had moved out of the valley onto the Morley Flats, then a SSW-NNE trend should be detectable in the primary mode of the fabrics. The results of the study of pebble orientation obtained from this area reveals that this is not the case. Indeed, the dominant trend appears to be NW-SE indicating that ice moving down the

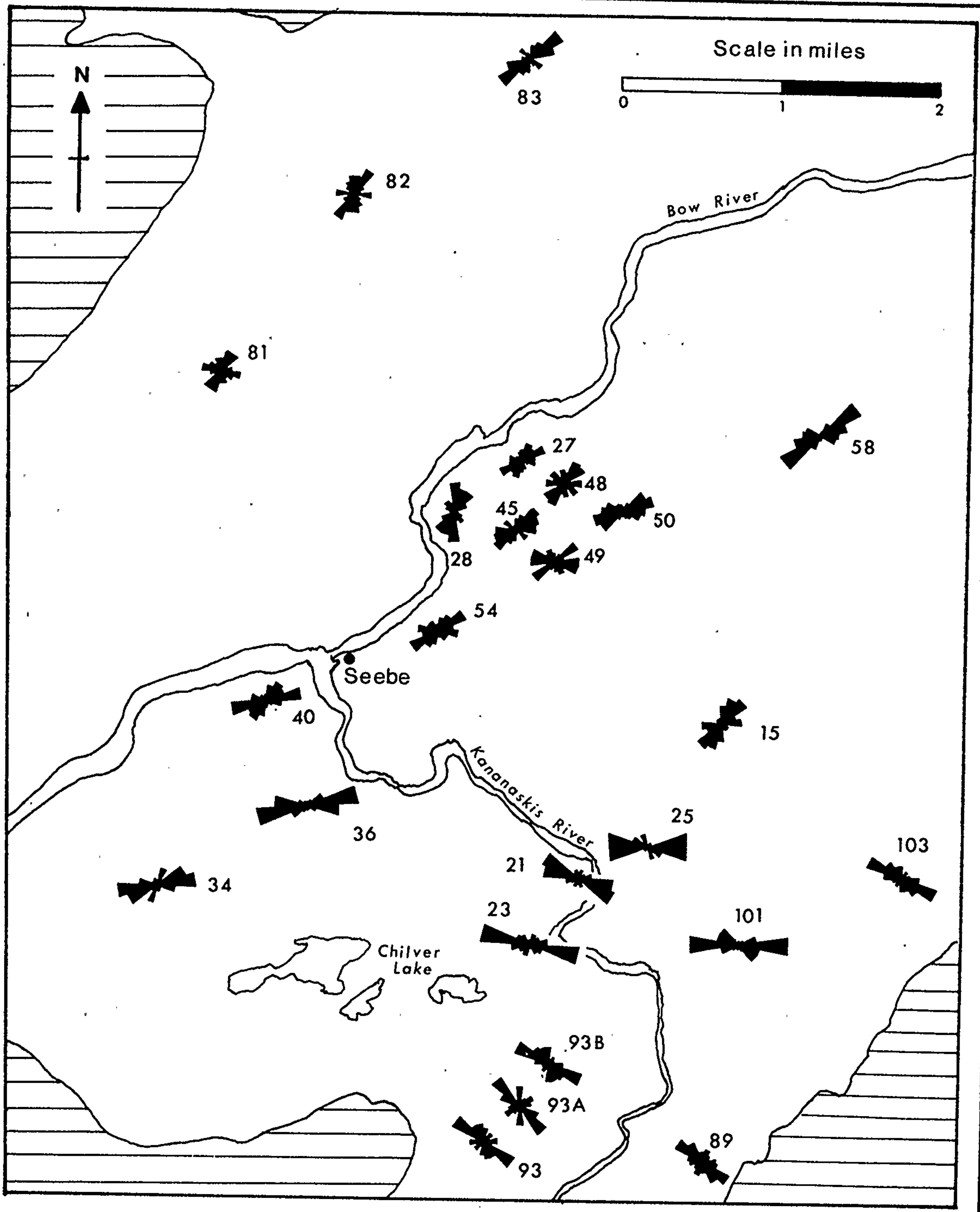


FIGURE 8. **Till fabrics from the western Morley Flats.**

Bow Valley and eastwards across the Flats spread southward into the lower areas of the Kananaskis Valley. This point will be discussed in more detail in Chapter V.

Laboratory Analysis

Mechanical analysis, carbonate analysis and the determination of pebble lithologies were carried out for each site on the Morley Flats in order to analyse the spatial variation in tills in this part of the study area. For the purposes of comparison, samples were also collected from the Exshaw area of the Bow Valley to the west of the Morley Flats.

Figure 9 shows the variation in the grain-size properties of till on the Morley Flats and in the Exshaw area. The sand fraction ranges from 40%-70%, the silt fraction from 20%-40% and the clay fraction from 10%-25%. The four sites where the sand fraction exceeds 60% occur along Highway 1A on the north side of the Bow River and appear to have been considerably affected by water-washing during deglaciation. Three sites in the western area of Chiniki Valley exhibit a high silt and clay percentage and are thought to have been affected by the former presence of a lake in this portion of the area during the deglacial sequence (Chapter VI). Overall, the tills of the Morley Flats appear to be relatively homogeneous in terms of grain-size properties and are directly comparable to the samples obtained from the Exshaw area.

The percentages of calcite and dolomite in tills on the Morley Flats are shown in Figure 10 and again it is difficult to distinguish two groups on the basis of this analysis. The high carbonate percentages are directly attributable to the predominantly carbonaceous bedrock of

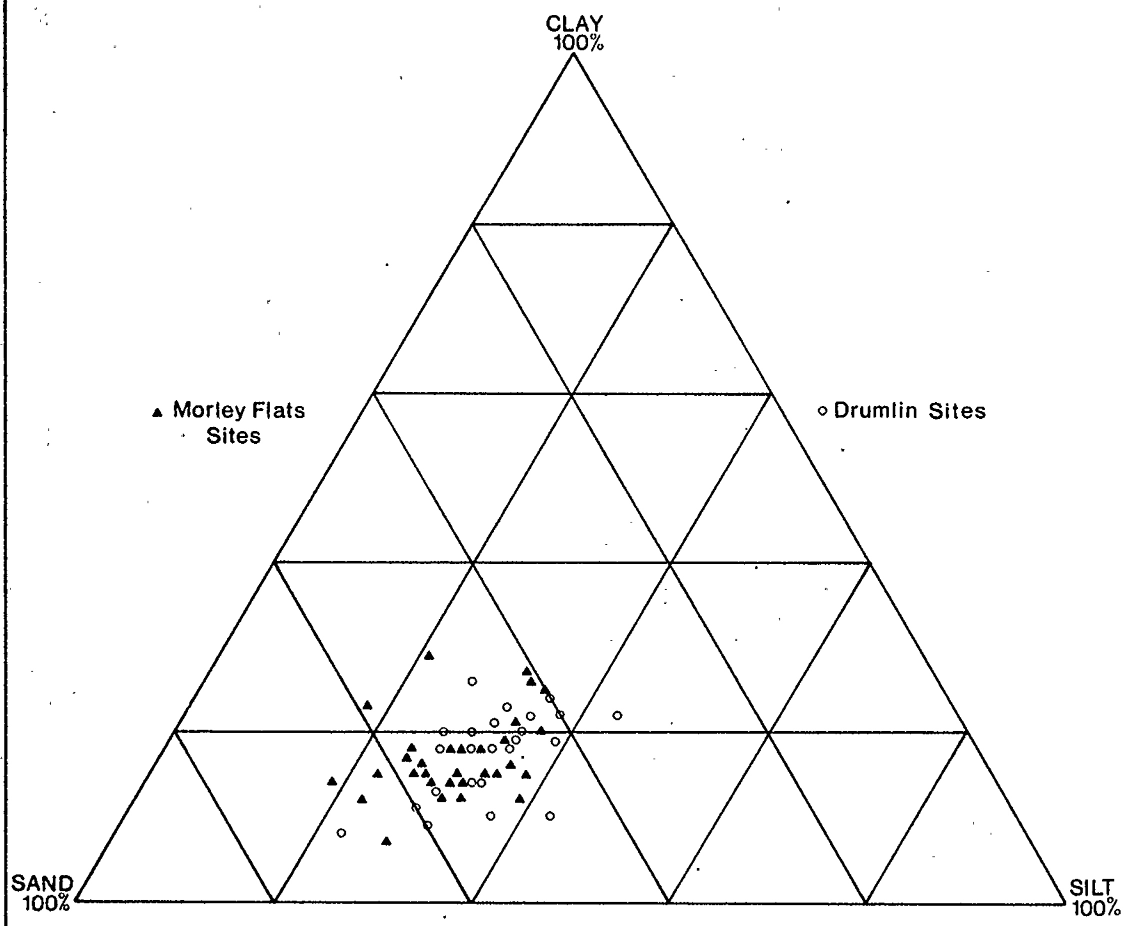


FIGURE 9. Results of the Mechanical Analysis of tills on the Morley Flats.

the Front Ranges to the west of the study area and are consistent with the carbonate percentages obtained by Tharin (1960) for mountain tills in the Calgary area.

As with the two previous analyses, the determination of pebble lithologies in the tills of the Morley Flats and the Exshaw area revealed no statistically significant areal variation (Figure 11). Limestone and dolomite pebbles formed the dominant lithology at all sites examined, being as high as 80% of the 300 pebbles counted in some localities. Quartzite and sandstone pebbles were also common although the number never exceeded 40% of the total for a particular site. Examples of the pink Lower Cambrian quartzite described in Chapter III were found at most sites and occasionally pebbles of green, basic igneous rock (dolerite?) occurred. The latter were found by Rutter (1965, p. 33) in till to the northwest of Banff and are thought to have been derived from the Crowsfoot dyke located near Bow Lake (Smith, 1963) and possibly from dykes in the Lake Louise area (Akehurst, A., personal communication to Rutter, 1966). Mesozoic pebbles represented a very low percentage of the total pebbles counted at most sites due largely to the lack of resistance to erosion offered by the Cretaceous strata underlying the Flats.

In summary, a combination of field and laboratory evidence suggests that:

(1) The glacial deposits occurring at the surface on the Morley Flats are homogeneous in terms of source area.

(2) They resulted from deposition by Bow Valley ice.

(3) If Kananaskis ice did move down the Kananaskis Valley during the late-Quaternary period, this ice did not reach the Morley Flats area of

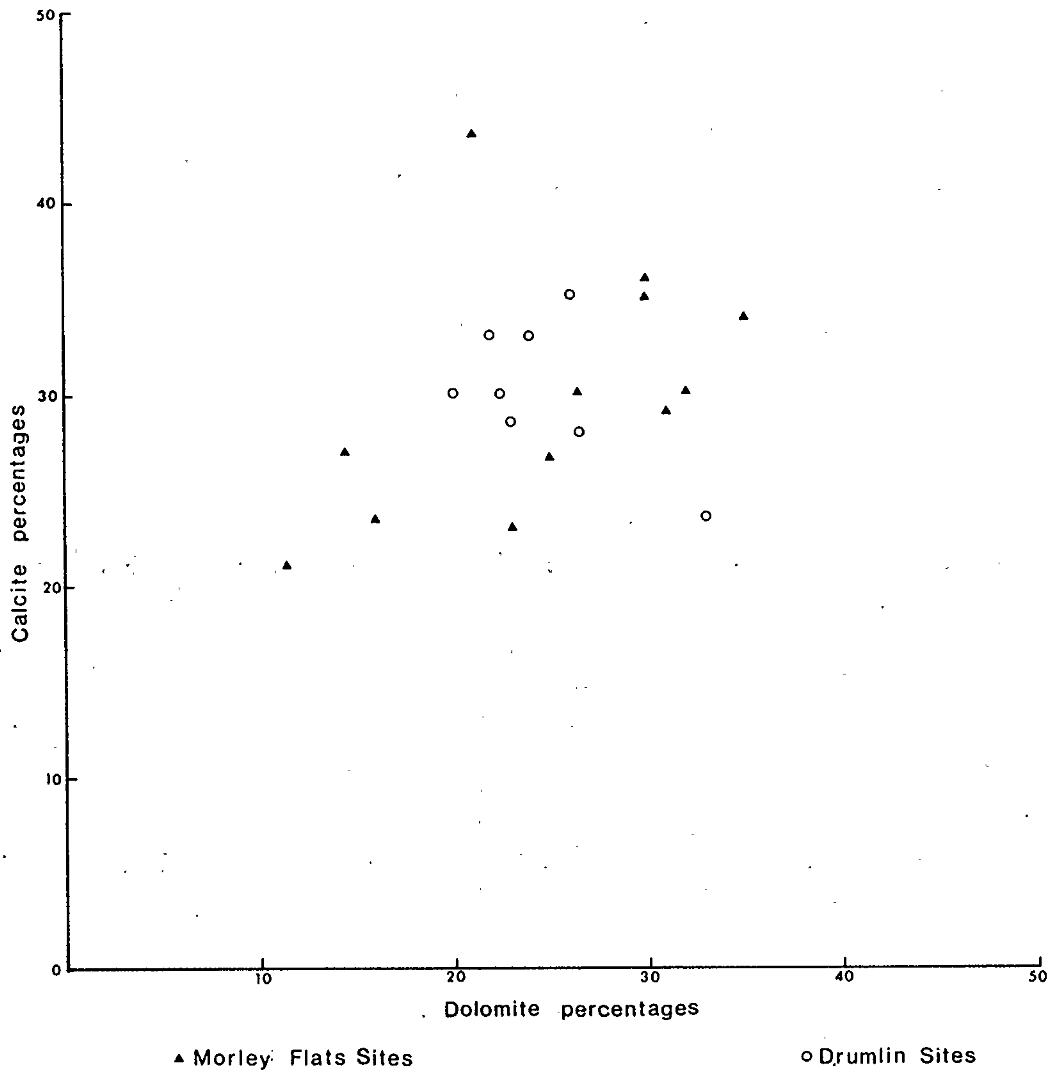


FIGURE 10. Carbonate content of tills on the Morley Flats.

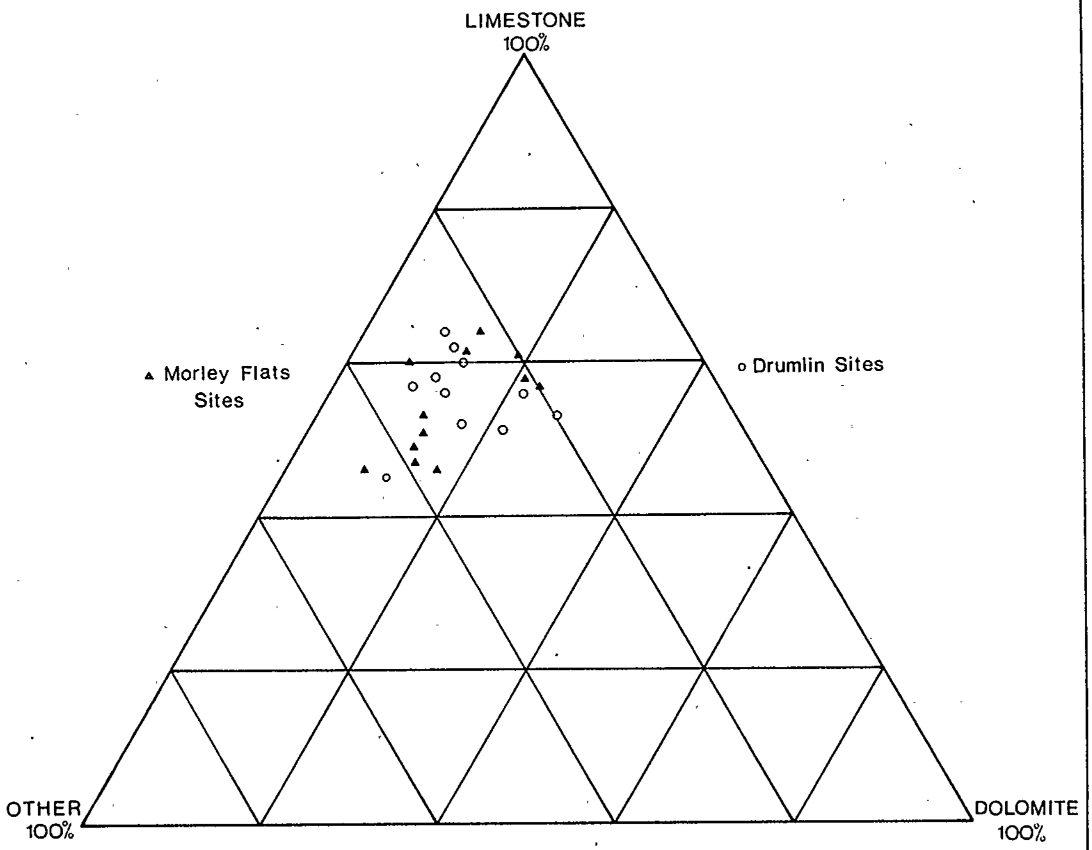


FIGURE 11. **Proportional lithological composition of tills on the Morley Flats.**

the Bow Valley.

(4) The fabrics near the mouth of the Kananaskis Valley indicate that Bow Valley ice flowed southwards into the lower areas of that valley.

Two-Till Sequence

At only two localities on the Morley Flats are sections exposed where more than one till unit is present. One is on the Stony Indian Reserve to the west of Morley and was not sampled during the course of this investigation. The second occurs on the north bank of the Kananaskis River in the southwest portion of the Morley Flats area.

The section on the Indian Reserve is exposed in the steep bluffs overlooking the Bow River. A black, blocky, deeply-weathered till is separated from the overlying buff-grey till by a thin band of outwash gravels. A thicker layer of coarse gravel and sand overlies the upper till (Rutter, personal communication, 1971). It is possible that the two-till sequence recorded by Nichols (1931) and discussed in Chapter I is the same as the one described here.

The site along the Kananaskis River was investigated by the author. Again, two distinct till units are present, although in this case the lower member is also buff-grey (Plate 3). This is separated from the upper till by approximately 5 feet of coarse sand and gravel which is thought to be outwash deposited during the retreat of the glacier which laid down the lower till. The upper till is between 4 and 5 feet in thickness and is lighter in colour and less compact than the lower one. The whole sequence is overlain by up to 6 feet of coarse gravels. Fabric analysis reveals that both tills were deposited by glaciers moving in the same direction (110-113^{o}) across the area which suggests that both the upper and lower deposits are the products of Bow Valley ice. No distinction could be made between the tills on the basis of mechanical analysis, carbonate analysis or pebble composition.

The Age of the Morley Flats Tills

Rutter (1965, 1966a, 1966b, 1971) suggested that only two advances of Bow Valley ice crossed the Morley Flats in Wisconsin times. He tentatively assigned the earliest advance to Bull Lake age (Figure 3) on the basis of correlation with the work of Richmond in the U.S.A. The basal till exposed in the section on the Indian Reserve is thought to have resulted from that glacial phase (Rutter, personal communication, 1970). The widespread buff-grey till which in most cases constitutes the upper till on the Morley Flats was therefore assigned by Rutter to the Main Bow advance (Early Pinedale Stade). The Canmore advance tentatively correlated by Rutter with the Middle Pinedale Stade is represented only in the extreme western area of the Flats where the hummocky gravel area of the Bow Valley Provincial Park constitutes the destroyed terminal moraine of that glacier (Rutter, 1965).

If this sequence is correct, then the two-till exposure along the Kananaskis River poses a problem. The lower till in that locality does not appear to correspond to the Black Till described by Rutter in the section on the Indian Reserve, or the Pre-Bow till located in a borehole near Canmore (Rutter and Wyder, 1969), as it is grey in colour and shows no signs of deep weathering. Moreover, the difference between the lower and upper till is minimal.

It is possible that the upper till may represent a minor readvance of the Main Bow glacier. However, supporting evidence for this hypothesis either in terms of two-till sequences further east or the presence of recessional moraines is lacking. An alternative suggestion is to assign the upper till to the Canmore advance glacier which is thought to have terminated in this locality. This theory is more attractive as it is consistent with the postulated areal extent of the Canmore advance glacier and would explain why two-till sequences of this nature are not found to the east of the Kananaskis River on the Morley Flats proper. If this hypothesis is adopted, then the lower till at this site is assigned to the Main Bow advance glacier.

INTERPRETATION OF THE RIDGES

Distribution and Morphology

The longitudinal ridges occupy approximately 70 square miles of the Morley Flats between Seebe in the west and the Ghost River dam in the east. Although the majority are concentrated on the south side of the Bow River between Seebe and Morley settlement, it is possible to trace the features southward over the low ridge into the valley occupied by Chiniki Lake. Isolated ridges are also found on the north side of the Bow River along the 1A Highway.

The long axes of the ridges have an average azimuth of N 75°W and are from 1000 to 1400 feet in length. The width of the ridges varies from 200 to 900 feet and in general their height lies between 15 and 75 feet. The slopes are relatively steep and meet the adjoining flats at a sharp angle. The ridges which occur to the north of the Bow River are single units and are often larger than those on the south side of the Bow and on the slopes above Lake Chiniki. The latter group are often compound features with one ridge merging into the next en echelon. The ridges in the area around Morley settlement, in the valley of Chiniki Creek and on the north side of the Bow River are markedly drumlinoidal (Plates 5 and 6) in form with a steep proximal slope facing upvalley and a gentle distal slope on the eastern side. However, the landforms due south and east of Seebe vary considerably in morphology and often possess low swales in the summits (Plate 4). Dry channels cut through the ridge country and a number of terrace levels are evident, although these were not examined in detail.

Crevasse-filling Hypothesis

The ridges on the Morley Flats have been interpreted as drumlins (McConnell, 1895; Tharin, 1960) and crevasse-fillings (Nelson, 1963). The writer disagrees with the crevasse-filling hypothesis for the following reasons.

(1) A preferred orientation of pebbles was recorded at all sites in the ridge country and in most cases the primary mode was orientated parallel to the long axes of the ridges (Figure 12).

(2) The ridges on the Flats are composed of a blocky, buff-grey till which is partially masked by coarse gravel. Laboratory analysis reveals that there is no statistically significant difference between till in the ridges and till elsewhere on the Flats in terms of grain-size, pebble lithologies or carbonate content (Figures 10-12). No evidence could be found of collapsed structures or waterlain material which would indicate that the ridges were crevasse fillings.

(3) Crevasse fillings commonly occur in a form in which two or more directions of ridge orientation prevail (Mackay, 1960). Also as a group they do not possess the streamlined form displayed by the ridges on the Morley Flats.

(4) Borehole data from a single ridge near Ozada suggests the presence of what appears to be stratified material (Rutter, personal communication, 1970). Again it is difficult to reconcile the presence of stratified till with the mode of origin postulated by Nelson.

Drumlin Hypothesis

Field and laboratory evidence from the Morley Flats lends support to the contention of McConnell and Tharin that the elongated ridges are drumlins. For the purposes of this thesis, a drumlin is defined as:

> a low hill having an oval outline and not exceeding 60 metres in height. It is formed mainly of till but sometimes contains stratified material or a rock core.
> (Embleton and King, 1968, p. 322)

The results also suggest that the features are dominantly accretional landforms.

As was mentioned above, a strong preferred orientation of pebbles was obtained at most sites with the primary mode orientated parallel to the long axis of the ridge. Wright (1957, p. 26) observed the same phenomenon in the Wadena drumlin field in Minnesota. He concluded that the stones were carried in the basal ice by sliding and that the drumlins formed from the accretion of basal till. Embleton and King point out that:

> The orientation of stones in the till of drumlins is a

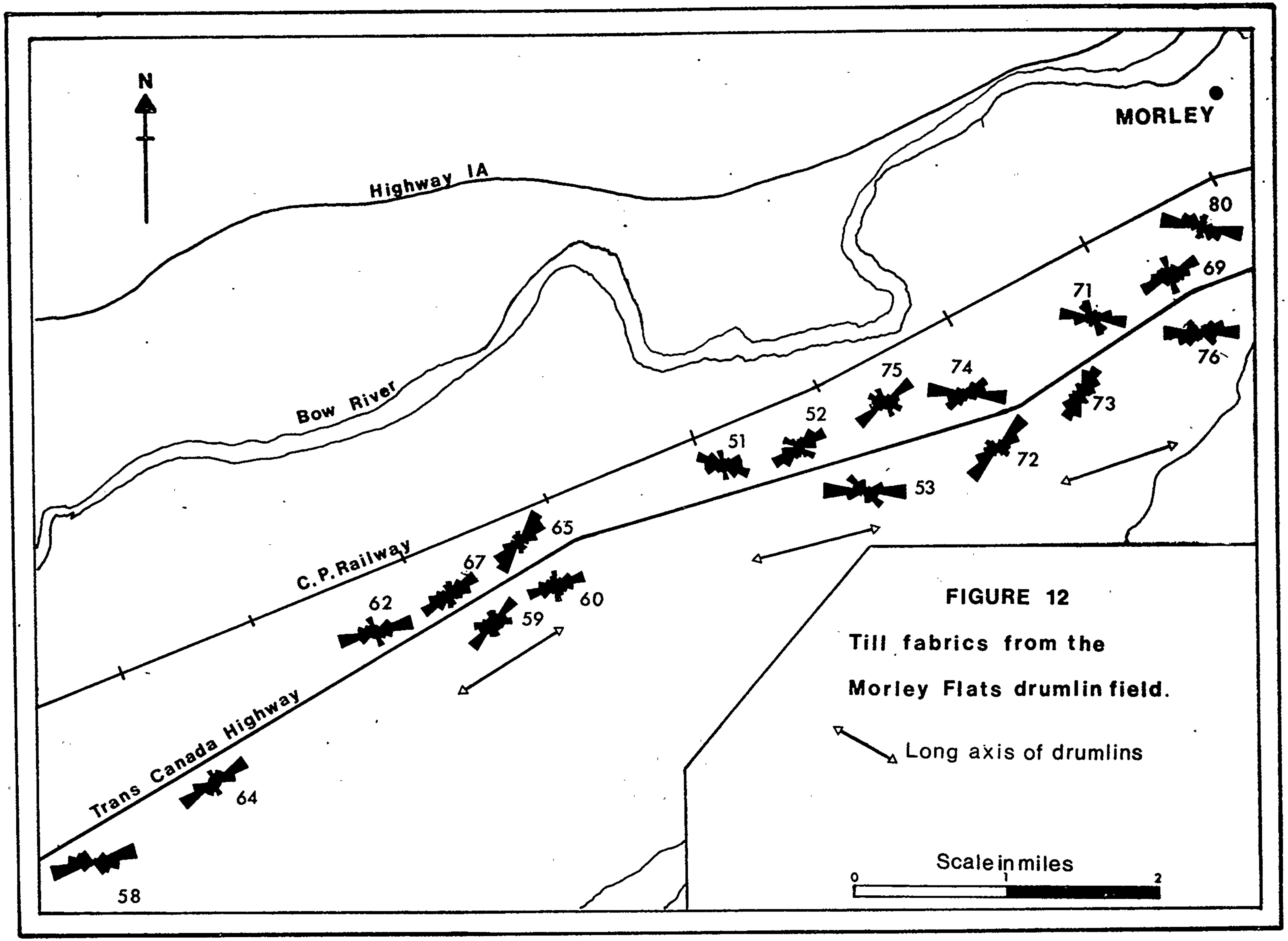


FIGURE 12

Till fabrics from the Morley Flats drumlin field.

> strong argument in favour of their deposition by moving ice, which is also responsible for shaping them into drumlin form. Both the drumlin elongation and the stone orientation have clearly been determined by the same ice flow, and where this can be shown to be true, those particular drumlins can confidently be stated to be depositional in character.
> (Embleton and King, 1968, p. 322)

Fabrics obtained from a single drumlinoidal ridge near Ozada show that in this case divergence occurred at the stoss end of the ridge and ice then flowed round the till mound (Figure 13). The dips of pebbles in the two ends of the ridge further suggests that some form of moulding action took place as the pebbles tend to plunge upvalley on the steeper proximal slope and downvalley on the more gentle distal slope. The characteristics of this particular ridge are therefore consistent with the interpretation of the landforms as depositional drumlins.

Finally, the similarity between till in the ridges and that elsewhere on the Flats coupled with the suggestion of stratified till in the bore-logs of Rutter in the ridge near Ozada lend further support to the contention that the ridges on the Flats are accretional drumlins. Similar stratification was used by Fairchild (1906) in his original suggestion that the drumlins of the Finger-Lakes region of New York State were formed by a depositional process.

Discussion

Although the ridges on the Morley Flats conform to many of the characteristics associated with accretional or depositional drumlins, the shape of the landforms poses a problem. Many of the ridges, particularly in the area to the south of Morley settlement possess a marked drumlinoidal profile, but this is not the case in all areas of the ridge country.

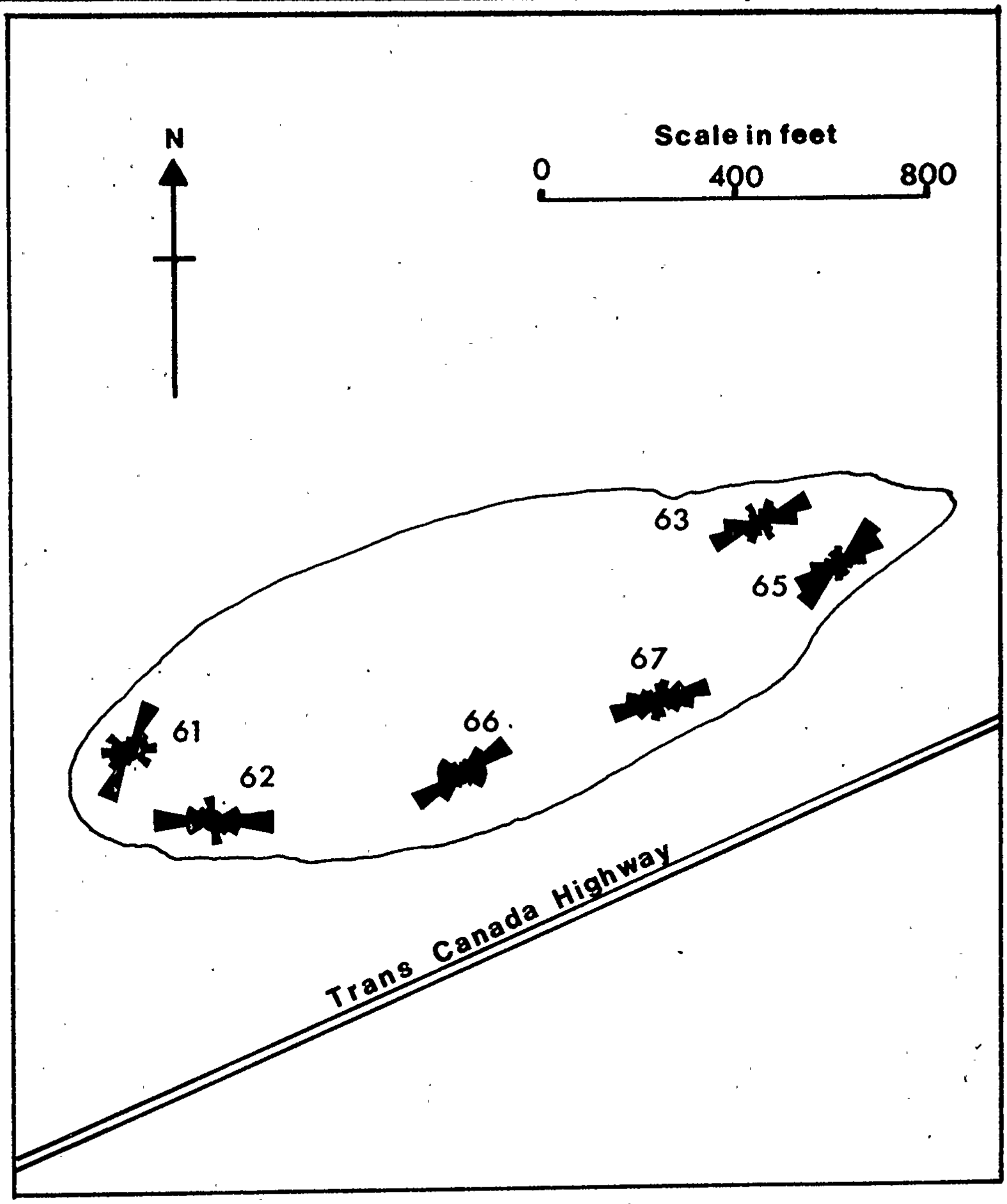


FIGURE 13 Till fabrics in a drumlin on the Morley Flats.

Near the mountain front for example, the ridges are less numerous and rarely exhibit the characteristic steep proximal slope and more gentle distal slope commonly found in drumlins. Also, a number possess a low swale-like depression on the summit. It is proposed that these ridges may owe their unusual form to post-depositional deformation by meltwater issuing from the Bow and Kananaskis Valleys during successive deglacial phases, whereas the more closely-spaced ridges near Morley would have derived some degree of protection from erosion by meltwater and would therefore retain their original morphology. The presence of outwash gravels on the sides of the ridges and in some cases on the summits lends support to the meltwater erosion hypothesis. The low swales on the ridge tops may be due to the melting out of residual ice blocks which remained after the main glacier had retreated from the area.

While this hypothesis may prove adequate to explain the shape of some of the ridges, it is difficult to attribute all the variations in ridge morphology to post-depositional deformation. For example, in the area near Morley settlement, classic drumlin features occur adjacent to ridges which cannot be interpreted as drumlins purely in the morphological terms. An attempt was made to map the variation in form throughout the study area, but this proved virtually impossible due to the degree of intergrowth between many of the ridges and the great variety of types within the area.

However, although there is no apparent uniformity between the ridges in terms of shape, the internal characteristics discussed above strongly suggest that the processes responsible for the formation of the drumlinoidal ridges were the same throughout the study area, and that the features resulted from the accretion of subglacial material beneath moving ice. The variations in form of the ridges may therefore be a function of dynamic conditions prevailing in the ice at the time of formation. Different stress zones in a valley glacier have been reported by McPherson and Gardner (1968), and it may well be that alternating zones of high and low pressure within the glacier which formed the ridges on the Morley Flats was responsible for the development of perfect drumlin features in some localities while longitudinal ridges which do not exhibit the characteristic drumlin profile developed in others.

Age and Significance of the Drumlinoidal Ridges

The laboratory analysis discussed above demonstrates that the drumlins are composed of the same material which is ubiquitous throughout the Morley Flats region. It was also suggested that the widespread buff-grey till on the Flats was deposited by the main Bow Valley glacier, regarded as Pinedale 1 by Rutter (1965), and therefore it is logical to assume that the drumlins were formed during the same glacial phase.

The interpretation of the ridges as drumlins composed of Bow Valley Till rather than as crevasse fillings removes one of the strongest lines of argument for the former presence of Kananaskis ice on the Morley Flats in late-Wisconsin times. Evidence for the extension of Bow Valley ice into the valley of the Kananaskis will be discussed in the following chapter.

CHAPTER V

THE KANANASKIS VALLEY

INTRODUCTION

This chapter deals with the nature and origin of surficial material in the Kananaskis Valley portion of the study area. The areal extent of Bow Valley ice is traced and an explanation put forward for the apparent absence of Kananaskis ice in the lower ten miles of the valley during the late-Wisconsin period.

INTERPRETATION OF TILLS

One of the major problems encountered in the Kananaskis Valley was the widespread occurrence of reworked material and the relatively small number of sites where glacial till was present in an unaltered state. Ground moraine which closely resembles that on the Morley Flats in terms of colour, texture and degree of compaction is restricted to the area around the field centre and a few localities in the main valley to the south of Barrier Lake. Elsewhere, the surficial material has undergone considerable modification through the processes of downslope movement either in the form of creep (Harris, 1971) or flow. Even where sections of compact till occur, sand lenses and thin bands of fine gravel in the material are often present. In many cases, the random fabric coupled with the marked similarity between these deposits and those occurring around Seebe Ridge on the Morley Flats suggest that these tills may have resulted from ice stagnation.

When sampling the surficial material in the Kananaskis Valley, the writer was careful to examine in detail only those sites where there appeared to have been a minimum of reworking. Hence it was possible to effect a reasonable comparison between till in the Kananaskis Valley and the glacial deposits on the Morley Flats on the basis of the results obtained from the laboratory analysis.

Laboratory Analysis

The range of grain sizes in the tills of the Kananaskis Valley is considerably greater than in tills on the Morley Flats (Figure 14). The sand fraction varies from 26%-70%, the silt fraction from 18%-48% and the clay fraction from 8%-32%. It is felt that this wider range in particle size is due largely to subsequent alteration of the material although some modification may have taken place during the deglacial sequence. Overall, however, there is no difference between till on the Flats and till in the valley in terms of the relative proportions of sand, silt and clay. Moreover, there is no apparent difference between tills in the study area and tills in the Exshaw area on the basis of this analysis.

The percentages of calcite and dolomite in the tills of the study are shown in Figure 15. Again, it is difficult to separate tills in the Bow Valley from those in the Kananaskis Valley. The Student's "t" test was employed to determine whether there was a statistically significant difference between tills in the two areas in terms of calcite, dolomite or total carbonate percentages (Appendix F). The data was

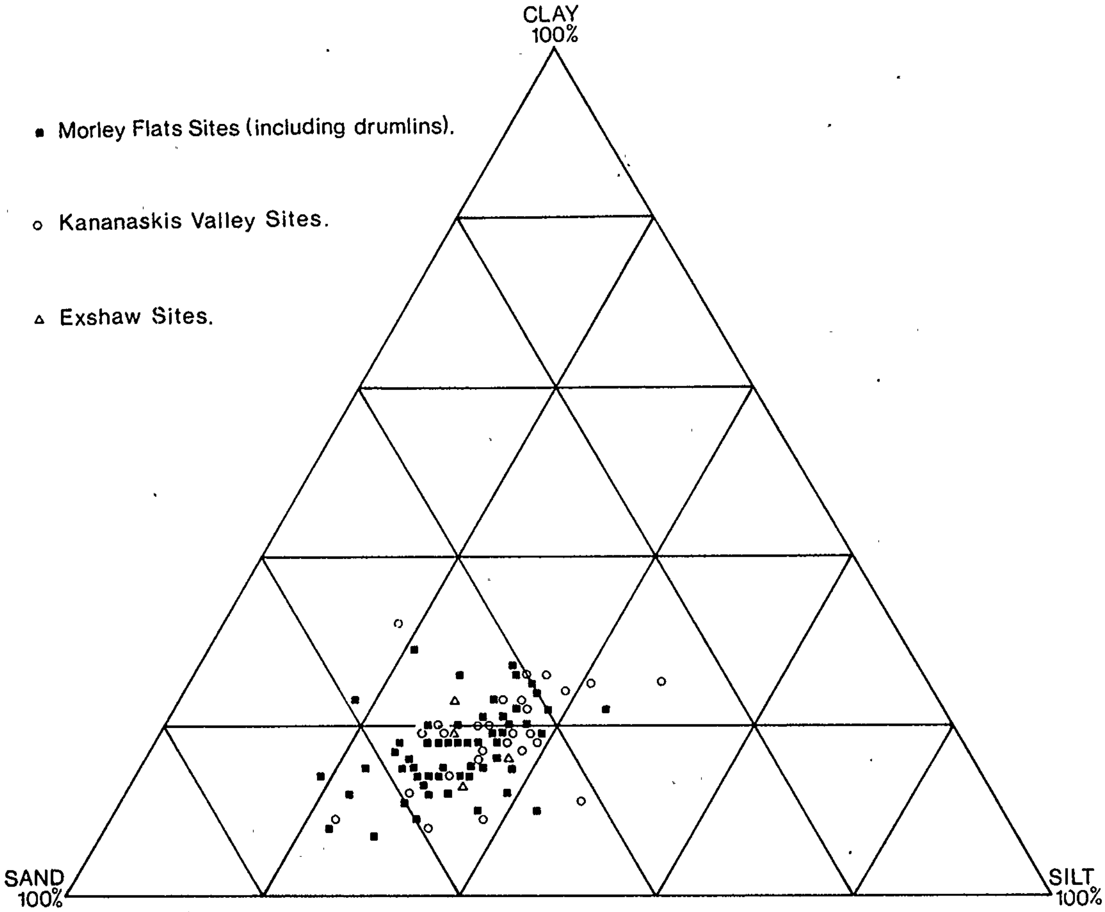


FIGURE 14. **Results of the Mechanical Analysis of tills in the Study Area.**

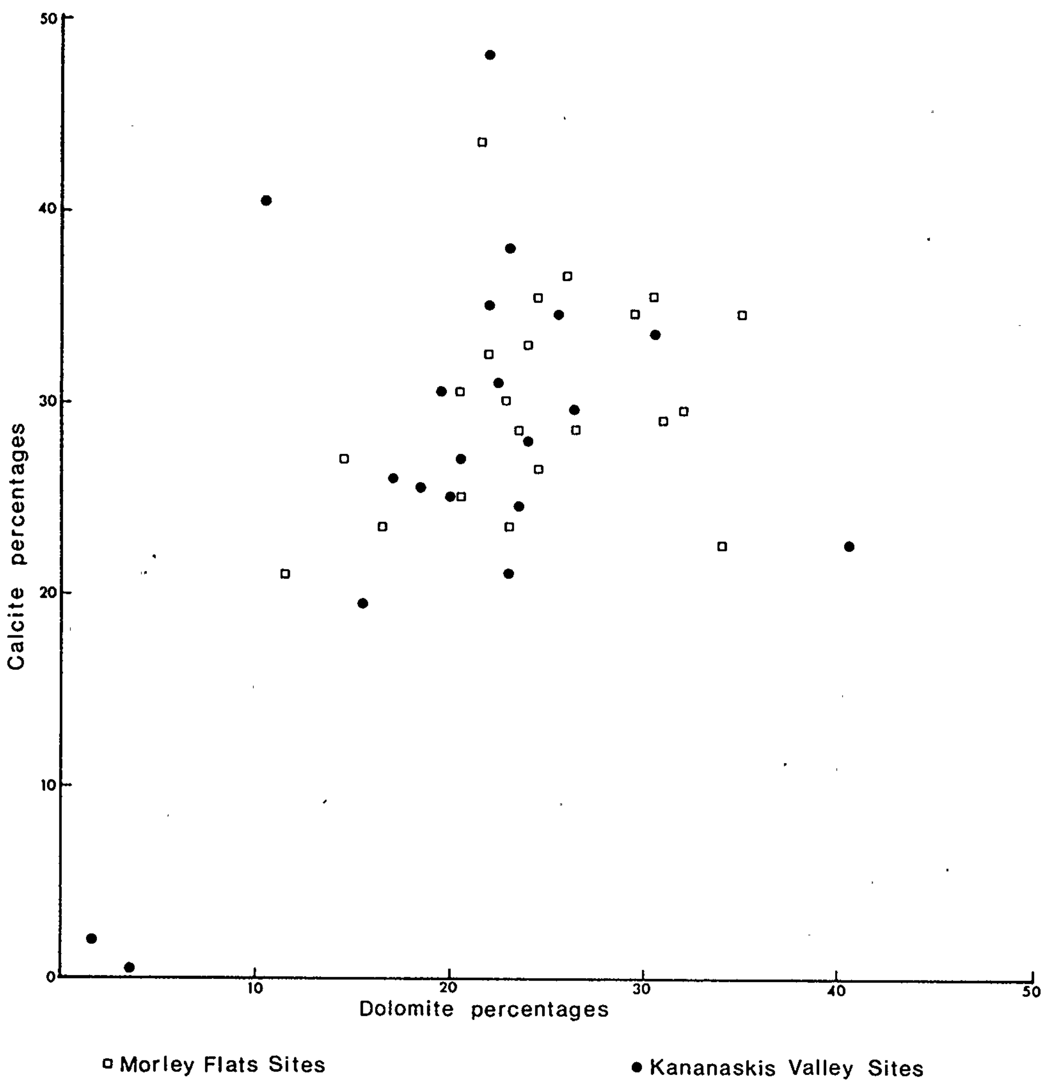


FIGURE 15. Carbonate content of tills in the Study Area.

normally distributed, and the null hypothesis was therefore set up that there was a statistically significant difference between the means of the two populations. At the 5% level of significance the null hypothesis was rejected indicating that there was no statistically significant difference between the calcite, dolomite or total carbonate percentages of the tills in the two areas, and that there was a strong possibility that all the tills in the study area were derived from the same glacier.

The determination of pebble lithologies in the surficial deposits of the Kananaskis Valley was felt to be of particular importance as this was the only method of analysis where the results would be unaffected by reworking of the surficial material. The pink-banded quartzites which were found on the Morley Flats occurred at many sites in the valley although the dark green igneous pebbles were absent. Figure 16 shows the distribution of pebble types in the Kananaskis Valley when compared to the lithological content of tills on the Morley Flats and in the Exshaw area. As with grain-size results, several sites in the Kananaskis Valley are different from the main group. These apparent anomalies can be explained by comparing these sites to the bedrock geology map (Figure 8). Relatively high proportions of soft shale occur in the surficial deposits to the east of Barrier Mountain and in the Marmot Basin area, and are a reflection of shale outcrops in those two localities.

The Kendall Coefficient of Concordance (Seigel, 1956, p. 229) was used to test the degree of similarity between pebble content in the tills of the Exshaw area, the Morley Flats and the Kananaskis Valley (Appendix G). A non-parametric test was necessary owing to the non random nature of the sampling pattern. The pebble groups were first ranked for

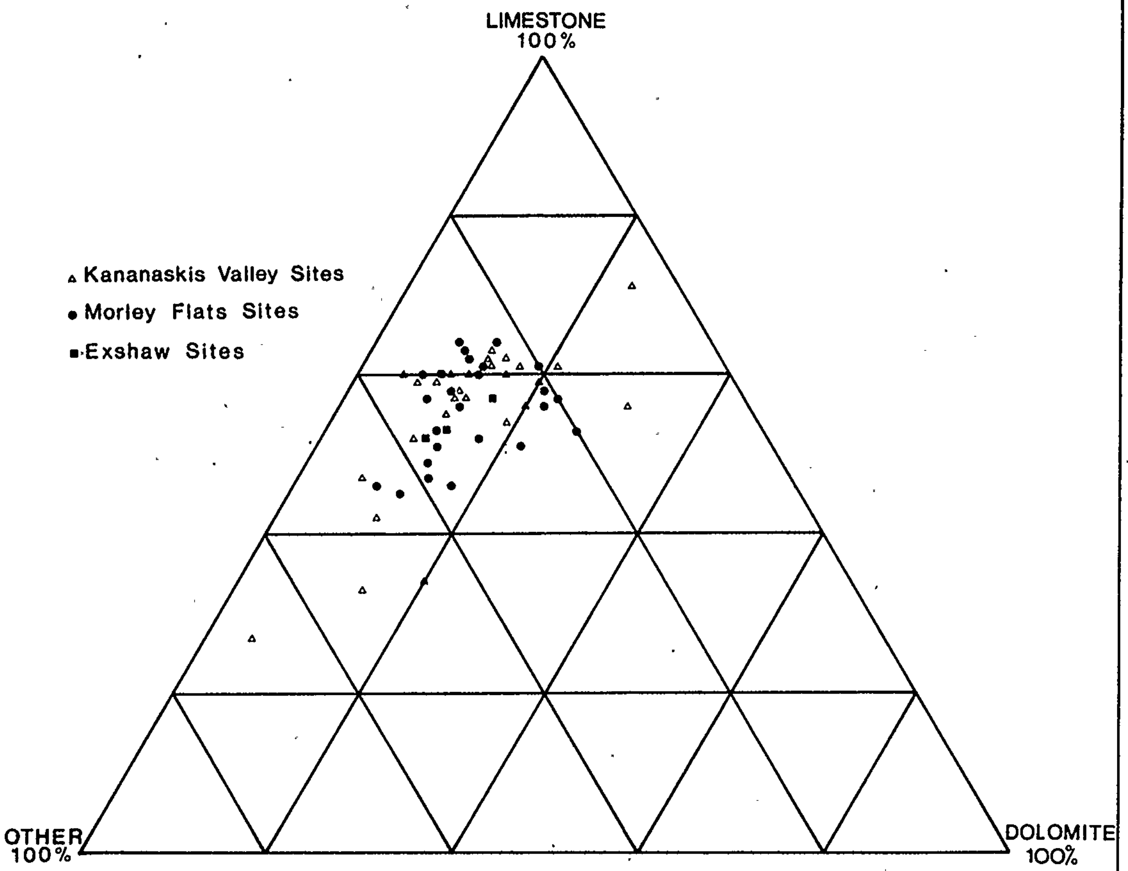


FIGURE 16. Proportional lithological composition of tills in the Study Area.

each of the three areas and the null hypothesis set up that there was a statistically significant difference between the areas in terms of pebble content in the tills. The null hypothesis was rejected, as there is a high degree of concordance among pebble types occurring in these three areas.

The laboratory results suggest that the tills occurring in the study area were all deposited by the same ice mass. Supporting evidence for this hypothesis stems from fabric data in the lower valley, and the postulated depth of ice in the Bow Valley during the late-Wisconsin period discussed below.

Fabric Analysis

Till fabrics in the Lower Kananaskis Valley to the north and east of the Field Centre reveal that Bow ice flowed around the eastern flanks of Pigeon Mountain and covered the whole of the valley to the east of Barrier Lake. On the northern slopes of Barrier Mountain the preferred orientation is east-west indicating that ice must have also moved down the Kananaskis Valley itself (Figure 17). These two ice streams must therefore have converged in the Barrier Lake area. However, the laboratory analysis has shown that there is no significant difference between tills in the Kananaskis Valley and deposits in the Bow Valley to the north. Moreover, the evidence strongly suggests that ice formerly occupying these two areas originated in the Bow Valley. If this is so, then Bow ice must have crossed over into the valley of the Kananaskis at points in the lower valley other than the one mentioned above. An examination of ice heights in the Bow Valley during the period of the main Bow Valley advance helps explain this phenomenon.

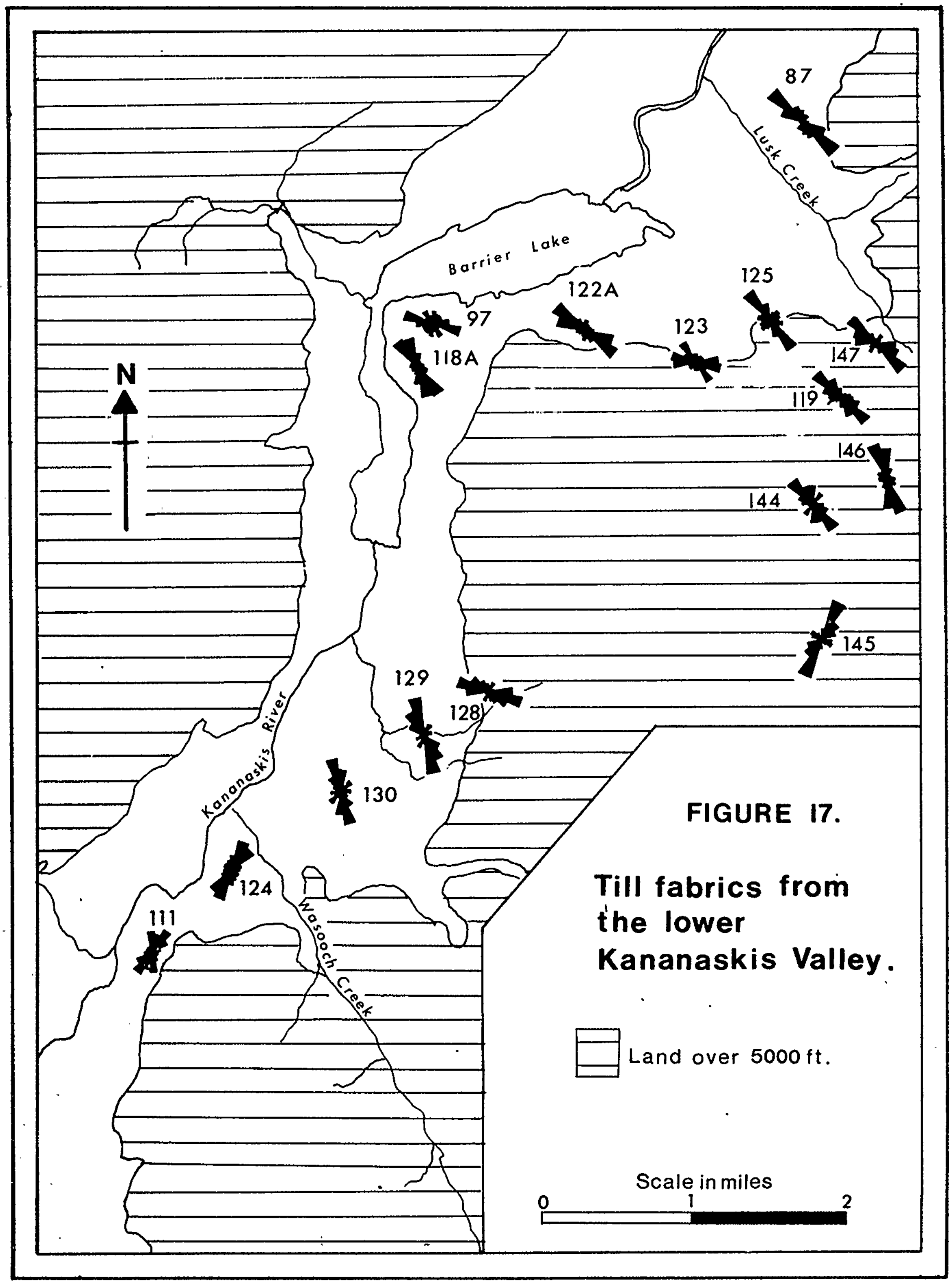


FIGURE 17.

Till fabrics from the lower Kananaskis Valley.

ICE HEIGHTS

On the basis of lateral breaks in slope and the presence of erratics on the mountain sides, Rutter (1965) suggested that in the Banff area, the main Bow Valley glacier attained a maximum thickness of 3000 feet. In the study area, pink quartzite erratics were found on the summit of Pigeon Mountain (elevation 6500 feet) whereas no erratics were discovered on the upper slopes of Barrier Mountain (elevation 7191 feet). Thus, in this portion of the study area, Bow ice must have been at least 2000 feet in thickness which is consistent with Rutter's estimate for the Banff area. If this was so, then glacial diffluence between the Bow and Kananaskis Valleys could have taken place on a massive scale, as at certain points, the divide between the two valleys is considerably less than 2000 feet in height. Simple and multiple diffluence of former ice masses has been reported in Scotland (Linton, 1963) but little has been written on this phenomenon in the Front Ranges of Canada.

GLACIAL DIFFLUENCE BETWEEN THE BOW AND KANANASKIS VALLEYS

Bow ice appears to have spilled over into the Kananaskis Valley at two points (Figure 18). The first is the low col to the west of Pigeon Mountain which is approximately 750 feet above the valley floor (Plate 7), and the second is the low divide above Marmot Basin (Plate 8) which is approximately 1800 feet above the floor of the Kananaskis and Bow Valleys.

The col on the western slopes of Pigeon Mountain is a little over half a mile in width and is considered to be the less important of

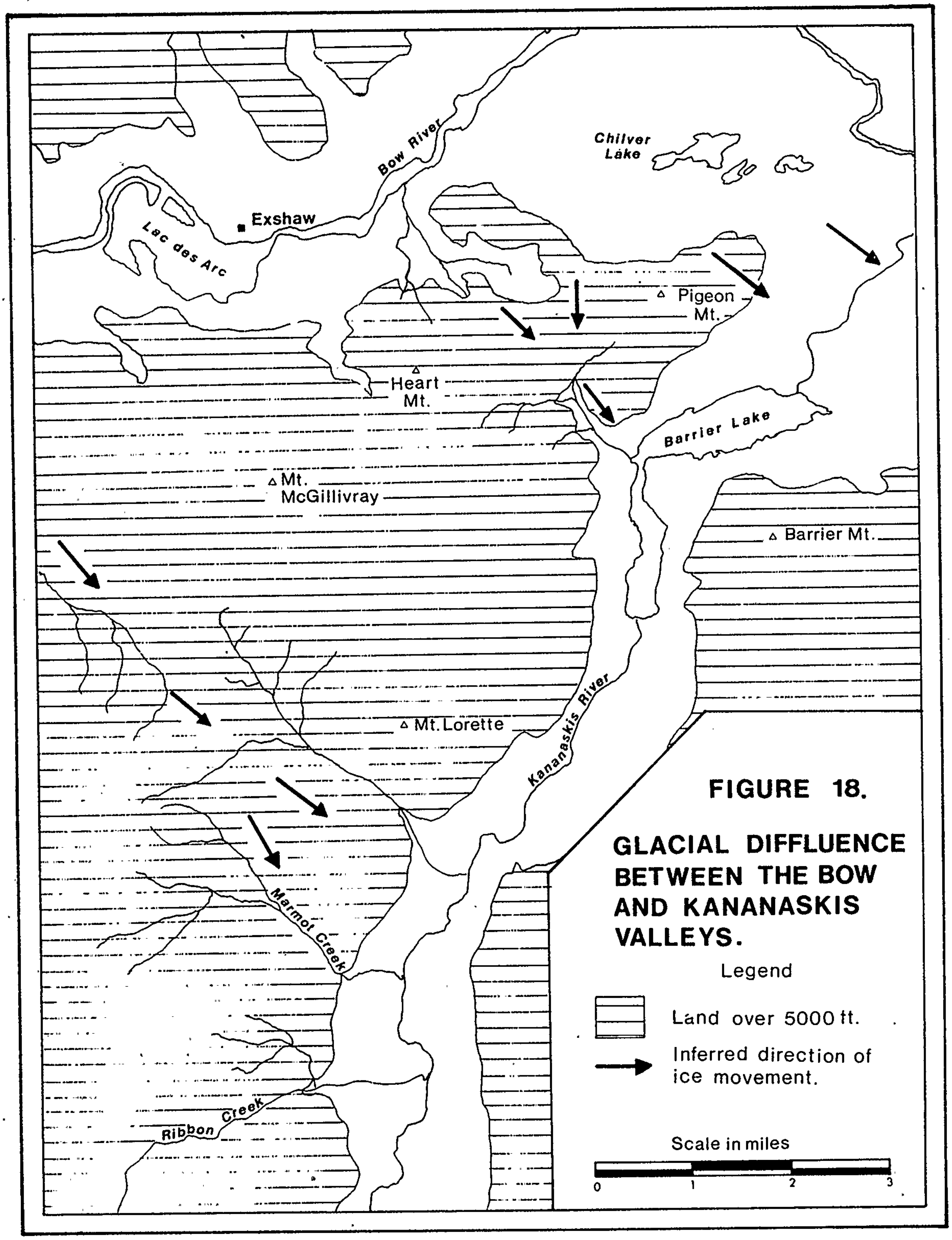


FIGURE 18.

GLACIAL DIFFLUENCE BETWEEN THE BOW AND KANANASKIS VALLEYS.

the two spillways. No till was found in the channel, but the presence of quartzite erratics and large areas of grooved and striated bedrock testify to the former passage of ice across this low divide.

The divide above Marmot Basin is over three miles in width and is cut into soft shales and sandstones of the Fernie, Kootenay and Spray River Formations. As a result, no striated or grooved surfaces were found although limestone, dolomite and quartzite erratics were common. The surficial material on the Kananaskis side of the divide has been considerably modified and hence no fabrics were taken to determine the direction of ice movement in this area. However, the wide, flat valley floor below the divide, coupled with the steep ice-scoured ramp facing the divide on the opposite side of the valley suggests that ice moved across the divide and rode up onto the steep slope on the eastern side of the Kananaskis Valley (Figure 18). The similarity between surficial deposits in the ten miles of the Kananaskis Valley from Marmot Basin to the Field Centre, and those on the Morley Flats gives credence to this theory of glacial diffluence.

Although no trace could be found of the former presence of Kananaskis ice in the lower ten miles of the valley, the possibility of ice having moved at least some way down the Kananaskis Valley in the late Wisconsin period cannot be ruled out. However, until such time as detailed field work is carried out in the upper valley, the movement and extent of Kananaskis ice must remain a matter for conjecture.

AGE OF TILLS IN THE KANANASKIS VALLEY

Several lines of evidence suggest that the surficial deposits in the lower ten miles of the Kananaskis Valley were deposited by ice from the Bow Valley glaciers. If this is so, then tills in the Kananaskis Valley are assigned to the main Bow advance glacier as ice heights for the later Canmore advance did not exceed 750 feet in the Exshaw area (Rutter, 1965) and therefore ice of this advance would not have been of sufficient thickness to spread over into the Kananaskis Valley. Hence, if these age correlations are correct, the lower Kananaskis Valley has been ice free since the time of the main Bow Valley advance.

CHAPTER VI

THE DEGLACIAL SEQUENCE

INTRODUCTION

In order to complete the late-Quaternary history of the lower ten miles of the Kananaskis Valley and adjacent areas of the Morley Flats, it is necessary to discuss the sequence of events which followed the onset of deglaciation. Gravel deposits on the Morley Flats are interpreted as outwash on the basis of their thickness, distribution and relationship to other deposits in the study area, and are thought to have resulted from deposition by meltwater issuing from ablating ice masses in the Bow and Kananaskis Valleys. The presence of lacustrine material, shoreline features and spillways in the lower Kananaskis Valley suggest that a large lake formed in this area of the valley during the late-Wisconsin period (Lake Kananaskis). These features will now be discussed in more detail.

MORLEY GRAVELS

Thick deposits of coarse gravel blanket the whole of the Morley Flats region and can be traced over the low ridge to the south of the Flats into the valley of Chiniki Creek. The gravels vary in thickness from a few feet in sections exposed along the Kananaskis River to over 200 feet near Ozada on the Morley Flats proper. On the low ridge above Chiniki Lake, borehole data reveals that almost 180 feet of coarse gravel overlies bedrock in that locality. Although stratification is present in some sections, interbedded sands were never found. Lithological analysis was carried out at a number of sites on the Flats and the results were consistent with those already obtained from till underlying the gravel. Fabric analysis was employed at five sites although it was usually possible to determine the preferred orientation by eye. Figure 19 shows that the gravels resulted largely from water moving down the Bow Valley, although water escaping from the Kananaskis Valley may also have been partly responsible for their deposition.

The distribution, character and orientation of the gravels on the Morley Flats suggests that the deposits are glacio-fluvial in origin and were laid down by water released by the ablating main Bow Valley glacier. However, it is probable that outwash from the Canmore advance and Eisenhower Junction glaciers also contributed to the gravel deposits in the Morley Flats portion of the study area.

The Kame-moraine Complex

This term was introduced by Rutter (1965) to describe the distinct morphological unit to the west of Seebe (See Figure 20), and is thought by Rutter to represent part of the dissected terminal moraine of the Canmore advance glacier. It is an undulating area composed of coarse gravel and sand and contains a number of sinuous, elongated ridges up to 40 feet in height which often meet at sharp angles. A section exposed in one of these ridges adjacent to Highway 1A reveals that the features are composed of coarse gravels and sand lenses which are often interbedded (Plate 9). For this reason the ridges are interpreted as either

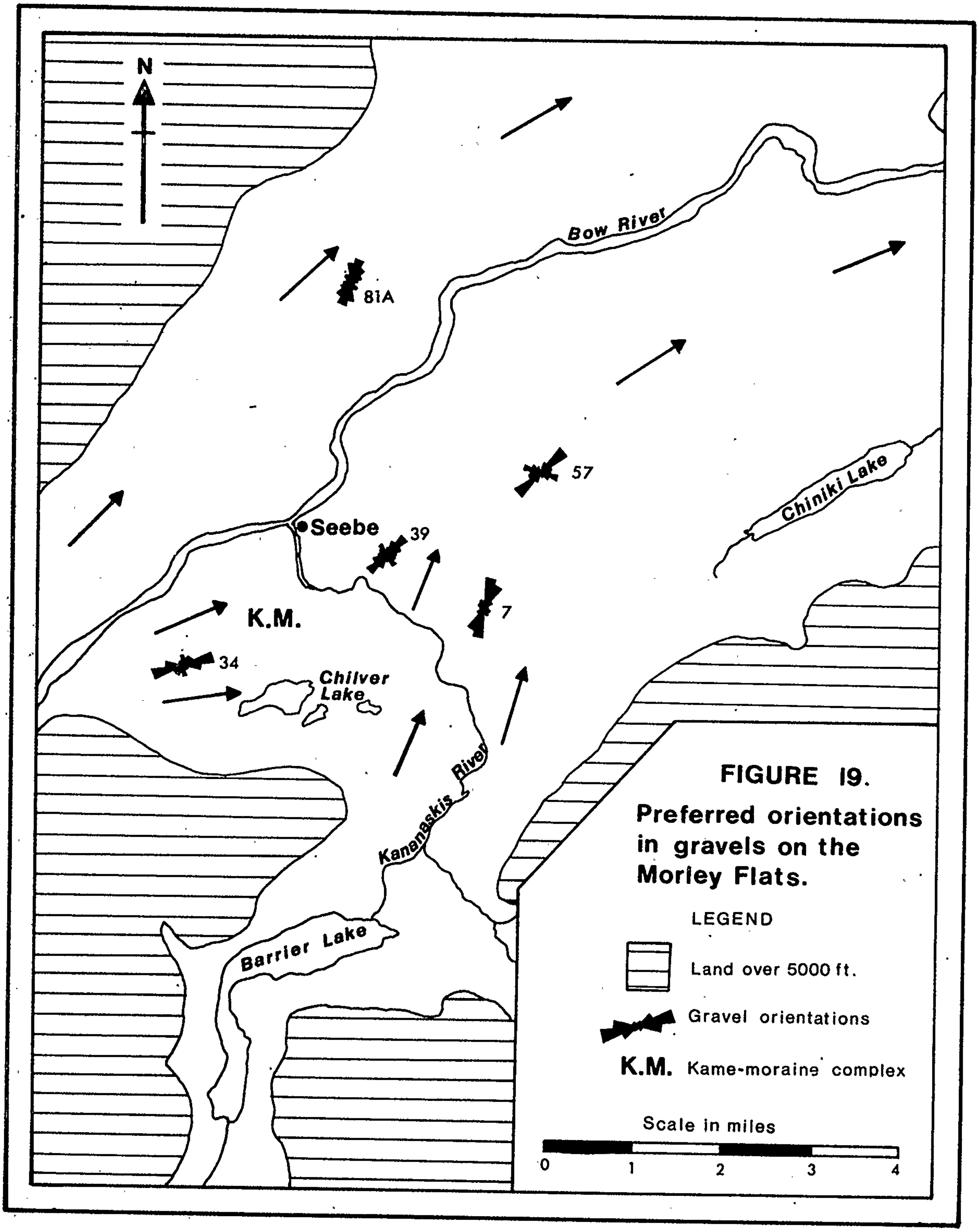


FIGURE 19.
Preferred orientations in gravels on the Morley Flats.

crevasse fillings or eskers. Kames are common in the area and are also found on the north side of the Bow River along Highway 1A. These vary between 20 and 50 feet in height and contain thin beds of coarse gravel, fine gravel and sand which dip gently to the east or southeast. Occasional patches of till occur in the Kame-moraine area but these are local in extent and cannot be differentiated from till elsewhere in the study area.

LAKE KANANASKIS

The former presence of a lake in the lower Kananaskis Valley was first reported by Beach (1943) who noted that:

> . . . considerable impounding of waters must have occurred in the lower Kananaskis Valley as evidenced by the thick deposits of sand and gravel in the valleys of Lusk Creek and Stony Creek.
>
> (Beach, 1943, p. 49)

In the present study, the existence of Lake Kananaskis is inferred from the following lines of evidence:

(1) The distribution of lacustrine material.

(2) The distribution of kame deposits.

(3) The presence of shoreline features.

(4) The presence of spillways and overflow channels.

Lacustrine Material

Extensive deposits of lacustrine material were found in the lower Kananaskis Valley around Barrier Lake and in the area known as the Wabash Flats to the west of Lake Chiniki. The deposits were usually recognisable in the field, being grey-yellow in colour, blocky in character and containing few or no pebbles. Some samples did contain limestone, dolomite or quartzite pebbles although these are thought to have been ice-rafted. Mechanical analysis was carried out to determine the grain-size variation in the sediments and the results are depicted in Figure 21. The low percentages of sand and the relatively high proportions of silt and clay were felt to be important diagnostic properties of the lake material. Unfortunately, no mollusca were found either in the field or in samples analysed in the laboratory.

Kame Deposits

A number of kame deposits (Figure 21) and associated features which occur in the lower Kananaskis Valley are thought to be related to the former presence of a glacial lake. In the gorge below Barrier Lake, alternating layers of coarse and fine gravels occasionally interbedded with sand lenses dip at approximately 25^{o} towards the south. These gravels overlie, and are partly overlain by, lacustrine sediments and are thought to have been deposited by water flowing into the lake from the ablating Bow glacier to the north. Similar gravel deposits are found on the low ridge to the east of Pigeon Mountain although in this case associated lake deposits are absent. In the large embayment to the east of Barrier Mountain several kame features occur with the dip of the beds being towards the north and west. Adjacent to the Environmental Sciences Centre, a low mound consisting of alternating layers of coarse and fine sand is interpreted as a kame on the basis of the presence of cross-bedding in the feature and its stratigraphic relationship to the underlying lake silts. It is believed that this kame was deposited at a

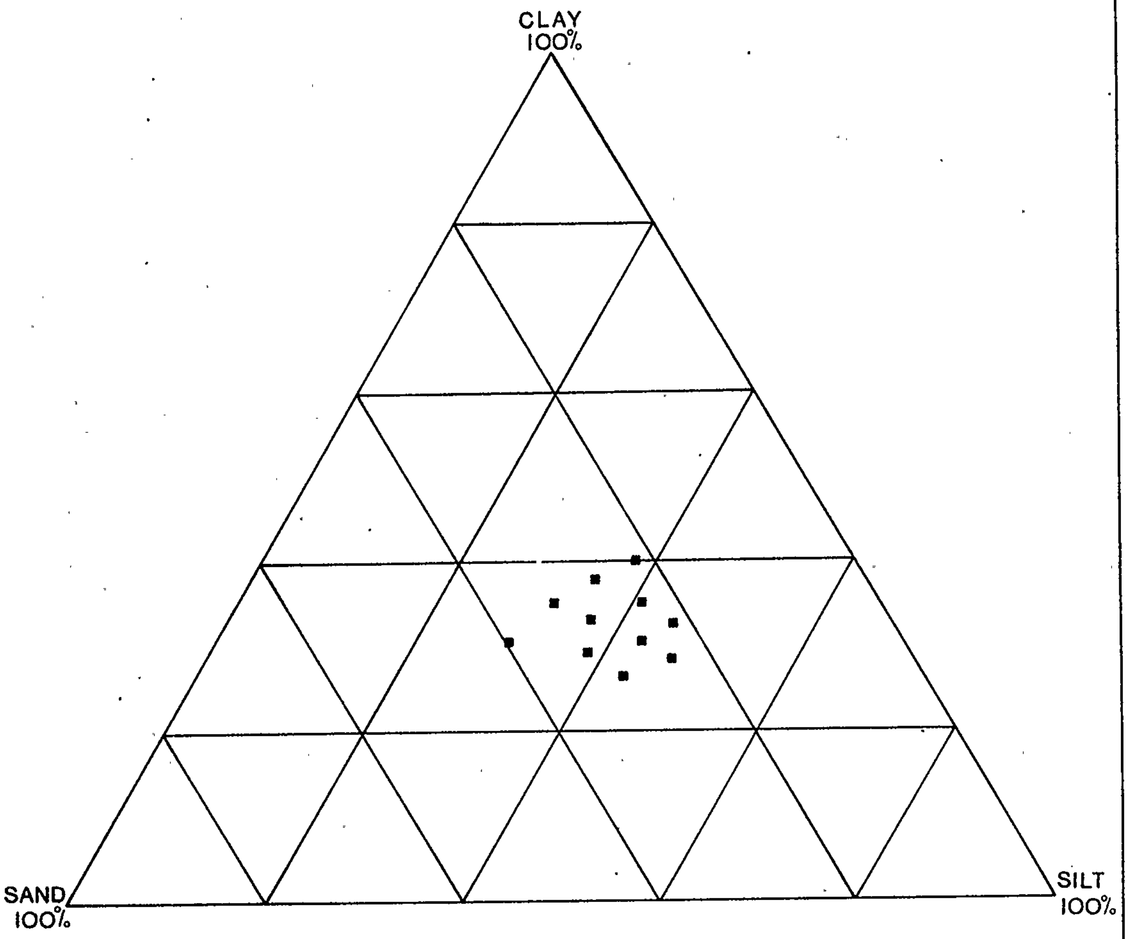


FIGURE 20. **Results of the Mechanical Analysis of lacustrine deposits in the lower Kananaskis Valley.**

later stage in the development of the lake by streams flowing northward from the embayment on the eastern side of Barrier Mountain.

Shoreline Features

In the study area, a series of well-defined terraces are preserved on the northeast slope of Barrier Mountain (Figure 21, Plate 10). These terraces were investigated in the field although the dense vegetation cover prevented a detailed analysis and the use of surveying techniques. However, it was found that the surficial material consists largely of coarse gravels and sands which seem to have undergone considerable reworking. Using air photographs, it was possible to distinguish six terraces extending for approximately three miles with the uppermost terrace having an average elevation of 5000 feet. The uniform level of the terraces coupled with the similarity in height between the upper terrace and the col on the spillway to the east (see below) strongly suggests that the features are lake terraces which developed along the margins of glacial Lake Kananaskis.

Spillways

Three major overflow channels are recognised in the study area (Figure 21). The first lies to the east of the Field Centre and is drained by the underfit streams of Lusk Creek and Sibbald Creek (Plate 11). The former flows westward into the Kananaskis River while Sibbald Creek drains to the east into the Elbow River drainage system. A low col at approximately 5000 feet forms the watershed between these two streams, and at this point the channel is almost 750 feet in depth and 500 feet in width. Thick deposits of coarse gravel occur on both sides of the col

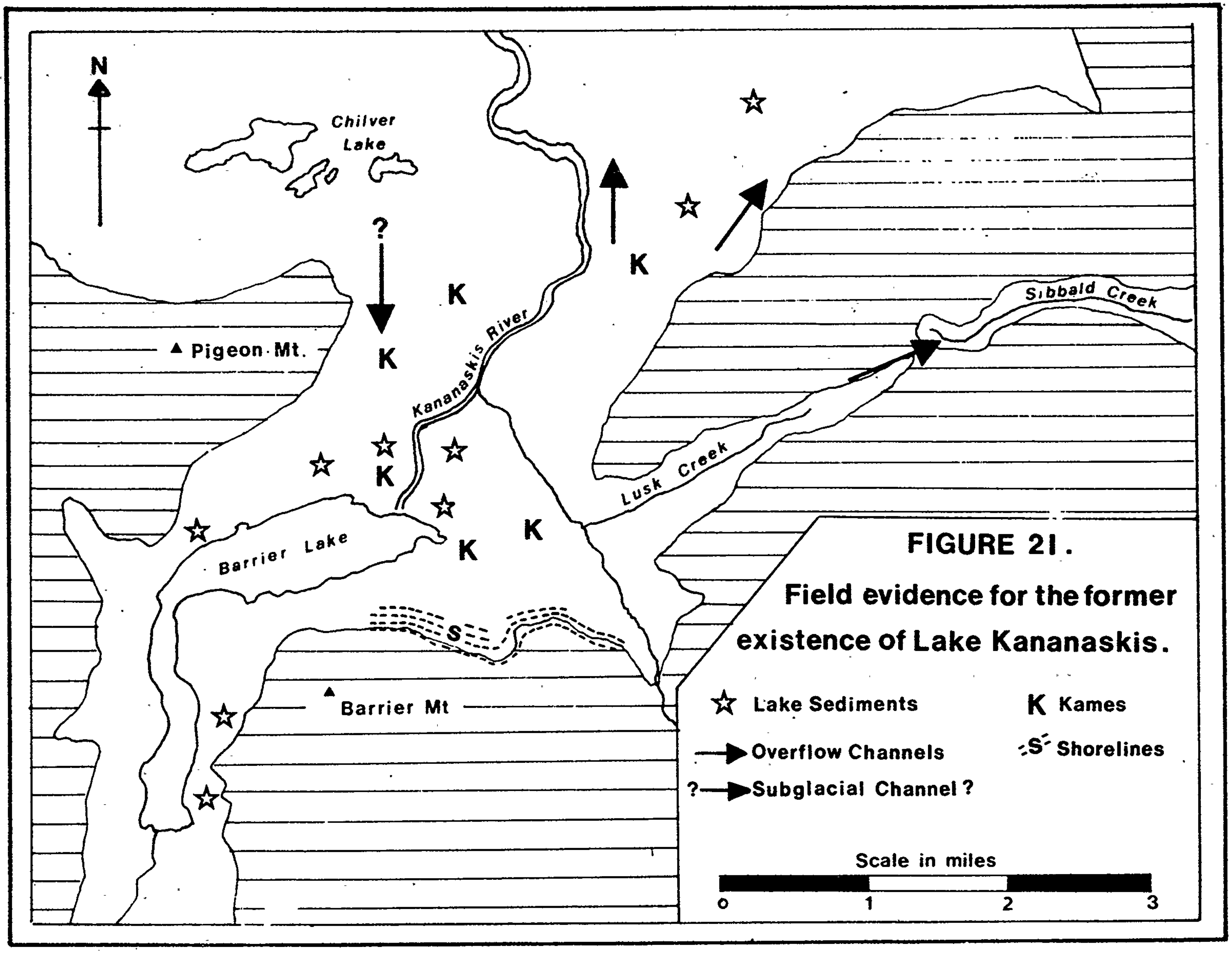


FIGURE 21.
Field evidence for the former existence of Lake Kananaskis.

but are absent on the col itself. Lithological analysis of the constituent pebbles shows that the gravels are similar on the two sides of the col, and are comparable to gravel deposits in the lower Kananaskis Valley and on the Morley Flats. It would therefore seem that water flowed from west to east through this channel from the lake which developed in the lower areas of the Kananaskis Valley.

A second spillway is thought to have developed through the valley now occupied by Chiniki Lake and Chiniki Creek (height 4500'). To the west of Chiniki Lake, extensive deposits of lacustrine material indicate that at one time Lake Kananaskis extended beyond the confines of the lower Kananaskis Valley. It is suggested that once Bow ice had retreated from the mouth of the Kananaskis Valley, water began to escape eastwards through the valley of Chiniki Creek. Also, the sinuous, dry valley (height 4450') now occupied by the Forestry Trunk Road into the Kananaskis Valley is felt to be a third channel through which water from Lake Kananaskis escaped before the Kananaskis River adopted its present northerly course.

A fourth channel occurs on the northern side of the lower Kananaskis Valley cutting through the low ridge to the east of Pigeon Mountain, and is an apparent anomaly in the channel sequence outlined above. This channel at approximately 4600 feet is oriented north-south and possesses a wide, flat floor filled with deposits of sand and coarse gravel. However, the gradient slopes from north to south suggesting that water flowed southward from the Bow Valley into the Kananaskis Valley, and it is therefore difficult to conceive of this channel as being a spillway for Lake Kananaskis. Hence, it is interpreted as a subglacial channel which developed beneath Bow Valley ice as the glacier stagnated on the northern slopes of the Kananaskis Valley.

Discussion of Lake Kananaskis

It is suggested that the Bow Valley glacier stagnated in the lower Kananaskis Valley and that water released by the ablating ice mass was impounded in the valley by ice remaining on the Morley Flats to the north (Figure 25). The lake reached a maximum depth of at least 750 feet forming the uppermost of the shoreline features on the northeast slope of Barrier Mountain before water began to escape eastwards over the col between Lusk Creek and Sibbald Creek into the drainage system of the Elbow River which was ice free at this time (Figure 22). It is not certain as to how far southwards the lake extended into the Kananaskis Valley although lake sediments were found in that portion of the valley immediately to the west of Barrier Mountain. As the Bow ice continued to thin and waste northwards, the lake level fell, forming the lower terraces, and water escaped to the northeast through the valley of Chiniki Creek (Figure 23). The distribution of lake sediments in that portion of the valley to the west of Chiniki Lake suggests that at this time the lake must have extended some distance to the north and east of its original position during the initial stages of lake formation. In the late stages of deglaciation, drainage assumed a northward course firstly along the sinuous channel which now contains the Forestry Trunk Road into the Kananaskis Valley and finally along the course of the Kananaskis River itself (Figure 24). The present course of the Kananaskis River is therefore a post-glacial feature and originally the river

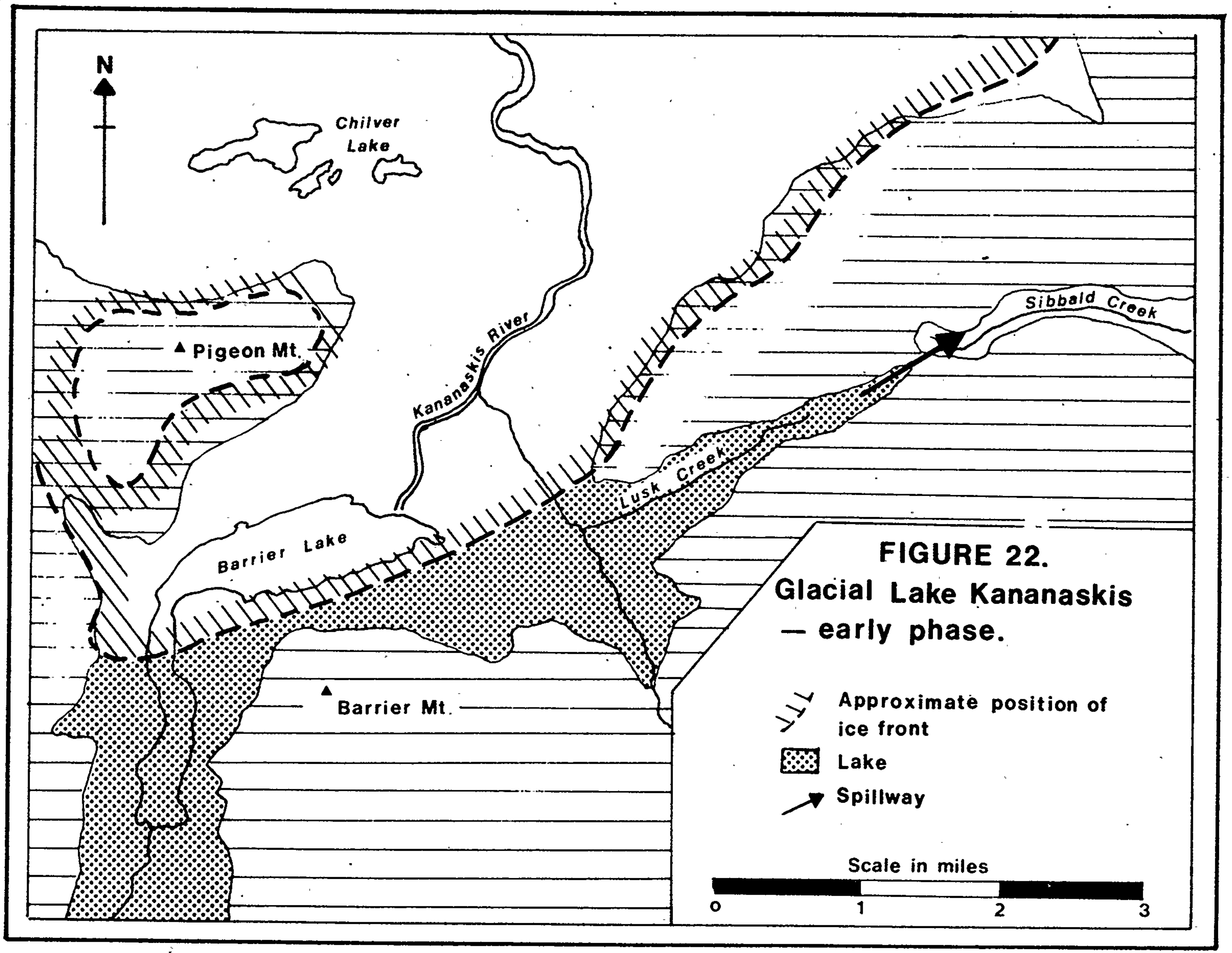


FIGURE 22.
Glacial Lake Kananaskis — early phase.

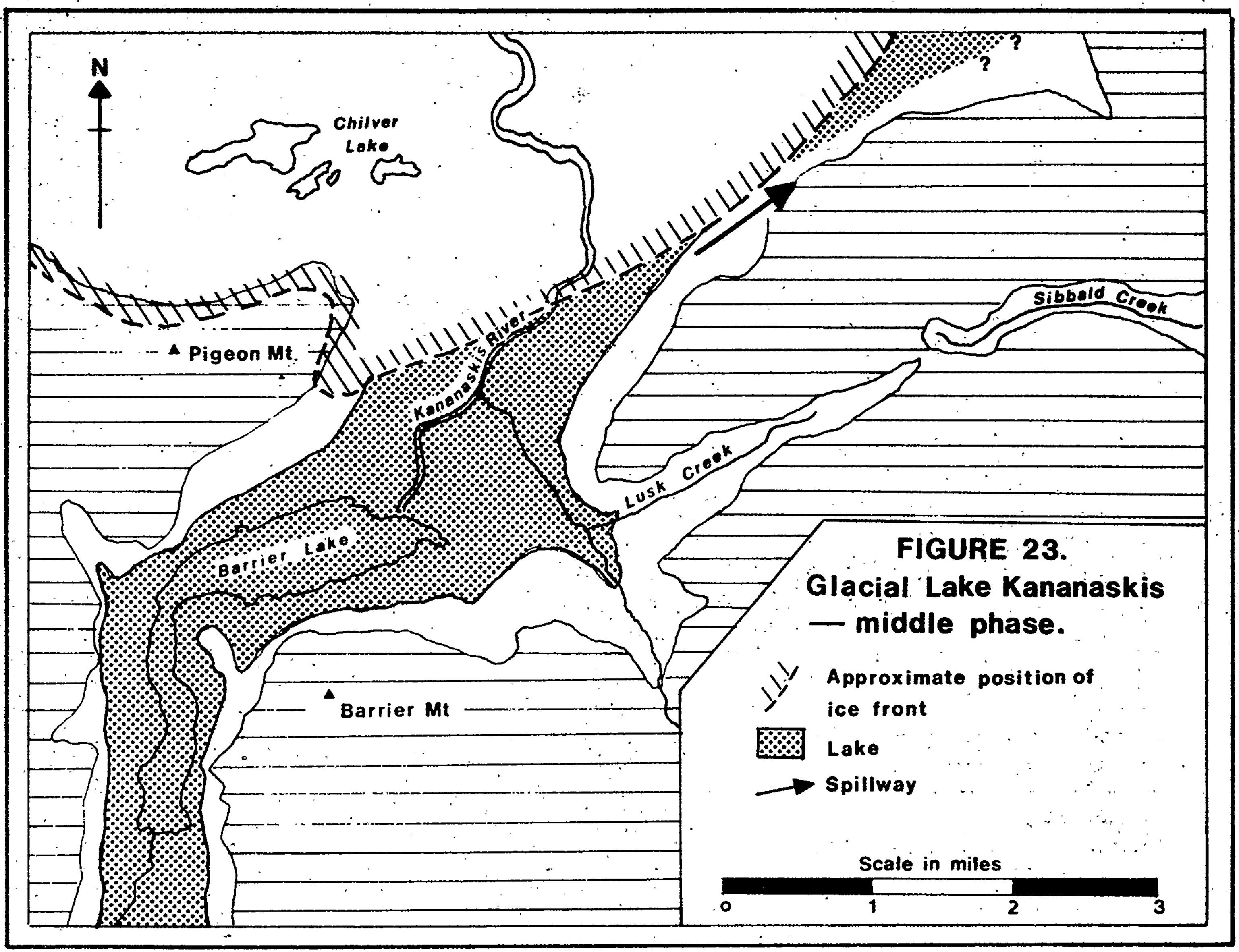


FIGURE 23. Glacial Lake Kananaskis — middle phase.

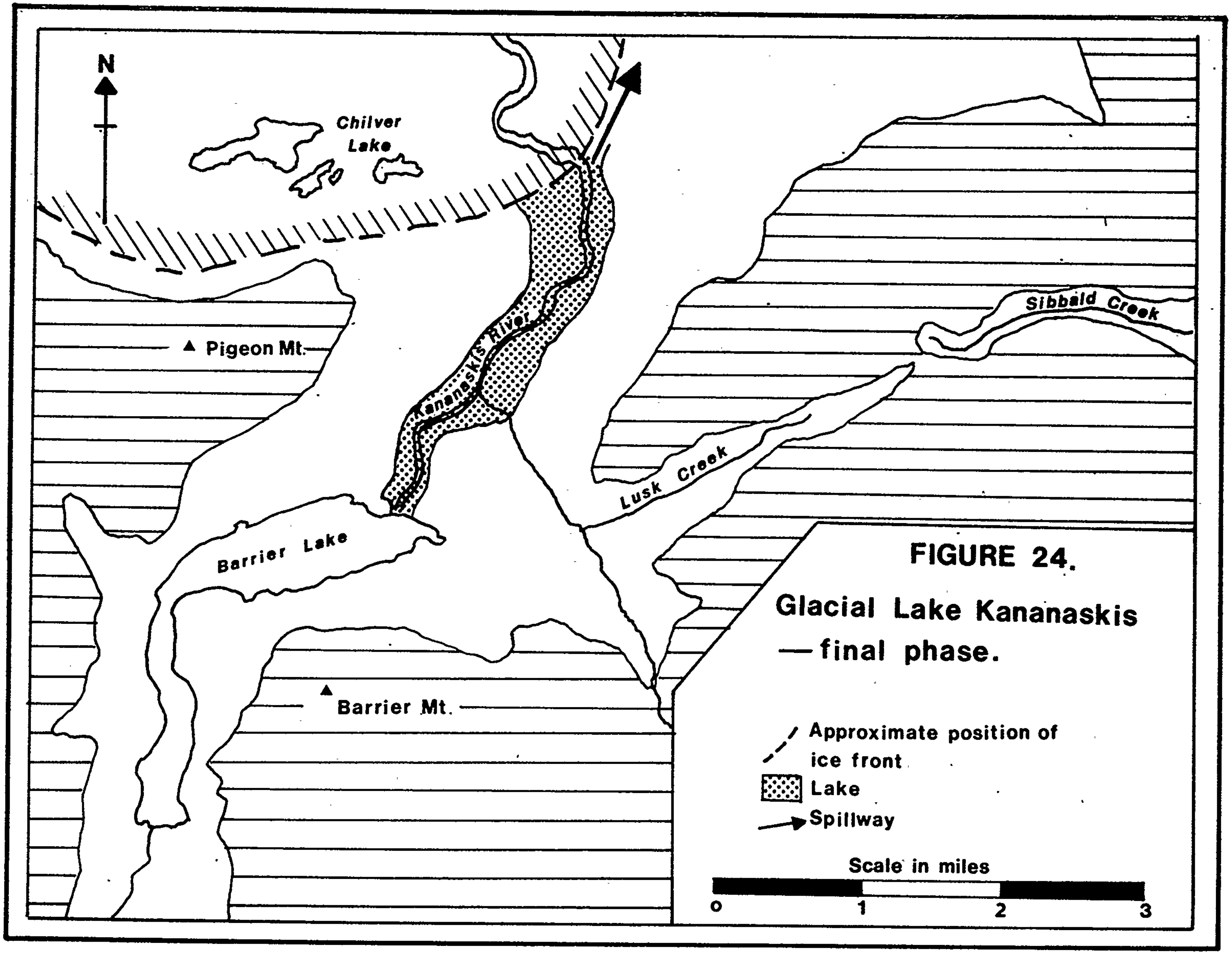


FIGURE 24.

Glacial Lake Kananaskis —final phase.

probably flowed eastwards through the valley of Chiniki Creek towards its confluence with the Bow River somewhere in the vicinity of Morley settlement. This interpretation is consistent with that put forward by Rutherford (1927) and by Rutter (1965).

CHAPTER VII

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

At the beginning of this study it was thought that evidence would be present in the Morley Flats area of the Bow Valley and adjacent areas of the Kananaskis Valley to show that some interaction took place between ice from a large tributary valley and a major valley glacier. It has been shown in the foregoing chapters that this does not appear to have been the case and indeed the evidence strongly suggests that ice from the tributary Kananaskis Valley never entered the study area in late-Quaternary times. Moreover, the whole of the study area appears to have been occupied by Bow Valley ice during the late-Wisconsin period.

The following sequence of events is therefore suggested. Evidence from the Banff area of the Bow Valley shows that during the early Classical Wisconsin a major ice advance occurred in the Bow Valley which spread out into the foothills zone at least as far as the present position of Calgary. This glacier attained a thickness of almost 3000 feet in the middle Bow Valley and diffused over two major cols into the valley of the Kananaskis. Thus at the height of the main Bow Valley advance, Bow ice occupied at least the lower ten miles of the Kananaskis Valley as well as the Morley Flats area of the Bow Valley to the north. During this glacial phase, a number of longitudinal ridges were formed on the Morley Flats which are interpreted in this study as being drumlins deposited beneath the ice of the main Bow Valley glacier. With the onset of deglaciation, the ice occupying the lower Kananaskis Valley stagnated and a lake formed which was dammed by Bow Valley ice still remaining on the Morley Flats to the north. Wasting and thinning of this ice mass allowed the water impounded in the lower areas of the Kananaskis Valley to escape initially in an easterly direction and finally towards the north. The Canmore advance reached the western margins of the Morley Flats but the ice was not of sufficient thickness to allow diffluence to take place into the valley of the Kananaskis. Hence it is suggested that the lower ten miles of the Kananaskis Valley as well as the Morley Flats area of the Bow Valley have been ice-free since the time of the main Bow Valley advance. However, the landscape of the Morley Flats and to a lesser extent of the Kananaskis Valley have been considerably modified by the effect of meltwater released by the Bow Valley glaciers during successive deglacial phases.

The results of this study raise a number of points which are felt to be important in the formulation of proposals for future research in the Front Ranges of Canada.

(1) This study underlines the problems inherent in correlating ice advances in valleys of the Front Ranges on the basis of average altitude of late Pleistocene moraines. While it is true that viable correlations may be possible in major valleys (as demonstrated by Rutter), these may not necessarily hold true for tributary valleys.

(2) There is a pressing need for more regional studies of this type in order to examine the relationship between tributary and major valley glaciers. It is evident from the present study that ice movement in the Front Ranges may well have been a much more complicated phenomenon than

was hitherto imagined. A detailed analysis of individual valley systems is now necessary to test whether the example of the lower Kananaskis Valley is unique or whether massive glacial diffluence is a more widely spread phenomenon.

(3) Although problems can arise with C14 dating techniques in a predominantly calcareous area, there is still a need for more radiometric dates from the Front Ranges of Canada. Unfortunately, no dateable material was discovered in the present study area, but until such time as adequate dates are available from the Rocky Mountain Front Ranges, suggested chronologies will continue to rest on gross correlations and hence be somewhat unsatisfactory.

(4) On the regional scale, it is felt that a number of specific studies could prove rewarding. In particular, the upper Kananaskis Valley is worthy of investigation in order that a solution to the problem of ice flow in that area may be reached. Also, the area of the Bow Valley above the Eisenhower Junction needs to be mapped in order that a valid sequence of events for the whole of the Bow Valley can be formulated.

(5) Finally, on the national scale, there is still much to be done on the topic drumlins and associated features. In this field, the increasing interest in the behaviour of material at the base of ice masses coupled with the use of simulation models in the laboratory should prove rewarding in the search for a closer understanding of drumlin genesis. It may well be that the traditional dichotomy between "erosional" and "depositional" schools of thought might be modified and a complex process of drumlin formation as suggested by Gravenor (1953) could prove to be a

more viable proposition. In essence, a complete re-evaluation of our use of the term "drumlin" may be necessary, and attention be focused instead on a whole variety of geomorphic features of which the traditional drumlin is but one.

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APPENDIX A

AZIMUTHAL FREQUENCIES FOR TILL FABRICS IN THE STUDY AREA

Sample	Classes									Type
	10-30	30-50	50-70	70-90	90-110	110-130	130-150	150-170	170-190	
N-7*	19	13	4	1	0	2	3	3	5	Gravel
N-15*	9	8	15	5	2	1	1	3	6	Till
N-21*	2	4	3	4	1	22	6	4	4	"
N-23*	3	1	2	4	15	19	2	3	1	"
N-25*	-	-	18	18	6	2	6	-	-	"
N-27	4	5	7	8	12	6	6	2	-	"
N-28*	3	13	10	10	5	-	1	3	5	"
N-34*	7	1	13	19	6	1	1	2	-	"
N-35*	5	5	19	10	2	1	1	3	4	Gravel
N-36*	2	9	22	14	2	1	-	-	-	Till
N-39*	3	7	14	7	4	3	4	6	2	Gravel
N-40*	7	9	7	13	6	3	2	2	1	Till
N-45*	2	5	-	1	4	6	12	11	9	"

Sample	Classes									Type
	10-30	30-50	50-70	70-90	90-110	110-130	130-150	150-170	170-190	
N-48	6	4	10	9	2	8	4	6	1	Till
N-49*	5	3	1	3	11	3	11	9	4	"
N-50*	2	2	1	1	4	11	13	9	7	"
N-51*	3	8	8	20	5	3	1	2	0	"
N-52*	4	9	13	7	1	7	4	2	3	"
N-53*	-	3	8	19	5	9	4	2	-	"
N-54*	5	18	5	7	4	4	1	1	5	"
N-57*	-	2	8	18	8	4	3	6	1	Gravel
N-58*	1	5	19	11	7	6	1	-	-	Till
N-59*	5	4	18	6	6	4	1	1	5	"
N-60	3	7	13	7	6	3	4	6	1	"
N-61*	2	14	6	6	8	4	6	2	2	Till
N-62*	2	8	18	8	4	3	6	1	-	"
N-63*	5	5	18	9	2	3	4	1	3	"
N-64*	4	5	20	10	2	1	1	4	3	"
N-65*	2	20	10	5	3	-	3	3	4	"

Sample	Classes									Type
	10-30	30-50	50-70	70-90	90-110	110-130	130-150	150-170	170-190	
N-66*	3	8	15	6	6	6	3	1	2	Till
N-67*	4	3	7	19	9	4	1	3	-	"
N-69*	4	18	8	3	3	2	8	4	-	"
N-71*	3	2	3	8	19	3	5	6	1	"
N-72*	3	18	10	5	4	5	3	2	-	"
N-73*	13	9	5	3	2	1	4	3	10	"
N-74*	2	6	11	7	18	4	1	-	1	"
N-76*	2	3	6	9	17	7	6	-	-	"
N-80*	5	2	0	4	19	9	6	1	4	"
N-81	5	5	10	10	-	4	8	5	3	"
N-81A*	2	6	10	8	18	3	2	1	-	Gravel
N-82	8	8	12	4	7	2	1	3	5	Till
N-83*	6	7	18	9	-	-	5	2	3	"
N-84*	5	5	18	9	2	3	4	1	3	"
N-87*	3	3	-	-	2	10	20	7	5	"
N-89*	2	2	2	1	5	6	18	9	5	"

Sample	Classes									Type
	10-30	30-50	50-70	70-90	90-110	110-130	130-150	150-170	170-190	
N-93*	7	1	3	2	2	4	19	6	6	Till
N-93A	1	2	5	4	2	7	20	2	7	"
N-93B*	1	3	1	5	3	18	7	7	5	"
N-97	7	3	5	4	4	4	7	13	3	"
N-101*	-	2	7	22	9	9	1	-	-	"
N-103*	1	3	1	3	9	18	8	5	2	"
N-111*	9	8	14	8	3	2	2	2	-	"
N-118*	6	2	1	2	2	3	4	19	11	"
N-119*	3	1	1	2	4	4	8	18	9	"
N-122A*	3	-	2	3	12	18	5	4	4	"
N-123	2	3	3	3	10	11	5	10	3	"
N-124*	1	2	3	4	6	14	12	4	2	"
N-125*	2	4	4	3	5	4	18	7	3	"
N-128*	10	5	2	-	4	1	-	9	19	"
N-129*	2	1	7	12	18	3	5	-	2	"

Sample	Classes									Type
	10-30	30-50	50-70	70-90	90-110	110-130	130-150	150-170	170-190	
N-130*	4	1	7	3	15	10	1	6	3	Till
N-144*	3	2	3	1	4	8	15	10	4	"
N-145*	4	19	9	6	1	4	5	2	-	"
N-146*	4	1	-	2	3	3	5	19	13	"
N-147*	-	3	2	1	9	10	19	5	1	"

*This indicates that the required level of significance as determined by the Chi-square test was obtained at this site.

APPENDIX B

RESULTS OF MECHANICAL ANALYSIS OF
SAMPLES FROM THE STUDY AREA

Till Samples

Sample	Sand	Silt	Clay	Sample	Sand	Silt	Clay
N-2	54	31	15	N-44	59	23	18
N-2A	57	31	12	N-45	57	27	16
N-3	47	37	16	N-46	47	34	19
N-4	51	30	19	N-46A	57	28	15
N-5	49	28	23	N-51	53	37	10
N-6	53	34	13	N-52	40	36	24
N-15	54	31	15	N-52A	47	43	10
N-16	55	31	14	N-54	57	29	14
N-21	55	33	12	N-55A	57	25	18
N-21A	54	32	14	N-55B	51	34	15
N-23	52	30	18	N-55C	47	34	19
N-23	54	32	14	N-56	45	32	23
N-24A	53	28	19	N-57	50	30	20
N-24B	57	28	15	N-60	43	35	22
N-25	55	33	12	N-61	47	35	18
N-27	47	38	15	N-62	57	30	13
N-28	43	37	20	N-63	45	35	20
N-34B	65	28	7	N-65	40	36	24
N-43B	51	34	15	N-65A	60	31	9

Sample	Sand	Silt	Clay	Sample	Sand	Silt	Clay
N-66	52	34	14	N-102	41	33	25
N-67	46	35	19	N-103	50	21	29
N-68	42	39	19	N-104	45	34	21
N-69	49	33	18	N-105	50	32	18
N-70	60	29	11	N-106	49	39	12
N-71	53	33	14	N-108	50	35	15
N-73	40	38	22	N-109	48	36	16
N-74	54	28	18	N-111	40	35	25
N-75	47	32	21	N-112	38	36	16
N-76	47	26	27	N-113	34	41	25
N-77	51	31	18	N-114	27	48	25
N-78	54	26	20	N-115	70	22	8
N-80	32	45	22	N-116	42	36	22
N-81	62	23	15	N-117	48	32	20
N-82	67	19	14	N-118	54	27	19
N-83	58	26	16	N-119	52	29	19
N-84	58	25	17	N-120	42	47	11
N-87	47	34	18	N-122A	45	32	23
N-89	44	37	19	N-122B	43	35	22
N-93	52	28	20	N-123A	59	29	12
N-93A	56	30	14	N-123B	53	38	9
N-93B	50	34	16	N-124	44	39	18
N-100	40	36	24	N-125	44	36	20
N-101	41	32	26	N-126	50	33	17

Sample	Sand	Silt	Clay	Sample	Sand	Silt	Clay
N-127	69	23	9	N-130	37	39	24
N-128	47	32	21	N-131	50	18	32
N-129	45	35	19				

Lacustrine Samples			
Sample	Sand	Silt	Clay
N-132	40	30	30
N-133	33	32	35
N-134	30	37	33
N-135	24	41	35
N-136	27	35	38
N-137	22	38	40
N-138	22	46	32
N-139	32	39	29
N-140	26	44	30
N-141	24	48	28
N-142	30	44	26

N.B. Sand: 2.0 mm - 0.05 mm.

Silt: 0.05 mm - 0.002 mm.

Clay: finer than 0.002 mm.

APPENDIX C

PROPORTIONAL LITHOLOGICAL COMPOSITION OF SAMPLES FROM THE STUDY AREA

(in percentages)

Sample	Lime-stone	Dolomite	Chert	Sand-stone	Quart-zite	Shale	Other	Type
N-15	53	12	1	7	25	-	-	Till
N-21	46	9	1	15	25	5	-	"
N-23	47	14	-	13	24	1	-	"
N-24	46	9	1	15	25	5	-	"
N-25	60	7	1	6	19	4	-	"
N-28	61	13	1	12	13	-	-	"
N-42	47	17	-	5	29	2	-	"
N-43	46	12	1	13	25	2	-	"
N-48	49	13	1	9	26	1	1	"
N-52	64	13	1	6	12	1	-	"
N-55	58	21	-	6	12	3	-	"
N-56	57	23	2	6	12	1	-	"
N-58	60	19	4	2	14	2	-	"
N-61	53	27	3	6	13	1	-	"
N-64	56	22	2	13	6	1	-	"
N-65	55	13	-	8	19	3	1	"
N-66	58	11	2	11	15	3	-	"
N-67	51	22	2	12	10	1	-	"
N-68	57	9	1	10	19	3	-	"
N-70	52	17	-	8	21	2	-	"

Sample	Lime-stone	Dolomite	Chert	Sand-stone	Quart-zite	Shale	Other	Type
N-74	64	9	1	10	12	1	-	Till
N-77	60	14	1	13	10	2	-	"
N-79	62	11	1	7	18	1	-	"
N-83	51	13	-	12	12	6	2	"
N-89	56	20	2	7	10	4	-	"
N-93	59	7	1	18	12	7	-	"
N-93A	60	10	1	7	19	4	-	"
N-93B	61	13	2	5	17	2	1	"
N-94	42	13	2	9	31	3	-	Gravel
N-95	46	20	3	13	13	3	2	"
N-96	36	11	3	28	13	8	2	"
N-97	56	31	3	4	1	6	-	Till
N-98	52	7	2	21	18	3	1	Gravel
N-99	51	10	2	11	23	2	1	"
N-102	60	16	-	18	3	2	-	Till
N-104	61	17	2	6	11	2	1	"
N-106	52	10	1	19	16	2	-	"
N-111	54	19	-	10	10	6	1	"
N-113	34	14	-	16	5	30	1	"
N-116	62	17	1	11	4	3	1	"
N-118	59	20	3	5	9	5	-	"
N-120	55	12	1	11	2	20	-	"
N-122A	47	7	2	24	3	17	1	"

Sample	Lime-stone	Dolomite	Chert	Sand-stone	Quart-zite	Shale	Other	Type
N-122B	60	5	-	18	12	4	-	Till
N-124	71	24	-	2	2	1	-	"
N-125	63	13	-	12	8	3	-	"
N-127	57	12	5	11	7	8	1	"
N-128	61	21	2	8	4	4	1	"
N-129	60	12	3	10	12	3	1	"
N-130	62	13	1	10	11	3	-	"
N-131	47	7	2	24	3	17	-	"
N-145	42	11	-	26	4	13	-	"
N-146	27	5	-	29	-	38	1	"
N-148	34	20	2	9	10	24	1	"
N-149	62	9	-	8	14	9	1	"
N-150	64	14	-	10	9	3	1	"
N-152	57	7	-	13	10	11	2	"
MB-1	22	3	1	43	1	21	6	Till?
MB-3	27	-	-	50	-	33	-	Till?

APPENDIX D

PERCENTAGES OF CALCITE AND DOLOMITE IN TILL SAMPLES FROM THE STUDY AREA

Sample	Calcite	Dolomite	Total Carbonate Percentage
N-1	27.0	14.5	41.5
N-2	29.4	31.8	61.2
N-4	29.6	31.4	61.0
N-19	25.0	20.0	45.0
N-20	48.0	22.0	70.0
N-25	29.6	26.6	56.2
N-40A	20.6	11.6	32.2
N-48B	43.6	21.2	64.8
N-54	23.6	15.8	38.4
N-60	30.8	20.8	51.6
N-61	28.7	23.1	51.8
N-63	35.2	26.2	61.4
N-67	30.2	23.0	53.2
N-70	23.4	33.1	56.5
N-71	28.2	26.7	54.9
N-76	33.0	22.4	55.4
N-79	33.2	24.2	57.4
N-81	34.2	35.4	69.6
N-87	33.6	30.4	64.0
N-93A	35.6	30.5	65.9
N-93B	34.6	29.8	64.4

Sample	Calcite	Dolomite	Total Carbonate Percentage
N-97	23.8	40.4	64.2
N-102	23.2	23.2	46.4
N-108	26.6	24.8	51.4
N-109	19.6	14.8	33.4
N-111	25.6	18.4	44.0
N-114	40.6	16.6	56.2
N-116	35.0	22.2	57.2
N-118	34.0	25.2	59.2
N-119	29.8	26.8	56.6
N-123A	21.0	23.8	44.8
N-123B	31.1	22.4	53.5
N-128	28.0	24.3	52.3
N-131	38.0	23.2	61.2
N-146	24.6	23.6	48.2
N-148	25.6	17.2	42.8
N-149	26.7	20.4	47.1
N-124	30.2	19.5	49.7
MB-1	0.4	3.6	4.0
MB-2	2.0	1.6	3.6

APPENDIX E

THE CHI-SQUARE TEST TO DETERMINE THE SIGNIFICANCE OF THE RESULTS OF TILL FABRIC ANALYSIS

Using the formula $\chi^2 = \frac{\Sigma(O-E)^2}{E}$

where O is the observed frequency in a cell

E is the expected frequency in a cell

Example: Site N-111

Classes	1	2	3	4	5	6	7	8	9
Observations	9	8	14	8	3	2	2	2	-

H_o: There is an even distribution of 5.5 approximately in each class.

Significance level: 0.01

Degrees of freedom k - 1 = 8

$$\chi^2 = \frac{(9-5.5)^2}{5.5} + \frac{(8-5.5)^2}{5.5} + \frac{(14-5.5)^2}{5.5} + \frac{(8-5.5)^2}{5.5} + \frac{(3-5.5)^2}{5.5} + \frac{(2-5.5)^2}{5.5} + \frac{(2-5.5)^2}{5.5} + \frac{(2-5.5)^2}{5.5} + \frac{(0-5.5)^2}{5.5}$$

$$\chi^2 = 2.22 + 1.13 + 13.11 + 1.13 + 1.13 + 2.22 + 2.22 + 2.22 + 5.55$$

$$\chi^2 = 30.93$$

$\chi^2_{0.01}$ obtained 30.93

$\chi^2_{0.01}$ calculated 20.09

H_o rejected.

There is a significant preferred orientation of pebbles at this site.

APPENDIX F.

DIFFERENCE OF MEANS TEST (t test) TO COMPARE THE PERCENTAGES OF CALCITE, DOLOMITE AND TOTAL CARBONATES IN TILL SAMPLES FROM THE MORLEY FLATS AND LOWER KANANASKIS VALLEY.

Using the formula:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(N_1 \times S_1^2) + (N_2 \times S_2^2)}{N_1 + N_2 - 2}} \times \sqrt{\frac{N_1 + N_2}{N_1 \times N_2}}}$$

Where $\bar{x}_1$ = Mean for Morley Flats tills.

$\bar{x}_2$ = Mean for Kananaskis Valley tills.

S_1^2 = Standard Deviation for Morley Flats tills.

S_2^2 = Standard Deviation for Kananaskis Valley tills.

N_1 = Total number of samples tested from the Morley Flats.

N_2 = Total number of samples tested from the lower Kananaskis Valley.

a) Calcite.

$H_o: \mu_1 = \mu_2$

Significance level: 0.05.

Degrees of freedom: $N_1 + N_2 - 2 = 34$.

$$t = \frac{30.145 - 30.01}{\sqrt{\frac{(18 \times 27.119) + (18 \times 49.491)}{34}} \times \sqrt{0.111}}$$

$$t = \frac{0.135}{2.12.} = 0.06$$

$t_{0.05}$ obtained = 0.06

$t_{0.05}$ calculated = 2.03

H_o therefore retained. There is no statistically significant difference between the percentages of calcite in the tills of the Morley Flats and the lower Kananaskis Valley.

b) Dolomite.

$H_o: \mu_1 = \mu_2$
Significance level: 0.05
Degrees of freedom : $N_1 + N_2 - 2 = 34$.

$$t = \frac{24.717 - 22.844}{\frac{(18 \times 553.67) + (18 \times 572.054)}{34} \times \frac{36}{324}}$$

$$t = \frac{1.8727}{1.8988} = 0.986$$

$t_{0.05}$ obtained = 0.986

$t_{0.05}$ calculated = 2.03

H_o therefore retained. There is no statistically significant difference between the percentages of dolomite in the tills of the Morley Flats and the lower Kananaskis Valley

c) Total Carbonates.

$H_o: \mu_1 = \mu_2$
Significance level: 0.05
Degrees of freedom: $N_1 + N_2 - 2 = 34$.

$$t = \frac{54.856 - 50.633}{\sqrt{\frac{1246.28 + 1370.46}{34}} \times \sqrt{.33}}$$

$$t = \frac{4.233}{2.894} = 1.456.$$

$t_{0.05}$ obtained = 1.456

$t_{0.05}$ calculated = 2.03.

H_o therefore retained. There is no statistically significant difference between the total carbonate percentages in the tills of the Morley Flats and the lower Kananaskis Valley.

APPENDIX G

A TEST OF THE DEGREE OF INTERDEPENDENCE BETWEEN SAMPLES OF 300 PEBBLES COLLECTED FROM THE MORLEY FLATS, THE LOWER KANANASKIS VALLEY AND THE EXSHAW AREA OF THE BOW VALLEY, USING THE KENDALL COEFFICIENT OF CONCORDANCE (W) (Seigel, 1956, Pp. 229-239).

	Limestone	Dolomite	Chert	Sandstone	Quartzite	Shale	Other
Exshaw area	1	4	5	3	2	7	6
Morley Flats	1	3	6	4	2	5	7
Kananaskis V	1	2	6	3	4	6	7
R_j	3	9	17	10	8	17	20
$R_j = 84$ $84 \div N = 12$							
$R_j - \frac{\Sigma R_j}{N}$	9	3	5	2	4	5	8
$\left(R_j - \frac{\Sigma R_j}{N}\right)^2$	81	9	25	4	16	25	64

Then S value $= \left(R_j - \frac{\Sigma R_j}{N}\right)^2$

$= 224$

S value obtained = 224.

Using the Kendall Table for R (Seigel, 1956, p. 286), S value calculated where k = 3 and n = 7 at the 0.01 level of significance = 185.6

Thus there is a high degree of concordance between pebble samples from the three areas. The index of concordance W is obtained by the following calculation.

$$W = \frac{S}{\frac{1}{12} k^2 (N^3 - N)}$$

$$W = \frac{224}{\frac{1}{12} \times 3^2(7^2 - 7)}$$

$$W = \frac{224}{31.5}$$

$$W = 7.14$$

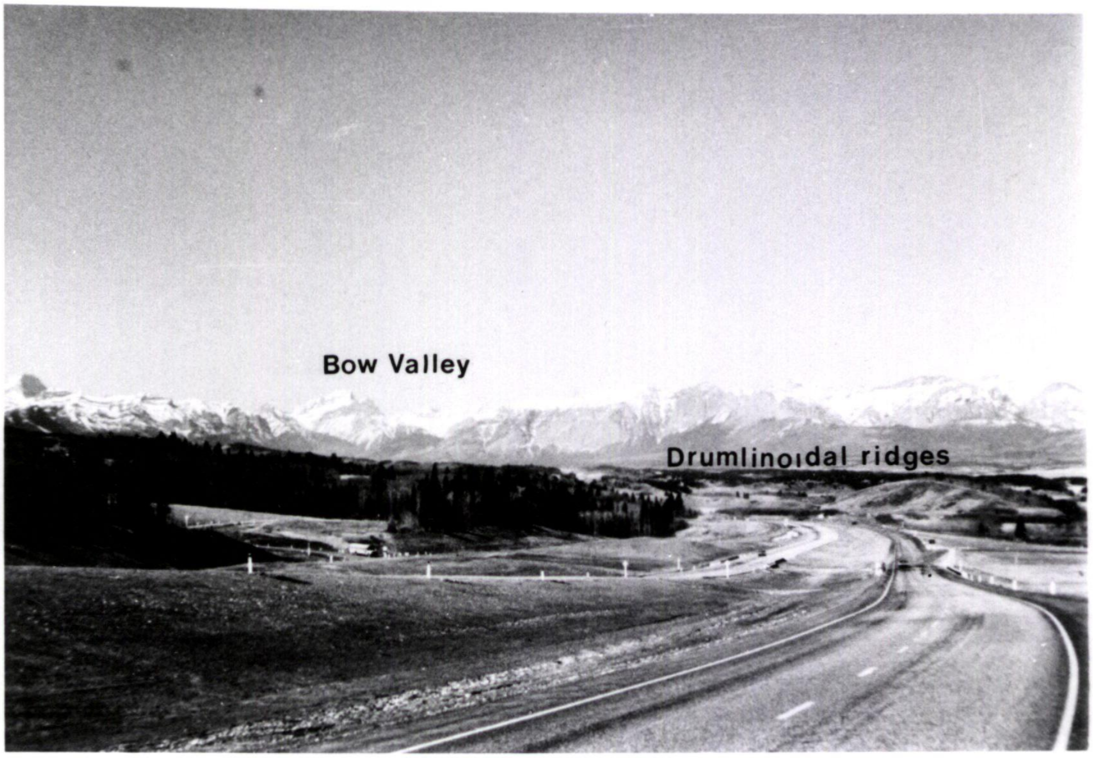
The high degree of concordance between the pebble samples from the three areas suggests that there is a strong possibility that all the pebbles were derived from the same glacier.

PLATE 1.

View westwards across the Morley Flats towards the mountain front. The area occupied by the drumlinoidal ridges can be seen in the centre of the photograph.

PLATE 2.

View southwards across the Morley Flats. The Kananaskis Valley can be seen in the distance towards the left of the photograph and the Bow Valley is to the right.


Bow Valley
Drumlinoidal ridges

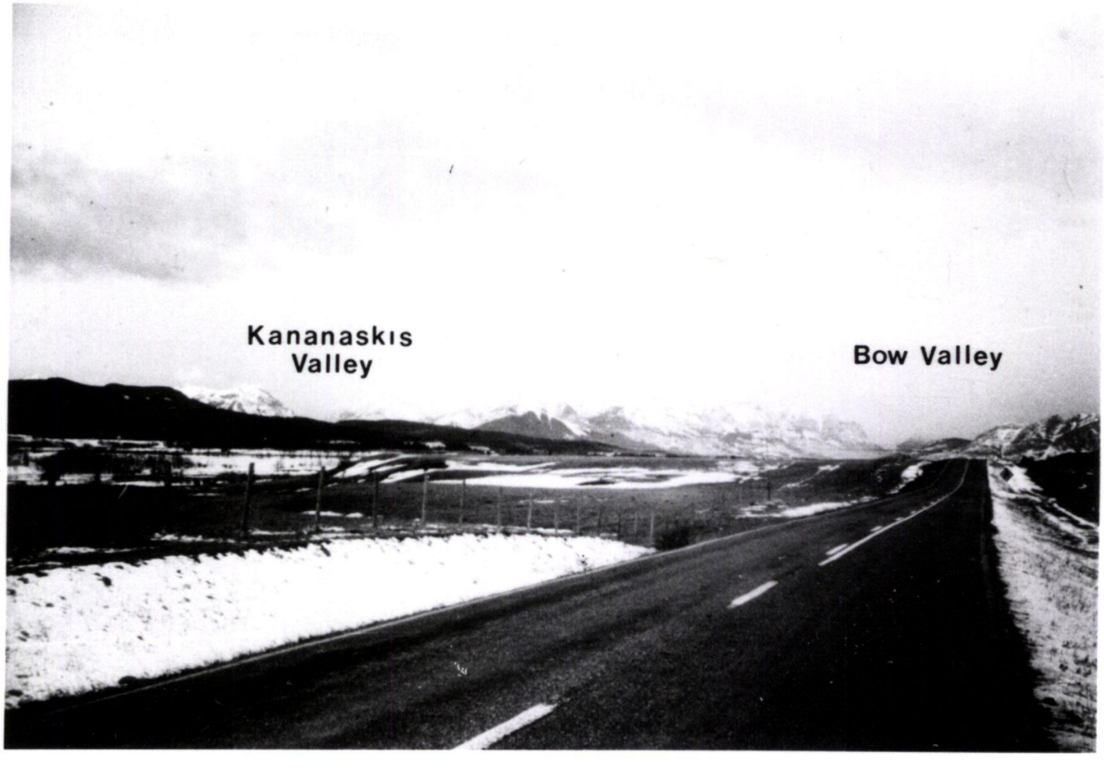

Kananaskis
Valley
Bow Valley

PLATE 3.

The two-till exposure along the Kananaskis River. The upper unit is thought to have been deposited by the Canmore advance, and the lower till is therefore assigned to the main Bow advance.

PLATE 4.

Drumlinoidal ridge near Ozada on the Morley Flats. Note the low swale-like form on the summit of the ridge.

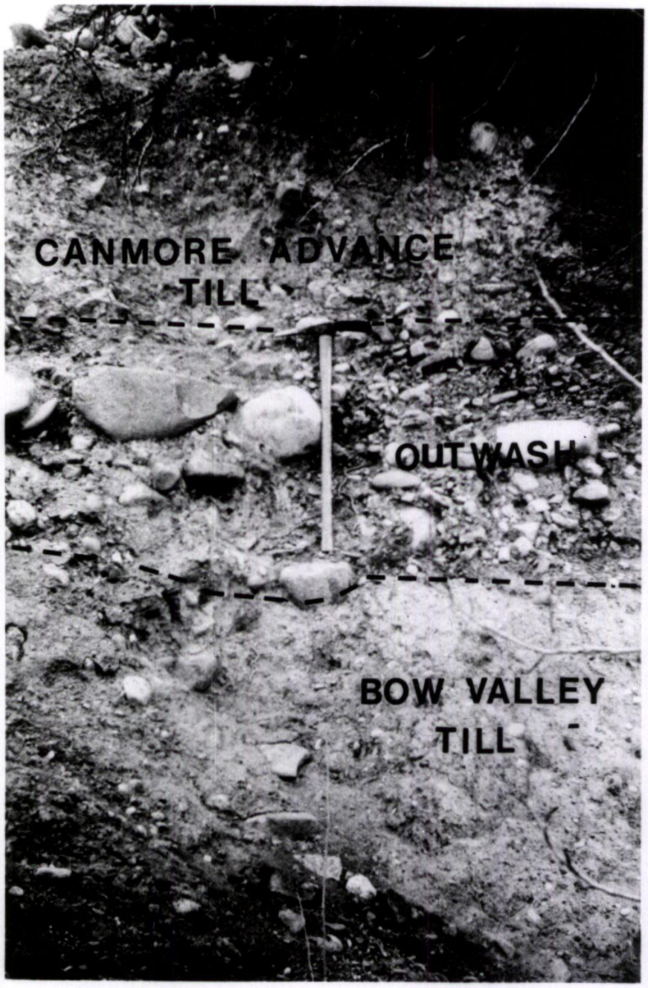

CANMORE ADVANCE
TILL
OUTWASH
BOW VALLEY
TILL

PLATE 5.

Drumlinoidal ridge on the central Morley Flats. Note the steep proximal slope which is characteristic of all the ridges in the central and eastern area of the Flats.

PLATE 6.

Text-book drumlin due south of Morley settlement.

PLATE 7.

View southwards from the western Morley Flats towards the low col between Pigeon Mountain in the centre and Heart Mountain on the right of the photograph.

PLATE 8.

View looking north-west from the lower Kananaskis valley over the low col above Marmot Basin. This col and the one shown in Plate 7 are thought to have been spillways in the late-Wisconsin period which allowed Bow Valley ice to spread over into the valley of the Kananaskis.

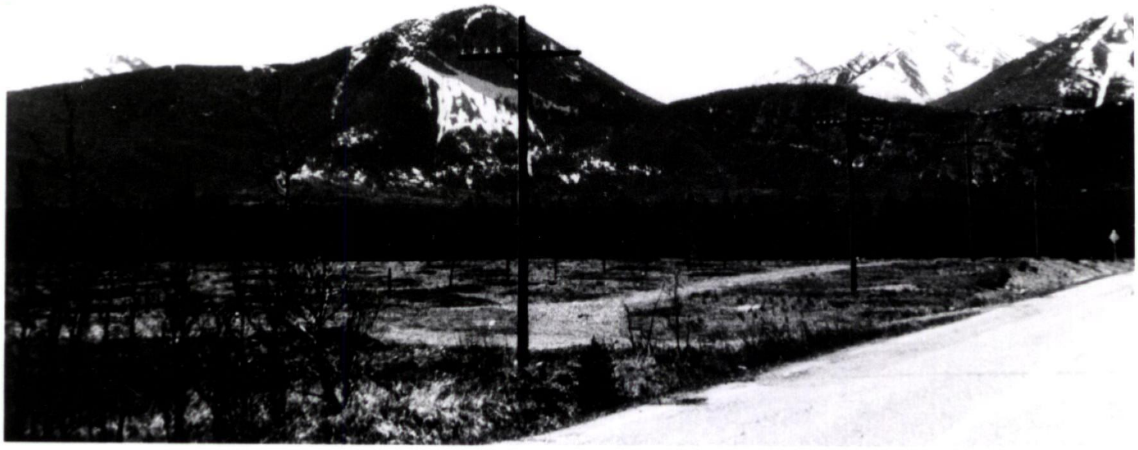


PLATE 9.

Long, sinuous ridge in the Kame-moraine complex. This hummocky area is thought to represent the destroyed terminal moraine of the Canmore advance glacier. Ridges such as the one shown in the photograph are common throughout this area and are interpreted as eskers or crevasse-fillings.

PLATE 10.

View south-westwards towards Barrier Mountain to show the flight of terraces which formed along the margins of Glacial Lake Kananaskis.

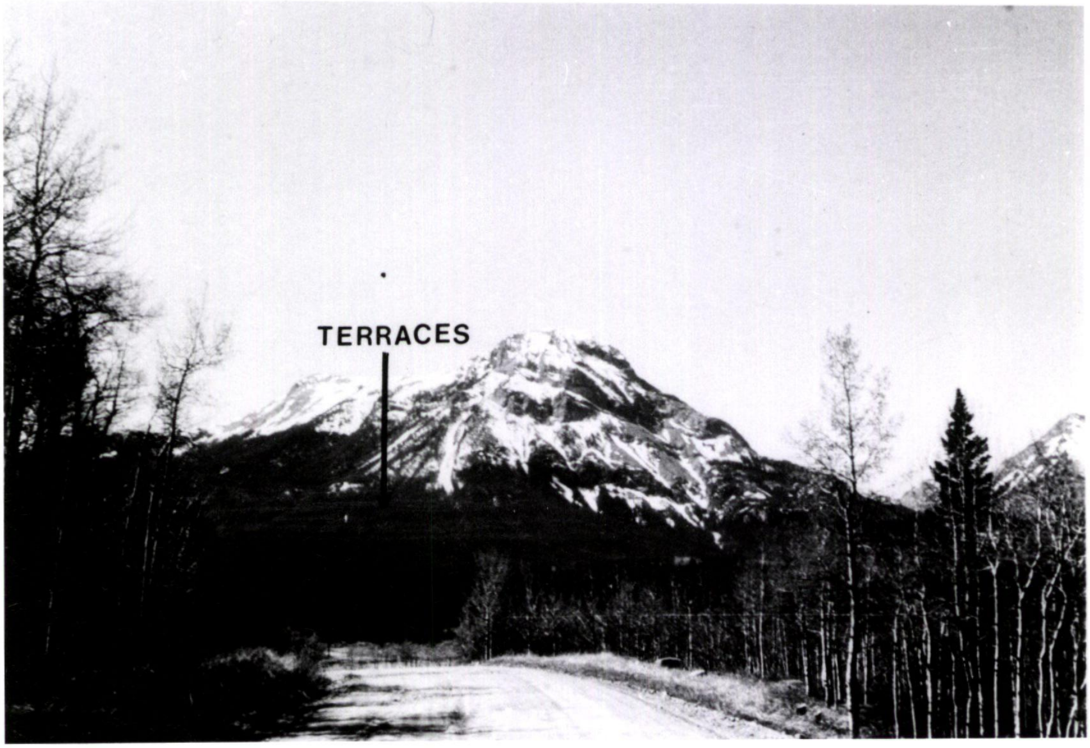
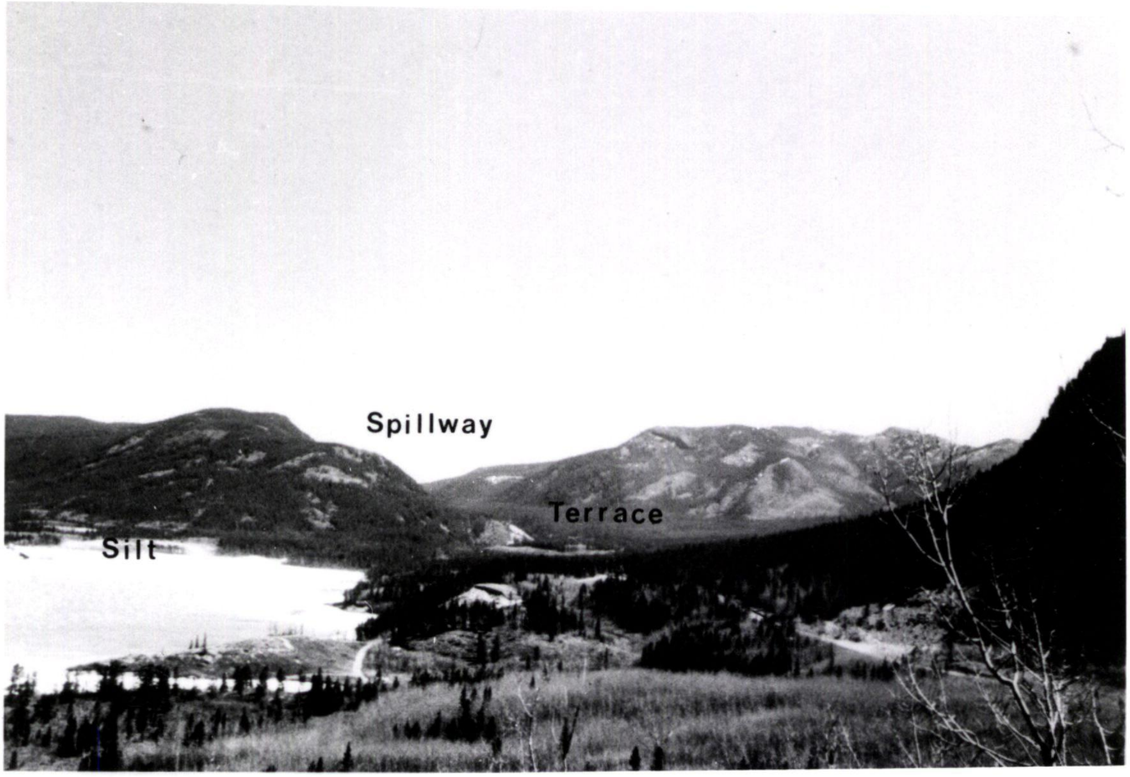

TERRACES

PLATE 11.

Barrier Lake looking east. The large spillway can be seen on the right of the photograph. Note the terraces on the eastern slopes of Barrier Mountain and the distribution of lacustrine material around the margins of the lake.


Spillway
Terrace
Silt